2002

Childhood Closed Head Injury And Memory Outcomes

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CHILDHOOD CLOSED HEAD INJURY

AND MEMORY OUTCOMES

A Dissertation

Presented to

The School of Graduate Studies

Department of Education and School Psychology

Indiana State University

Terre Haute, Indiana

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

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by

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May 2002

UMI Number: 3050245

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APPROVAL SHEET

The dissertation of Mary C. Boyd, Contribution to the School of Graduate Studies, Indiana State University, Series III, Number 891, under the title *Childhood Closed Head Injury and Memory Outcomes* is approved as partial fulfillment of the requirements for the Doctor of Philosophy Degree.

12/5/01
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ABSTRACT

Ten children younger than 96 months of age and 11 children 96 months of age or older with a history of closed head injury were followed for one-year after injury. Performances on measures of memory and learning were compared from immediately after injury and 1 year post-injury. There was no difference between groups on measures of visual memory, verbal memory, learning, and general memory indices. For children injured prior to reaching 96 months of age, the visual memory index scores recovered significantly more rapidly than did verbal memory scores. Implications for future research with children with closed head injuries are examined.

ACKNOWLEDGEMENTS

In completing this dissertation, I wish to express my sincere appreciation to several people. For his ongoing support and encouragement, I wish to thank Dr. Michael Bahr, my committee chair, who provided scholarly suggestions and encouragement. I would like to recognize Dr. Walker's reassurance and support of a project that was outside of the typical scope of work pursued by students of the Department of Educational and School Psychology. I appreciate the assistance of Dr. David Andrews and his studious review of the manuscript. The helpfulness of Dr. Martha Simcox, whose mentoring exposed me to this topic, was irreplaceable. I wish to recognize the support of Dr. Thomas G. Luerssen, of Riley Hospital's Neurosurgery Department. He encouraged the use of the data necessary for this research and made available the help of Heather Blalock for assistance in data gathering.

To my husband, Michael, I owe unending gratitude for his emotional and financial support, his understanding, and dogged commitment to this project, even when my commitment waned. And to our children, I appreciate their encouragement and sincere belief in my efforts.

Finally, I owe a lifetime of gratitude to my mother, Mary Ann Krieg Rechtin. Without her dedication and commitment to education, her sacrifices to ensure that I had the background for such an effort, and her influences as an educator, none of this would have been possible.

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Chapter 1

INTRODUCTION

Savage and Wolcock (1994) reviewed the epidemiological studies of acquired brain injury and concluded that despite the fact that an accurate estimate of the incidence of acquired brain injury is problematic, at a minimum 1 in every 550 school-age children will experience a head injury each year. Due to the advent of modern technology, most of these children survive to return to the classroom. Often subtle cognitive deficits that result from head trauma are overlooked, which could account for the disproportionate number of these children who evidence increasing academic difficulties (Savage & Wolcock, 1994; Segalowitz & Brown, 1991).

One frequent post-injury outcome is deficits in new learning (Chadwick, Rutter, Schaffer, & Shrout, 1981). However, evidence of that deficit may take some time to surface (Sohlberg & Mateer, 1989). Although we know that academic skills are compromised, the source of the deficit is not always clear.

It also appears that though children who experience trauma at a younger age seem physically more able to survive the traumatic event (Leurssen, Klauber, & Marshall, 1988; Levin, Ewing-Cobbs, & Eisenberg, 1995), the resulting cognitive deficits that emerge over time seem to be more profound than those of children who are older at the time of their injury (Anderson & Moore, 1995; Hudspeth & Pribram, 1990; Kriel, Krach, & Pasner, 1989). This finding is in conflict with earlier investigators who suggested that because younger children's neural development is not yet complete, their brains remained more "plastic" and therefore able to recover more effectively from brain damage (Teuber & Rudel, 1962).

Over the past 15 years researchers have begun to explore a developmental pattern of skill loss subsequent to head injury based on a model developed by Dennis (1988). According to this paradigm, skills that are established stand a better chance of being preserved than do emerging and yet to be developed skills. It is in the context of this developmental archetype that the current investigation was conducted.

Deficits in memory skills are the most frequently documented outcomes from head trauma (Jaffe et al., 1993; Levin, Eisenberg, Wigg, & Kobayashi, 1982; Levin et al., 1995). The development of memory skills in children has been explored in terms of several models (for a review see

Schneider and Pressley, 1997). Baddeley (1990) has proposed a paradigm that has received researchers' attention. This functional model maintains that operating slave systems are controlled by a central executive. The phonological loop and the visuospatial sketchpad are two slave systems that have been identified and researched. The phonological loop is considered to store and rehearse speech-based information. The visuospatial sketchpad is considered to manipulate visual information. Although evidence from several lines of investigation suggest the separability of the two slave systems (Baddeley & Liberman, 1980; Gathercole, 1994; Logie, 1986), their level of functioning and impact on cognitive development has yet to be clarified in the research.

Over the past 30 years, memory outcomes after a traumatic head injury have been researched using various instruments as measures for memory skills. Up until the past decade there have been no comprehensive instruments available to measure memory skills in children. As a consequence, the effect of age at the time of injury on memory skills one year post-injury has never been explored using such a nationally normed battery. In 1990, the Wide Range Assessment of Memory and Learning test (Adams & Sheslow, 1990; WRAML) was introduced to the market. The battery contains two separate major scales that are designed to evaluate visual and verbal memory skills. The WRAML, therefore, lends itself to the assessment of the development of verbal and visual memory skills as proposed by the Baddeley model. In addition to the Visual and Verbal Memory Indices, the WRAML provides a Learning Index in which the child has to perform some learning tasks during the assessment. The child's performance is then measured as a function of how well the task was learned. Each of these three indices reflects the child's performance on three subtests. A General Memory Index provides a global measure of the child's performance on all nine subtests of the instrument.

