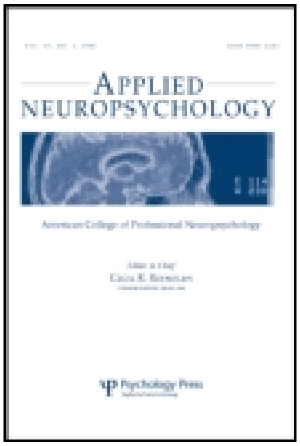

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Memory and Learning in Pediatric Traumatic Brain Injury: A Review and Examination of Moderators of Outcome

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This article reviews empirically supported assessment methods to examine impairments in memory and learning following pediatric traumatic brain injury (TBI). Critical factors affecting outcome are explored with an emphasis on an examination of age at injury. The article closes with discussion of current evidence-based interventions for deficits in memory and learning following pediatric TBI.

Key words: *learning, memory, outcome, pediatric, traumatic brain injury*

INTRODUCTION: MEMORY, LEARNING, AND ACADEMIC ACHIEVEMENT IN PEDIATRIC TBI

Traumatic brain injury (TBI) continues to be the leading cause of death (Graham, 2001; Jankowitz & Adelson, 2006) and one of the most frequent causes of disability in children (Arffa, 1998; Bigler, Clark, & Farmer, 1996) with an estimated annual childhood and adolescent incidence between 180 and 300 per 100,000 (Anderson, Catroppa, Rosenfeld, Haritou, & Morse, 2000; Guthrie, Mast, Richards, McQuaid, & Pavlakis, 1999). Although better survival rates have been reported in children compared with adults with TBI, the long-term consequences are typically more devastating due to their age and thus compromised developmental potential (Mazzola & Adelson, 2002). The most debilitating effects of TBI typically result from alterations in cognitive and neurobehavioral functioning (Jaffe et al., 1992; Silver, 2000). One of the most prevalent cognitive deficits following TBI is memory impairment, which substantially affects a child's ability to learn and retain information—skills that will be essential for success following their return to school. Indeed, memory impairment is well documented in both mild-to-moderate and severe injuries (Jaffe et al.; Yeates, Blumenstein, Patterson, & Delis, 1995), though the extent and quality of deficits vary.

This article will: (1) review currently supported methods of assessment and findings regarding memory and learning in pediatric TBI; (2) address age at injury and other moderators of outcome through a review of the literature; and (3) discuss the current empirically supported interventions to address memory impairments. Unless otherwise stated, the focus of the article will be on what is typically known regarding assessment and

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intervention in the chronic stage of injury (>4 to 6 months post-injury) rather than in the acute and subacute stages, given that this is the period when the issues have substantial relevance for clinical neuropsychology.

ASSESSMENT OF MEMORY AND LEARNING IN PEDIATRIC TBI

Severity of injury as measured by Glasgow Coma Scale (GCS) score or length of loss of consciousness has consistently been reported to be related to initial and long-term cognitive sequelae, including memory impairment (Levin, 1990; Levin, Goldstein, High, & Eisenberg, 1988). The Children's Coma Scale (Reilly, Simpson, Sprod, & Thomas, 1988) and the Children's Hospital of Philadelphia Infant Coma Scale or Infant Face Scale (IFS; Durham et al., 2000) are validated modifications of the GCS that are more appropriate to use with children, with the latter specifically designed for children younger than 2 years of age. In general, these scales rank severity on a mild, moderate, and severe continuum based on best motor, verbal, and eye responses, with the Children's Coma Scale and IFS based on child- and infant-appropriate behaviors. Brain injury is classified as mild (GCS $\geq$ 13), moderate (GCS 9–12), and severe (GCS $\leqq$ 8).