Theoretical Background

Since the 1960's, children with special educational needs have been able to have their needs met under an umbrella of services that are funded in part by the federal government. It was not until 1990 that the Individuals with Disabilities Education Act (IDEA) revamped special education law to include traumatic brain injury (TBI) as a separate disability category. IDEA (1990) states:

> "Traumatic brain injury" means an acquired injury to the brain caused by an external physical force, resulting in total or partial functional disability or psychosocial maladjustment that adversely affects educational performance. The term applies to open or closed head injuries resulting in mild, moderate, or severe

> impairments in one or more areas, such as cognition; language; memory; attention; reasoning; abstract thinking; judgment; problem-solving; sensory, perceptual and motor abilities; psychosocial behavior; physical functions; information processing; and speech. The term does not apply to injuries that are congenital or degenerative, or brain injuries induced by birth trauma. (p. 44802)

The academic implications for a child with a brain injury are different than for children with a mental handicap or a learning disability. This notwithstanding, children with brain injury are often educated with children with other disabilities and without attention to their unique and changing needs (Savage & Wolcott, 1994).

When a child experiences a moderate or severe closed head injury (CHI) the physiological consequences to the brain are usually diffuse in nature which results in the interruption of neural connections throughout the brain (Bigler, 1990; Savage, 1994). As a result, it appears that there is often an initial global regression in IQ followed by a period of recovery (Ewing-Cobbs, Miner, Fletcher, & Levin, 1986; Klonoff, Low, & Clark, 1977). Especially after the recovery, nonverbal skills seem to be more compromised than verbal skills (Chadwick, Rutter, Brown, Shaffer, & Traub, 1981; Winogron, Knights, & Bawden, 1984).

If verbal skills were well developed prior to the injury this trend would support the conception that well-learned and acquired skills recover at a more rapid rate than does the ability to learn new skills (Hebb, 1949).

Theory regarding recovery after pediatric TBI has been couched in two sets of beliefs. The first and earlier paradigm has been challenged or adjusted by more recent developments in the research. The theory proposed that young children who experience brain injury enjoy better outcomes than older children and adults (Lennenberg, 1967; Teuber & Rudel, 1962). The more recent model suggests that post-injury verbal skills appear to be more effectively preserved than nonverbal skills (Anderson & Moore, 1995; Chadwick, Rutter, Brown et al., 1981; Winogron et al., 1984). Levin, Grossman, Rose, and Teasdale (1979) regarded post-injury Wechsler Verbal IQ as a measure of premorbid status, and the changes over time of Wechsler Performance IQ as a better measure of recovery.

The idea that young children face a more optimistic recovery was based on a set of beliefs that came to be known as the Kennard Principle. Kennard's (1938) research with monkeys demonstrated that young monkeys experienced fewer motor impairments immediately after brain damage than older similarly injured monkeys. The Kennard Principle held that the brains of young organisms that were still in the process of developing enjoyed a plasticity in neuronal functioning that allowed them (to some degree) to reorganize their neurological processes after damage. Anderson and Moore (1995) noted in their literature review that further support for this optimistic prognosis for early childhood TBI was drawn from investigations that compared the outcomes from childhood hemispherectomies, that is the surgical removal of a part of the brain, to the outcomes of adults with apparently similar injuries. Many medical personnel still demonstrate a belief in the Kennard Principle (Webb, Rose, Johnson, & Attree, 1996). This notion continues to be held despite the fact that research tells us that young children and mildly injured infants who seemed to be fully recovered shortly after the injury, exhibit intellectual, sensorimotor, and behavioral deficits later at follow-up (Anderson & Moore, 1995; Craft, Shaw, & Cartlidge, 1972; Ewing-Cobbs, Miner, Fletcher, & Levin, 1989).

In 1988, Dennis proposed a model to accommodate the apparent cumulative skill deficits resulting from early brain damage. This model distinguished between three levels of skills: established, developing, and emerging. An established skill is one that is fully acquired and functional. A developing skill is one that has been partially acquired and is functional at some level. An emerging skill is not yet functional to any degree.

Dennis's heuristic also identifies seven aspects of skill development: onset, order, rate, strategy, mastery, control, and upkeep. The onset of a skill is defined as that point in time when behavioral evidence of the skill becomes apparent. Order refers to the emergence over time of the skill in relation to other developmental events in the child's life. Rate is the speed with which the skill develops. Strategy refers to the behavioral tactics a child uses to put the skill in place. Mastery is the final level of competence the child acquires. Control refers to the ability the child has to call up a skill and use it when required. Finally, upkeep refers to the long-term maintenance involved in sustaining the skill.

For children with a history of a head injury, different questions need to be asked about the skill depending on the age and skill development of the child at the time of the injury. It would be likely that an injury that occurs in utero or very early in a child's life is more likely to interfere with the onset and order of the development of a large number of skills, since few, if any, skills have had an opportunity to appear. Once a skill emerges, other aspects of skill development are likely to be affected.

Various researchers have reported on investigations into the impact of head trauma based on the age of the child at the time of his or her injury. Anderson and Moore (1995) reported on investigations that have specific implications for cognitive recovery for children of different ages who had been admitted to the hospital with head injuries. These researchers studied the outcomes of 36 children who had been admitted to the hospital for head injuries at 4 months and 2 years after injury. The researchers divided their sample into two groups according to their age at injury. Sixteen children were placed in an early head injury group, and 20 older children were placed in the late head injury group. Children in the early injury group were between the ages of 3 years 11 months and 6 years 11 months with a mean age at injury of 5 years 8 months. The children in the late injury group were between the ages of 7 years 11 months and 14 years 9 months, with a mean age of 10 years, 10 months.

The researchers administered either the Wechsler Intelligence Scale for Children - Revised (1974; WISC-R) or the Wechsler Preschool and Primary Scale - Revised (1989; WPPSI-R). Initially, the data were analyzed using a repeated measures analysis of variance. Group and interaction effects were nonsignificant, but the recovery trends in the two groups suggested some differences. In comparison to the late injury group, the early injury group made little or no gains over a 2-year period post-injury. In order to investigate this trend, the researchers recorded the scores of the children into three standard IQ categories: deficient/below average, average, and above average. The two groups were compared at approximately 4 months and 2 years post-injury. Although no difference between the two groups was detected at the 4 month assessment, there was a slight increase in the percentage of children in the early injury group falling into the deficient/below average category 2 years after injury. This trend was reversed for the late injured group. The result was a significant difference in FSIQ between the early and late injury groups at 2 years between the categories within which the IQ score fell.

In order to understand the trend, the investigators then divided the FSIQ scores into VIQ and PIQ. Repeated measures analysis of the VIQ scores revealed no significant main effects for group or for time. The recovery trajectories for the 2 groups were similar. However, the same analysis on the PIQ scores indicated that the main effect for time was statistically significant as was the interaction.

The authors observed that the two groups exhibited different degrees of nonverbal recovery with the early injury age group making smaller gains than the later injury group. Therefore, the investigators created 2 discrepancy variables. They subtracted PIQ from VIQ for each subject at 4 months and 2 years. At 4 months VIQ exceeded PIQ for both groups. At 2 years, the pattern was maintained by the early injury groups, but PIQ exceeded VIQ for the late injury group. The researchers concluded that age is a relevant factor in predicting recovery of children after a traumatic head injury, with children who sustained their injuries before they reached the age of 10 less likely to exhibit cognitive recovery within the 2 years after injury.

Levin and Eisenberg (1979) studied 42 children who had experienced a CHI inflicted by a blunt instrument. They divided the children into two groups according to their age at injury: 6-12 years of age, and 13-18 years of age. They also classified the children by the severity of their injury based on the duration of their comas. Neuropsychological evaluations were generally performed during the time of the children's hospital stay. The children's neuropsychological scores were synthesized into language, visuospatial skills, learning and memory, motor, and somatosensory skills. Trends in their data indicated a poorer performance by even the mildly injured adolescents on more stringent measures of learning and memory as compared to a control sample of high school students. In this sample, younger children were more impaired than older children who had endured the same degree of wounds.

Levin et al. (1988) tested the hypothesis that impairment of verbal learning immediately on resolution of post-traumatic amnesia and at 1 year is more strongly related to the severity of the head injury in adolescents than in children. The investigators divided children with a history of head injury into three groups based on their age at injury. The ages of the groups were: 6-8 years of age, 9-12 years of age, and 13-15 years of age. Using the Glasgow Coma Scale and physical and neurological injuries, the authors classified the head injuries of these children as mild, moderate, and severe. They then gave the children the Continuous Recognition Memory Test (Hannay, Levin, & Grossman, 1979) in order to assess visual memory, and they administered the Selective Reminding Test (Buschke, 1974) to assess verbal memory. Children were tested at baseline and one year. In order to compare children across time and age, the investigators used the scores from the control group to transform the visual and verbal memory scores into standard scores with a mean of 100 and a standard deviation of 15. Using a multivariate analysis of variance with repeated measures, the researchers found that deficits in visual recognition memory were directly related to the severity of the CHI in all three age ranges. The severity of CHI in the adolescents was also found to be directly related to the residual verbal memory deficit but was inconsistent in children injured at a young age. The investigators speculated that young children were likely to experience increased verbal deficits as they aged, and skills were likely not to emerge in a predictable manner.

The present effort is a methodological exploration designed to determine the effect time has on the memory skills of children who have experienced a moderate to severe head injury at a younger age as opposed to an older age. One of the more recognized outcomes from a CHI has been impaired memory skills. A number of research efforts have been attempted to explore the relationship between memory and pediatric head injury (Gaidolfi & Vignolo, 1980; Jaffe et al., 1993; Kinsella et al., 1995; Levin & Eisenberg, 1979; Levin, Eisenberg, Wigg et al., 1982; Levin et al., 1979; Levin et al., 1988; Richardson, 1963; Tompkins et al., 1990). None of these studies has used a comprehensive nationally normed instrument to compare visual and verbal memory skills because no such instrument was available prior to 1990. There also appears to be no study comparing memory skills as measured by the WRAML. Further, a literature review suggests that no investigation has compared children injured at a younger age to children injured at an older age using such an instrument.

Statement of the Problem

Review of the literature suggests that memory deficits are a typical outcome from TBI (Jaffe et al., 1993; Levin et al., 1995; Levin, Eisenberg, Wigg et al., 1982). The literature suggests that cognitive outcomes from TBI may be different for children depending on their age at injury (Anderson & Moore, 1995; Levin & Eisenberg, 1979; Levin et al., 1988). Until recently, there has been no comprehensive, nationally normed instrument available to measure memory skills in children.

The purpose of this research was to investigate the memory skills of children ranging in age from 5-15 at the time of their injury and who were treated at a metropolitan children's facility in the Midwestern part of the United States. It investigated the outcomes one year post-injury for children who were injured before their eighth birthday and compared their age-appropriate visual and verbal memory skills to those of children who were injured after their eighth birthday.

Research Questions

This current research is designed to investigate the memory deficits that are found in children with a history of TBI. The questions in this research will address children who have experienced a moderate to severe CHI prior to their admission to the hospital and eventual inclusion in the CHI testing protocol. The children were followed for one year after their injuries. Specific questions that were posed in this research include:

1. Do children who experience a moderate to severe CHI at an older age (96 months or older) experience greater improvement in their verbal memory skills than children who experience a moderate to severe closed head injury at a younger age (less than 96 months)?