Following the acute phase of injury, accurate assessment of memory and learning is particularly critical in childhood TBI, given that it is one of the most-often disrupted aspects of cognition in brain injury and is a sensitive predictor of outcome (Anderson, Catroppa, Morse, & Haritou, 1999; Anderson et al., 2000; Guthrie et al., 1999; Woodward & Donders, 1998). Equally important, the adequate evaluation of memory and learning governs the choice of appropriate intervention strategies in the areas of rehabilitation and education. More than two decades ago, Fletcher (1985) suggested that deficits in memory and learning were likely crucial in underlying long-term problems in acquiring new information. Indeed, in an early investigation of children 2 years post-TBI, Kinsella and colleagues (1997) reported that verbal memory performance as noted on the Rey Auditory Verbal Learning Test (RAVLT; Rey, 1964) was the only significant predictor of subsequent education placement beyond the contribution of the GCS. Nonetheless, a thorough examination of the types of memory deficits noted in children following TBI was compromised by the limited availability of formal measures to assess memory, such as the RAVLT or the Buschke Selective Reminding Test (Buschke & Fuld, 1974).

Earlier studies that examined memory impairment in childhood TBI typically focused on a description of relative impairments in lateralized memory abilities such as verbal or visual memory processes (Levin, 1990; Levin et al., 1993; Verger et al., 2000; Yeates & Taylor, 1997). However, a substantial number of investigations have also focused on a quantitative examination of verbal learning and memory using instruments such as the RAVLT (Rey, 1964) and the California Verbal Learning Test-Children's Version (CVLT-C; Delis, Kramer, Kaplan, & Ober, 1994; Donders & Minnema, 2004; Mottram & Donders, 2006; Yeates et al., 1995).

In an examination using the CVLT-C, Yeates and colleagues (1995) reported overall poorer performance in verbal memory in children with closed head injury compared with controls; however, the deficits varied qualitatively as a function of injury severity. More specifically, learning throughout trials in those with mild-to-moderate injury was similar to that of controls, and recognition was intact, although greater difficulty was noted with delayed recall. In contrast, those with severe injury displayed deficits in learning throughout trials, delayed recall, and recognition memory, and they exhibited more significant errors of intrusion.

In a similar investigation, consistent with Yeates et al. (1995), Roman and colleagues (1998) found at 1 and 3 months post-injury that children with severe TBI demonstrated deficits in impaired verbal recall across learning trials and after short and long delays. However, the deficits occurred despite normal semantic organization, recall consistency, and learning slope, and without evidence of increased intrusions, perseverations, or impaired retention. That is, level of recall after delay was similar to levels of recall during learning trials. In older children with severe TBI, an increase in false-positive rates on recognition testing was noted, while general recognition deficits were evident in both older and younger subjects. In general, both younger and older children with severe TBI at 1 month post-injury revealed deficits in encoding, while more pronounced deficits in recognition memory were noted among the older cohort. In contrast, those with mild-to-moderate injury performed comparably to control children.

Quality of verbal learning performance was more extensively examined in a recent investigation of memory performance using the CVLT-C in a large cohort of children with TBI chosen from an 8-year series of consecutive referrals to a rehabilitation facility by Donders and Minnema (2004). The results revealed significantly higher rates of proactive interference (PI: earlier list learning compromised later learning) during verbal learning in children within 1 year post-injury compared with the standardization sample, although evidence of retroactive interference, rapid forgetting, and retrieval problems were evident in both samples. In addition, as might be expected, those with anterior cerebral lesions displayed higher rates of PI. Moreover, speed of information processing was found to mediate this effect, suggesting that processing speed is an important factor that should be examined and addressed when considering remedial and compensatory intervention approaches, particularly as they relate to academic supports. Mottram and Donders (2006) recently attempted to elucidate profile subtypes on the CVLT-C in children with TBI using cluster analysis. Although no unique profile was noted, the authors concluded that overall performance was strongly impacted by injury severity mediated by speed of information processing.

The CVLT-C has been an invaluable instrument for examining the quality and quantity of verbal learning in pediatric TBI. However, when an examination of verbal memory is coupled with a valid instrument of visual memory, a more comprehensive description of impairment emerges. Some studies have suggested a relative vulnerability of visual memory processes in some cases (Levin et al., 1988; Lowther & Mayfield, 2004) while others have reported a greater loss of verbal memory (Anderson & Catroppa, 2007; Hawley, Ward, Magnay, & Mychalkiw, 2004). For example, the increased vulnerability of visual memory functioning was suggested in an earlier study by Levin and colleagues (1988) for which they reported initial and persistent visual recognition memory deficits in both children and adolescents at 1 year post-injury, while verbal memory impairment persisted only in the adolescents. As will be discussed shortly, these differences are likely due to the complex nature of predicting outcome which is based on a multitude of pre- and post-injury factors.