2. Do children who experience a moderate to severe CHI at an older age (96 months or older) experience greater improvement in their visual memory skills than children who experience a moderate to severe closed head injury at a younger age (96 months or younger)?
3. Do children who experience a moderate to severe CHI at an older age (96 months or older) experience greater improvement in their learning skills than children who experience a moderate to severe closed head injury at a younger age (96 months or younger)?
4. Do children who experience a moderate to severe CHI at an older age (96 months or older) experience greater improvement in their general memory skills than children who experience a moderate to severe closed head injury at a younger age (96 months or younger)?
5. Do the visual memory skills of children who experience a moderate to severe CHI at a younger age (96 months or younger) improve significantly more than their verbal memory skills?

Chapter 2

METHODS

Participants

The subjects in this study were obtained from an extant data base. Data were gathered from charts of children who were admitted to a major children's hospital in the Midwestern area of the United States for the management of a TBI. For admission to the program, subjects had to have sustained a brain injury severe enough to be admitted to the hospital and to be followed by various therapists and disciplines (e.g., speech pathologist, psychologist, occupational and physical therapists).

Participants were part of the program between the years of 1992 and 1999 and were evaluated at orientation or shortly after injury. The participants must have returned for their 1-year, follow-up, psychological evaluation and been evaluated with similar measures at both assessments. Due to the nature of the norms, the children had to be between 5-15 years of age at the time of their injury to be included in this investigation. Children who had passed their fifteenth birthday at the time of injury were not included in the hospital research team's protocol and, therefore, were not included in this study.

All subjects had to have had a TBI warranted as moderate or severe to participate in the study. Severity of the TBI was determined by the criteria established by Levin et al. (1988): the Glasgow Coma Scale (GCS) developed by Teasdale and Jennette (1974) and the presence of a skull fracture or localized injuries as observed through Computed Technology (CT). The GCS is a measure of alertness that is typically administered in the emergency room. Scores range from 3 to 15, with 3 being the most severe. A score of $\leq$ 8 is considered to be severe; a score of between 9 and 12 is considered to be moderate; and a score of >12 is considered to be mild. Intercranial hematomas and cerebral contusions were considered to be mass lesions, whereas small, slit-like ventricles typical of brain swelling were considered as diffuse. An injury was considered to be moderate or severe if the admitting GCS was $\geq$ 12 and if a mass lesion was evident in the admission CT.

Ten subjects (8 male and 2 female)ranging in age from 60 to 91 months of age met the criteria in the group of children who were < 96 months of age. This group ranged in age from 60-91 months with an average age of 76.1 months (or approximately just over age 6). Eight of these children had sustained a severe injury and two experienced a moderate injury. Eight of the children were injured in a motor vehicle accident (2 as a passenger and 6 as a pedestrian), 1 a motorcycle accident, and 1 was struck by an object. While demographic data were not collected, one behavior checklist asked for the mother's education. Five of the mothers of the younger children reported having a high school education and 4 reported greater than a high school education. For one mother, these data were not available. For the 11 children who were ≥ 96 months of age at the time of their injury, there were 5 male and 5 female patients ranging in age from 103-188 months with a mean age of 148.6 (or approximately 12.5 years old). Eight of these children experienced a severe injury and 3 sustained a moderate injury. Nine were injured in motor vehicle accidents (3 as a passenger and 6 as a pedestrian), one was injured on a bicycle, and one in a fall). Five of the mothers of the older injury group reported an education level of less than high-school, 3 indicated a high school education, 1 reported greater than high school, and for 1 mother there were no data available.

In order to fulfill the research requirements of Indiana State University, this proposal was submitted to a dissertation committee. Upon approval it was then surrendered to the Human Subjects Committee at Indiana State University for review and consent to proceed.

Instrumentation

The primary measure used in this study was the WRAML (Adams & Sheslow, 1990). Forster and Leckliter (1995) state that the WRAML represents the first well-standardized assessment of memory and learning for children between 5 years and 17 years 11 months of age. The authors of the WRAML present it as an atheoretical memory assessment with components that are consistent with prevalent memory theory. The instrument lends itself well to Baddeley's (1990) concept of working memory. The WRAML is divided into nine subtests that measure visual memory, verbal memory, and learning skills. Children between the ages of 5 and 8 are administered fewer items on some of the subtests. The WRAML yields six index scores: Verbal Memory Index, Visual Memory Index, Learning Index, General Memory Index, Memory Screening Index, and the Delayed Recall Index. The visual and verbal memory indices provide analogues to the visuospatial sketchpad and the phonological loop.

All indices of the WRAML yield scores with a mean of 100 and a standard deviation of 15. The WRAML is normed for children from 5 to 17 years 11 months of age. Children were selected for the norming sample using the 1980 U. S. Census and the 1988 Rand McNally Commercial Atlas and Marketing Guide. In terms of the norm group, 2363 children were sampled between December 1988 and November 1989. The norming sample was divided into 21 age groups, with 110 to

119 children in each group. For children between 5 and 13 years of age, groups representing half-year age spans were compiled. Children who were 14 and 15 years of age were classified in one-year interval groups. Sixteen and 17-year olds were categorized together to compile one age-group (Adams & Sheslow, 1990).

Three measures of reliability are reported in the WRAML administration manual. Coefficient alpha and person separation statistics were used to gauge the internal consistency of the instrument. Test-retest scores were used to compute a measure of stability. For the 21 age groups the median subtest alpha coefficients ranged from .78 to .90. The authors claim that no coefficient for any one subtest in any one age group demonstrated notable variability. For the Verbal Memory Index, the Visual Memory Index, and the Learning Index the median coefficients were .93, .90, and .91, respectively.

Person separation scores were obtained using the Rasch item analysis process. The scores range from .79 to .94. Significant separation was also demonstrated on the trials of the learning exercises. The authors stated that they considered each of the trials to be independent. Recognizing that others might not agree, they provided a test-retest measure for a small sample of children. From the results of this procedure the authors reported a .84 stability measure.

Criterion validity was demonstrated through correlation measures with the McCarthy Scale, the Stanford-Binet, and the Wechsler Memory Scales. For a sample of children who were 6 and 7 years of age, correlations were computed for the McCarthy Memory Index and the WRAML. The Verbal Learning subtest of the WRAML correlated at .90 with the McCarthy Memory Index, suggesting that the two procedures essentially measure the same thing.

The General Memory Index of the WRAML was correlated with the Stanford-Binet Short Term Memory Index for children who were 10 and 11. The two indices were found to correlate at .80. Sixteen- and 17-year-olds were administered both the WRAML and the Wechsler Memory Scale - Revised (WMS-R). The index scores for both tests were positively correlated. The highest correlation was between the WRAML General Memory Index and the WMS-R Attention and Concentration Index at .60. No correlation of conceptually related indices on the two tests was less than .44.

The authors report that factor analysis of the normative sample using a principal components analysis supports the three factor solution that basically conformed to the verbal, visual and learning factors. However, the visual learning subtest associated more strongly with the Visual Memory factor. The Story Memory Subtest was found to load more strongly on the Learning Index rather than the Verbal Memory Index.

Wasserman and Cambais (1992) and Phelps (1995) independently evaluated the WRAML using the original standardization data. Both of these independent investigations performed factor analytic studies using a principal components analysis. Neither investigation reported factors that were congruent with the indices reported in the test. Both investigations identified three factors. Some inconsistencies in factors were noted across age groups. Despite these difficulties, Wasserman and Cambais indicated that the WRAML offers a needed measure of memory functioning for children, and their overall impression of the test is positive.

Since these earlier efforts, others have examined the construct validity of the the WRAML; specifically the three factor model. Alyward, Gioci, Verhust, and Bell (1995) studied 323 children using a pairwise, principal factor analysis to produce a 3 factor solution. They labeled the modality factors in their solution as Visual Content and Verbal Semantic/Strategic and suggested a third functional processing factor be employed as well.

Burton, Bradley, Donders, and Mittenberg (1996) used the 2363 member normative sample to perform a factor analysis using a model that employed somewhat different questions than those employed in the principal components model used by the WRAML's authors. Nine unique hypotheses were employed as possible explanations of memory as measured by the WRAML. With this test the Verbal Memory and Visual Memory factors were supported. The authors labeled the third factor Attention/Concentration. Several years later the same primary authors published the results of a second study using similar assumptions and found the factors remained consistent with their clinical sample of 271 subjects (Burton, Mittenberg, Gold, & Drabman, 1999).

Two studies have used the WRAML to investigate memory function in children with TBI. Duis, Adams, Sheslow, Robins, & Leurssen (1996) administered the WRAML to children who were diagnosed with ADHD, specific reading disability, with a TBI, and controls. The researchers analyzed the scores from the four groups and found that the Verbal Learning score on the WRAML distinguished the reading disabilities group and the TBI group from the children with ADHD as well as the control group. Farmer et al. (1999) found that children who had a history of TBI demonstrated memory skills as measured by the Visual, Learning, and General Cognitive Indices of the WRAML that correlated with the severity of their injury.

Procedures

This study accesses an extant data base that was available to the researcher through the hospital from which it was gathered. The researcher participated in collecting the data from different disciplines throughout the hospital into the current data base. The lead investigator in the hospital then made available to the researcher the data used for this study. A current letter authorizing the researcher to use this database is found in the Appendix.

In 1990, patients who were admitted to the program were coordinated into various therapies. Data collected and used for this study were approved by the hospital's committee for human subjects. The assessment criteria for the program were developed by the practitioners and members of the traumatic brain injury research team. The results of these evaluations were placed in children's charts and maintained by the respective disciplines throughout the hospital.

Data from the WRAML were gathered by psychologists and intern psychologists associated with the hospital beginning in 1992. Regular evaluations were conducted by the various disciplines at immediately on orientation, 6 months post-injury, one year post-injury, and 2 years post injury. Data were gathered on intelligence, memory, speech, motor functioning, and physical changes to the brain by use of magnetic resonance imaging (MRI). Due to cost, MRI's were only performed until they had stabilized. Data for this investigation were collected between 1992 and 1999. The data included demographic information and the Verbal, Visual, Learning, and General Memory Standardized Indices of the WRAML. In a check for accuracy, data on all of the variables were cross-referenced a second time with each child's hospital file.

Data Analysis

In order to determine a change in memory scores over one year, a difference score was calculated for each index. Calculation was made by subtracting the baseline score from the score that resulted from the assessment one-year post injury.

A t test was employed because this research investigated two independent sets of data. The literature has consistently suggested that memory skills improve over the months and years following injury (Chadwick et al., 1981; Jaffe, Polissar, Fay, & Liao, 1996; Kloniff et al., 1977; and Levin et al., 1982), and so a one-tailed test of significance was used.

For Question 1 of this research, the Verbal Memory Index achieved at baseline was subtracted from the Verbal Memory Index score achieved one-year post injury. The resulting difference was labeled the Verbal Memory Difference Score to indicate the effect one year has on memory score after a head injury. These Difference Scores were then transferred as separate variables to a smaller separate spread sheet in the SPSS 7.5 for Windows (1996) program in preparation for analysis. Nine children from the early injury group and eleven from the late injury group had scores available for analysis. An Independent _t_ test was then performed to compare the differences in the mean Verbal Memory Difference Scores for the two groups and to determine if there was a difference in the changes in the Verbal Memory Indices based on the age of the child at the time of injury. A 1-tailed test of significance was performed.