Commensurate with reduced mortality and following recognition of the lack of methods to comprehensively examine the often-noted learning and memory deficits in children, the past couple of decades have seen a proliferation in the development of standardized batteries exclusively designed to examine both verbal and visual memory and learning in children and adolescents (Cohen, 1997; Reynolds & Bigler, 1994). Nearly concurrently, the development of the Test of Memory and Learning (TOMAL; Reynolds & Bigler), Wide Range Assessment of Memory and Learning (WRAML; Sheslow & Adams, 1990), and the Children's Memory Scale (CMS; Cohen, 1997) emerged. Second editions of the TOMAL-2 (Reynolds & Voress, 2007) and the WRAML-2 (Sheslow & Adams, 2003) have recently been published; however, to the authors' knowledge, formal investigations of memory and learning in children with TBI have yet to be published. A list of commonly used instruments to evaluate memory and learning is provided in Table 1.

TABLE 1
Selected Pediatric Tests of Memory and Learning

Test	*Age Range*
Benton Revised Visual Retention Test	8 years–adulthood
California Verbal Learning Test-Children's Version (CVLT-C)	5–16 years
Children's Memory Scale (CMS)	5–16 years
Rey Complex Figure Test and Recognition Trial (RCFT)	6–89 years
Rivermead Behavioral Memory Test for Children (RBMT-C)	5 years–adulthood
Test of Memory and Learning (TOMAL-2)	5–59 years
Wechsler Memory Scale-Third Edition (WMS-III)	16–89 years
Wide Range Assessment of Memory and Learning- Second Edition (WRAML-2)	5–90 years

Note. Dashes in age ranges indicate "through."

The validity of the original version of the TOMAL was first reported in an investigation by Lowther & Mayfield (2004), which involved 70 children and adolescents with moderate and severe TBI who were, on average, 6 months post-injury compared to 70 control children drawn from the standardization sample. Significant differences were reported on all of the TOMAL Indices (Verbal, Nonverbal, Composite, and Delayed) and subtests between groups with the exception of the Verbal Delayed Recall. Recently, Alexander and Mayfield (2005) reported the latent factor structure of the TOMAL following an analysis using performance by the aforementioned TBI population (Lowther & Mayfield). The TOMAL factor structure was reported to be characterized by a large complex memory and smaller sustained attention factors, which the authors suggested provided initial support for a "general memory" construct.

One of the original studies using the WRAML to assess memory and learning in children 5 to 16 years of age, who were between 4- and 5 years status post-severe TBI, revealed more pronounced verbal compared with visual memory impairment when compared to age and gender-matched controls. Interestingly, there were no significant differences noted in delayed recall or recognition memory (Nelson & Kelly, 2002). The factor structure and validity of the Screening version of the WRAML (WRAML-S; Sheslow & Adams, 1990) for the examination of memory in pediatric TBI was also recently reported by Woodward and Donders (1998). Consistent with the aforementioned studies, children with mild-to-moderate TBI outperformed those with severe injury on measure of immediate recall. In addition, although a two-factor model that included both verbal and nonverbal memory components emerged in the standardization sample, a general memory factor was supported in the TBI sample. The authors cautioned against an exclusive reliance on the WRAML-S in clinical evaluations.

There has also been an attempt to assess aspects of childhood memory with more ecologically valid instruments such as the Rivermead Behavioral Memory Test for Children (RBMT-C; Wilson, Ivani-Chalian, &

Aldrich, 1991; Anderson et al., 1999, 2000). In an investigation by Anderson and colleagues (1999), a dose-response relationship between severity of injury and memory performance on the RBMT-C in children with mild, moderate, and severe injuries was not evident in the acute phase post-injury, although more pronounced memory impairment was noted in the severe injury group at 12 months post-injury.

Although there have been several studies examining memory functioning using the CMS (Hawley et al., 2004) in other clinical populations such as reading disability (Kibby & Cohen, 2008) and specific language impairment (Riccio, Cash, & Cohen, 2007), very few studies have examined the pattern of memory deficits noted in TBI. In a community sample of 67 school-aged children at a mean of 2 years post-injury, Hawley and colleagues reported impaired/borderline performance for both immediate and delayed verbal recall in one-third of those with severe TBI, while one-fourth were reported to demonstrate impaired/borderline functioning for general memory.

Investigations of working memory following pediatric TBI have only recently surfaced (Levin et al., 2002, 2004; Mandalis, Kinsella, Ong, & Anderson, 2007). Consistent with prior investigations of memory functioning, more severe injury has been reported to be related to poorer performance on traditional N-back tasks of working memory (Levin et al., 2002, 2004) and on tests for which components of the Working Memory model proposed by Baddeley and Hitch (1974) have been purported to sample (Mandalis et al., 2007).

Studies have only recently begun to examine the long-term relevance of memory functioning and impairment on more complex aspects of behavior beyond academics. For example, in a provocative study examining social problem-solving in 52 children and adolescents who were examined during the 1st year following moderate-to-severe TBI, Hanten and colleagues (2008) reported that memory as measured by the Sternberg Task item recognition and strategic memory word span tasks as well as language task performance was robustly related to social problem-solving as measured by the interpersonal negotiation strategies task.

ECOLOGICAL VALIDITY OF ASSESSMENT IN PEDIATRIC TBI

The preceding review primarily focused on norm-referenced tests which yield performance that can be quantitatively compared to results of a normative sample (e.g., standard or age-corrected scores) rather than criterion-referenced tests or non-standardized or informal assessments. However, recently there has been a call for an examination of the discrepancy that often exists between test scores and everyday functioning; specifically, an examination of the ecological validity of assessment in childhood TBI (Silver, 2000). Silver reports that empirical research examining the degree that neuropsychological testing predicts real-world functioning in children following brain injury is sparse and that only moderate correlations between test scores and everyday functioning exist. However, it is further noted that the impediment to assessing the predictive value of neuropsychological testing in pediatric TBI is not perceived to be due to the limitation of measurement tools but the complexity in measuring outcome given the effect of critical intervening variables, such as mediators and moderators. A mediator is a variable that explains the mechanism by which a predictor variable affects an outcome or the criterion variable; that is, the predictor is associated with the mediator, which subsequently affects the outcome variable. In contrast, a moderator, which partitions a focal independent variable into subgroups that establish its domains of maximal effectiveness in regard to the criterion variable (Coelho, Ylvisaker, & Turkstra, 2005) advocate for non-standardized, functional, and context-sensitive assessment for individuals with TBI, given the shortcomings of standardized assessment in predicting performance (Ewing-Cobbs, Fletcher, Levin, Iovino, & Miner, 1998).

NEWLY RESEARCHED ASPECTS OF MEMORY AND LEARNING IN PEDIATRIC TBI—PROSPECTIVE AND IMPLICIT

Prior research has focused on an examination of explicit memory tasks such as list learning or story and design recall and has generally neglected to examine prospective memory or memory for a future intention, such as remembering to do a future errand or job (McCauley & Levin, 2004; Ward, Shum, McKinlay, Baker, & Wallace, 2007)—a classic example of an ecologically valid memory task. This aspect of memory is most likely to disrupt functional living skills such as remembering to take medication or turn in a school assignment. Likewise, implicit memory has rarely been examined, though there may be potential implications of accessing this form of memory for remediation (Ward, Shum, Wallace, & Boon, 2002). Unfortunately, although prospective and implicit memory may be critical aspects of memory that affect functioning and may have implications for intervention, there are currently no formal standardized measures that focus on of either aspect of memory, with the exception of some subtests of the RBMT-C (Wilson, Ivani-Chalian, Besag, & Bryant, 1993). Nonetheless, given their potential implication for future research, the experimental methods of the few studies that have been conducted are discussed.