For Question 2, the same process was followed. The Visual Memory Index achieved at baseline was subtracted from the Visual Memory Index achieved at one-year post-injury to achieve a Visual Memory Difference Score. In this case, 10 children from the early injury group and eleven from the late injury group had Visual Memory Scores available from the baseline and one-year evaluations. The resulting difference scores of the early and late injury groups were again transferred to an SPSS 7.5 for Windows (1996) spreadsheet and an Independent _t_ test was performed. This time the goal was to determine if there was a difference in the Visual Memory Difference Score based on the age of the child at injury. For the reasons noted above a 1-tailed test of significance was used to evaluate the probability of these results.

Question 3 was addressed in a similar manner. A Difference Score was derived by subtracting the index score. That is the Learning Index score at baseline was subtracted from the one-year Learning Index score. Nine scores in the early injury group and eleven from the late injury group were available for analysis. The difference between these two sets of scores was also transferred to SPSS 7.5 spreadsheet and an independent t test was performed to determine if there was a difference in the Learning Indices based on the age of the child at the time of the injury. Again, a 1-tailed test of significance was performed.

The same process was carried out to address the fourth question. The effect of one year on the General Memory Index (GMI) was measured by subtracting the baseline score from that achieved one-year after injury. Nine children from the early injury group and eleven from the late injury group had the required scores at the two intervals in time. These Effect Scores were then transferred to the new spreadsheet based on the age group of the children at the time of their injury. An Independent t test was performed to compare the distribution of General Memory Difference Scores of the children of the early injury group as compared to those of the late injury group. Again a 1-tailed test of significance was performed.

The last research question was addressed by pairing the Difference Scores for the Verbal and Visual Indices for the children who were injured at an early age. Although ten scores were available for the Visual Memory Index at both time intervals, the goal was to measure the change in the two indices for the same children. Therefore, only nine children's scores were analyzed. A paired t test was performed to compare the means of both groups of scores with a 1-tailed test of significance.

Chapter 3

RESULTS

Five research questions were explored in this investigation. This section reports the results of the four independent samples $\underline{t}$ tests for research questions 1 through 4 and the paired samples $\underline{t}$ test examining research question 5.

Research question 1 asked if children who experience a moderate to severe CHI at an older age (96 months or older) also experience greater improvement in their verbal memory skills than children who experience a moderate to severe CHI at a younger age (less than 96 months). Table 1 provides descriptive statistics and information regarding that analysis. Significance was not obtained at the traditional levels.

Research question 2 asked if children who experience a moderate to severe CHI at 96 months of age or older experience greater improvement in their visual memory skills as compared to children who experience a moderate to severe head injury at less than 96 months of age. Table 1 again lists the descriptive statistics and the results of the analysis. Significance was not obtained.

Research question 3 addressed the Learning Index scores of the WRAML. Specifically it asked if children who experienced a moderate to severe CHI at 96 months of age or older experienced a greater improvement in their Learning Index scores one year after injury as compared to children who are injured before 96 months of age. Table 1 lists the descriptive information for the sample and results, and similar to preceding analysis significance was not achieved.

Research question 4 was similarly analyzed and reported. This question addressed the change in general memory scores. Specifically, Research Question 4 asked if children who were 96 months of age or older at the time of their injury experienced greater improvement in their General Memory Index scores on the WRAML as compared to children who were injured before 96 months of age. Again, the test of significance did not meet the standard levels (see Table 1).

Research question 5 was analyzed using a paired t test because this question addressed the change in the Difference Scores for the same children on two different indices. Specifically, it asked if children who experienced a moderate to severe CHI prior to 96 months of age improved more significantly in their visual memory skills as compared to their verbal memory skills. The difference scores calculated for the children injured before 96 months of age for both the Visual and the Verbal Indices were used in a paired *t* test completed to determine if there was a difference between the recovery rates of the two skill areas. Because this question explored the relationship between the same children on different skills, only 9 subjects were available for this analysis. Results are shown in Table 2. This result was significant at the .025 level for a 1-tailed test.

Chapter 4

DISCUSSION

This research was an initial investigation of the source of learning deficits demonstrated by victims of pediatric head injury. Memory deficits have long been observed in this population (Levin & Eisenberg, 1979; Levin et al., 1988). The WRAML offered an instrument that was nationally normed and that categorized memory skills into the visual and verbal modalities. These modalities are currently recognized in the literature as separate functional components of memory (Baddeley, 1990). It also provided a General Memory Index and an index purported to measure learning. Researchers have suggested that when brain damage occurs at a certain period of development, the future evolvement of cognitive skills in the injured child is dependent on skills and the refinement of those skills that the child has developed at the time of the injury (Dennis, 1988). Based on this paradigm, a gross predictor of future cognitive outcome would then be the age of a victim at the time of injury, as it could be concluded that children injured at a younger age would have developed fewer skills than children who are injured at an older age (Schneider & Pressley, 1997).

In light of these theoretical propositions, this investigation followed a small group of children who were injured between the ages of 5-15 years. The subjects were divided based on their age at injury. Children who were 60 to 96 months of age were placed in the younger injury group and children who were greater than 96 months of age at the time of their injury were placed in the older injury group. The differences in the performance of the two groups on WRAML indices immediately after injury and at 1-year after injury were then compared. It asked four questions comparing the change in performance of nine or ten younger children (all index scores were not available for all children in the early injury group) to that of eleven older children on the Verbal Memory Index, the Visual Memory Index, the Learning Index, and the General Memory Index of the WRAML using a $\underline{t}$ test. Although each group increased their scores at one-year after injury, no differences in means between the younger and older children achieved significance levels that approached traditional test levels.

Research questions 1 and 2 addressed the improvement of both verbal and visual skills in younger as compared to older children. Dennis (1988) outlined a developmental model to address consequences of early brain injury. As discussed earlier, in Dennis' model different outcomes and levels of difficulties are likely to emerge over time based on the level of skill development of the child at the time of injury. Skills that as yet have not emerged or have not completely developed are likely to be disrupted in such a way that the skills never fully evolve or that they develop along different paths and/or at different rates. Therefore, within this model evidence of cognitive skill deficiencies is more likely to become apparent as the child develops and matures. Anderson and Moore (1995) supported this contention when they investigated the differences in older and younger children at 1 and 2-years after injury. These researchers used the Verbal and Performance Scales of the Wechsler Scales to measure skill changes. At 1-year after injury no significant differences were detected, but by 2-years after injury differences in the two groups began to become significant. Thus, because memory skills develop through adolescence (Schneider & Pressley, 1997), it is possible that if memory skills were to be measured in follow-up to this investigation, significant differences in recovery rates might also be noted.

Some researchers (Ewing-Cobbs, Fletcher, & Levin, 1989) who have approached pediatric brain-injury investigations from a developmental perspective have suggested that existing instruments lack the sensitivity necessary to measure adequately the deficits resulting from pediatric head trauma. When viewed from the perspective of Dennis' theory, the deficits may not exist or may exist only minimally as compared to peers or children injured at an older age, when assessments occur early after injury. It is only over time that significant differences may begin to emerge or can be detected by existing instruments. These issues deserve further exploration to clarify developmental as well as measurement issues related to head injury.

Research question 3 addressed the change in scores of younger children as compared to older children on the Learning Index of the WRAML at one-year after injury. As stated above, the test for this research question also did not result in significant difference scores for the two groups over a 1-year period. Although learning skills may also be subject to the effects of delayed deficits, especially for early pediatric head injury, it is also possible that the Learning Index is affected by difficulties related to construct validity. As mentioned in Chapter 3, studies of the WRAML using factor analytic techniques have resulted in factor relationships that call into question the Learning Index as a unified "factor" (Alyward et al., 1995; Burton et al., 1996; Burton et al., 1999; Phelps, 1995; and Wasserman et al., 1992). Thus, the recovery of Learning skills as measured by the WRAML, may be influenced by skill development prior to injury as well as some difficulties presented by the Learning Index itself. These issues also deserve further investigation.

The fourth research question measured the change in scores on the General Memory Index. The General Memory Index is a composite of the other three indices of the WRAML and it would be subject to the same developmental influences as are the sub-indices. Therefore, as noted above, while significant differences were not achieved at one-year after injury, it is possible that over time differences of a significant nature might be observed.

The fifth question in this investigation compared the recovery of verbal and visual memory skills in children who had not reached their eighth birthday at the time of their injury. This research question was explored to order to consider differences in the recovery of verbal and visual skills after head trauma. To date the Wechsler Intelligence Scales have offered a comparison of cognitive verbal and visual-spatial skills in the VIQ and the PIQ. Investigators exploring the cognitive outcomes of head injury have suggested VIQ provides a good measure of premorbid ability, while PIQ provides a measure for recovery (Levin et al., 1979). The use of the WRAML for related purposes has yet to be investigated and the relationship between these two instruments also deserves further study. The authors of the WRAML report significant, but low to moderate correlations between the indices on the WRAML and the IQ scores on the WISC-R. They report that the Verbal Index on the WRAML and the VIQ score on the WISC-R achieved a significant moderate correlation (i.e., .44). The Visual Index and the PIQ correlated similarly (i.e., .50). This would suggest that although the two instruments purport to measure similar traits, they are not strongly related. In fact, much of what the WISC-R measures, especially on the Verbal tasks, is primarily learned material. With the WRAML, each exercise in some way involves newly learned material.

Specifically, the fifth question explored in this investigation asked if visual skills recovered at a more rapid rate than verbal skills in children who are injured before 96 months of age. The t test used to investigate this relationship resulted in a significant difference in the scores for the two times. Visual memory skills in this younger group seemed to improve more rapidly than verbal memory skills. Based on Dennis' (1988) theory, such a pattern might be expected if visual memory skills were more developed than were verbal memory skills. Although this deserves further investigation, it is also important to note that these results are consistent with observations made using the PIQ and VIQ scores on the Wechsler Intelligence Scales. Within the context of the sparse developmental research, Anderson and Moore (1995) followed two groups of children who had experienced closed head injuries for two years after their trauma using the WISC-R and the WPPSI-R. Anderson & Moore found that when they grouped FSIQ scores into one of three IQ categories (deficient/below average,

average, and above average), a slight increase in the percentage of children injured at an early age fell into the deficient/below average category at 2-years after injury than had occurred at 4 months. Closer inspection revealed that while VIQ > PIQ for both groups at 4 months after injury, this remained true only for the children injured at a younger age at 2-years after injury. These findings hint at qualitatively different recovery trends for children based on their age at injury. Because qualitative differences in recovery trends may affect the usefulness of post-injury interventions (that is children injured at an early age may tend to learn and remember more effectively from one modality as opposed to another) these differences deserve further investigation.

From a different perspective, this investigation exposed a further gap in the research regarding age at the time of injury. While the fifth research question asked if the visual scores of children injured before 96 months of age improved more rapidly than their verbal scores, there was no corollary for children injured after 96 months of age. Boyd (2001) explored this issue using the same data set used for this current analysis. Using a paired t test, she compared the difference in the change in the visual and verbal skills in the older sample and found a significantly greater increase in visual skills for the older children as well (significance > .05). Further investigation would be necessary to further clarify the differences that exist in the recovery of the two age groups. Trends need to be explored and perhaps with longitudinal investigations over longer periods of time to determine whether parallels exist between the recovery of memory skills and other cognitive skills as measured on the Wechsler Scales.

Limitations of the Study

This study was an exploratory and heuristic effort. Its overall goal was to set the stage for further investigation into memory skills after a CHI. Because of the nature of the subjects in such research, a series of limitations were automatically imposed on data gathering. A literature review revealed that research suggests that the impact of head trauma can be subtle but profound. It further suggests that existing instruments are limited in measuring outcomes from head trauma. This effort was designed to encourage researchers to consider options with regard to investigations into memory deficits from a developmental perspective.

Because of the difficulties in acquiring data on children experiencing a CHI, this study was conducted using a small group of children. The children were seen at a large metropolitan children's hospital located in the Midwestern part of the United States, where a program was established and a psychological evaluation protocol was followed for children between the ages of 5 and 15 years of age. Therefore generalizations were limited to children who were injured between the ages of 5 and 15, receiving medical assistance, and returning for follow-up evaluations.

The data collection procedures at the hospital required that children who are followed make appointments and be brought to the hospital on a regular basis after injury. Many patients failed to keep appointments. Patients have been known to fail to make appointments because they perceived that they were fully recovered; they were experiencing financial hardships and insurance would not cover their visits; because of practical concerns; or due to disinterest. It was likely that bias was introduced due to this attrition. However, each year there are large numbers of children surviving pediatric head injuries and returning to school (Savage & Wolcock, 1994; Segalowitz & Brown, 1991). Therefore, the paucity of research and the need for knowledge in this area overrides this concern.

This research explored differences within the population of children who have experienced head injuries. It did not use a control group to investigate memory skills of children who had not experienced TBI. A standardized, norm-referenced instrument (WRAML) was used to measure memory skills, and therefore, it was possible to determine how the scores of the injured groups compare to a group of uninjured children of the same age. Kazdin (1992) argues that a measure of the extent to which treatment (which in the case of this research was the time period of one year) produces changes is the demonstration that at the end of treatment the patient sample is within the range of a well functioning sample on the measure of interest. The indices for the WRAML offered this comparison.

This study was limited to the memory outcomes from CHI one year post-injury. Thus, generalizations beyond one year were tenuous.

Because this research used no control group it was not possible to compare the change in the memory scores of the injured group to that of an uninjured group after repeated administrations of the WRAML over a period of a year. The absence of a control group, however, should not affect the comparison of change between children of an older age and children of a younger age at the time of injury. Again, this investigation was more exploratory and descriptive in nature. The hope is to encourage further research and collaboration between pediatric head injury teams such that they will facilitate ongoing research on this topic.

The results of this research were limited to one-year after injury. Several investigators have looked at trends in cognitive, memory, and other neuropsychological skills after head injury (Chadwick, Rutter, Brown et al., 1981; Jaffe, et al, 1996; Kloniff et al., 1977; and Levin et al., 1982). Consistently these investigators suggest the most notable period of improvement occurs within the first year after injury. Therefore, although data following children for longer periods of time is likely to result in additional, and even significant improvements in skills (Kloniff et al., 1977; Jaffe et al., 1996), this current investigation only explored changes over the the first year after injury.

Summary

The purpose of this investigation was to explore memory and cognitive outcomes from a CHI based on age at the time of injury. The results raised many questions regarding the relations between memory and other cognitive skills. Findings using the Wechsler Intelligence Scales and the results of this small study indicate that much information may be revealed by investigations that employ both the WRAML and the Wechsler Scales with the same populations. The WRAML merits further use in research to determine the functional similarities and dissimilarities between the skills it measures and the skills measured by the Wechsler Intelligence Scales. Finally, developmental theory suggests that a greater focus needs to be placed on the developmental implications of brain injury.

These issues are especially relevant to educators. If it turns out that children who experience head trauma at different ages tend to depend on one set of skills as opposed to another, that knowledge may benefit these children in the choice of the media used to teach them. If children injured at a younger age rely on verbal skills then it is in their best interest to teach these children in a way that rely heavily on visual presentation. It is for these reasons that this line of investigation should move forward.

In summary, this investigation followed the recovery of memory skills for children with a history of CHI. It found no significant differences in the recovery of memory skills as measured by the WRAML for children injured before or after 96 months of age. For children who were injured before 96 months of age, a significant difference in the recovery rate of Visual Memory Index score as compared to Verbal Memory Index scores was detected. This rate of recovery was suggested to be similar to findings in other investigations using the WISC-R and WPPSI-R.

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Table 1:

T Test Difference Scores for Memory Skills for Younger and Older Children

	<96 Months (n = 9)		≥96 Months (n = 11)			
	M	SD	M	SD	t	df
Verbal-Memory Index Scores	1.11	9.35	4.27	6.94	.868	18
Visual-Memory Index Scores	11.40 [a]	13.97	13.72	10.68	.431	19
Learning Index Scores	16.11	10.67	18.36	9.77	.492	18
General Memory Index Scores	13.22	13.28	15.36	8.57	.436	18

Note. Difference score was calculated by subtracting the memory scores immediately after injury from the memory scores one-year after injury.

Table 2:

Paired t Test Comparing One-Year Difference Score for Visual And Verbal Scores in Children Injured Before 96 Months of Age

	M	SD	t	df
Difference Score	-11.00	14.29	-2.31*	8

Note. Difference scores were calculated by subtracting the memory index scores immediately after injury from the memory index scores one-year after injury.

* Significant at the .025 level for a one-tailed test.