In a preliminary study by McCauley and Levin (2004), children and adolescents with mild and severe TBI who were at least 5 years post-injury were compared to an orthopedic control on a novel prospective memory experimental task. During the initial phase of this computer task, participants were to merely report when words were presented in blue letters. A short delay and intervening computer task for which all words were printed in black was subsequently followed by a return to the original task for which participants were to again report words printed, though they were not cued. Interestingly, both the mild and severe TBI groups demonstrated impairment on this prospective memory task compared with the orthopedic control, although the mild group benefited from a reminder, while the severe TBI group continued to remain impaired. In the only additional prospective memory investigation, Ward and colleagues (2007) attempted to flesh out the mediating role of executive impairment and age at injury on prospective memory using a dual-task paradigm. In this experimental paradigm, an *ongoing* task occupies attentional resources while a *prospective* memory task is required at specified times (time based) or in response to cues (event based) while the ongoing task is performed. In general, time-based prospective memory requires that an intention be completed at a specific time, while an event-based prospective memory involves an external cue (e.g., a timer; McCauley & Levin, 2004). As expected, children and adolescents with moderate-to-severe TBI performed more poorly than non-injured controls, and adolescents outperformed younger children on the prospective memory task. However, no interaction between age and injury status was noted, indicating that prospective memory was not differentially affected in those who sustained injury before or after puberty. Finally, benefit from prospective cuing was found to be lower when higher executive demands were required during the ongoing task.

In contrast to explicit memory for which conscious recollection of a prior task or experience is required, implicit memory does not require conscious or deliberate effort (Graf & Schacter, 1985). Both priming and procedural memory are classic examples of implicit memory and potentiated learning through prior exposure. One of the implications of a better understanding of procedural memory in children and adolescents with TBI is that this form of memory is often demanded in everyday school performance (e.g., writing or using a computer) and could be used to promote learning that is often dependent on explicit forms of instruction. Ward and colleagues (2002) examined procedural memory during motor-perceptual (rotary pursuit) and cognitive (mirror reading) tasks in a small cohort of children with moderate-to-severe TBI compared with matched controls. The children with TBI learned at a similar rate and retained information similar to that noted in the control children on both procedural memory tasks compared with explicit memory tasks. Similar results have also been reported in adults, suggesting that some aspects of memory may be preserved in children with TBI and further supporting the functional dissociation between implicit and explicit memory as has been also reported anatomically (Schacter, 2000).

EXAMINING PREDICTORS OF OUTCOME ON MEMORY AND LEARNING

Historically, injury-related variables such as severity and length of unconsciousness have been found to be important predictors of outcome in both adult and pediatric TBI (Hessen, Nestvold, & Sundet, 2006). However, recent investigations have revealed a more complex relationship between severity, demographic variables (e.g., socioeconomic status; SES; Anderson et al., 2001), age at injury (Anderson & Moore, 1995), time post-injury, and the vulnerability and specific facets of memory in pediatric TBI. In a study of memory functioning following TBI in preschool children, Anderson and colleagues (2000) found a significant relationship between severity and spatial learning but not story recall. In contrast, Catroppa and Anderson (2002, 2007) reported greater deficits on memory tasks, irrespective of modality in severe TBI in the acute (6 to 12 months post-injury) stage, in comparison to mild and moderate TBI. However, at 5 years post-injury, in the same sample of children, severe TBI was associated with decreased complex auditory-verbal memory performance, although children did not display impairment on immediate, working, or complex visual-spatial memory (Anderson & Catroppa, 2007). While recent literature suggests there is an increased risk for long-term verbal memory deficits in TBI, as noted, others have suggested that deficits in speed of information processing may be primarily responsible for the verbal learning deficits noted in pediatric TBI (Donders & Minnema, 2004).

A number of recent investigations have comprehensively examined the long-term (e.g., 4 to 5 years post-injury) effects of TBI on both cognitive and neurobehavioral functioning (Schwartz et al., 2003), as well as the cognitive and neural correlates of persistent deficits (Schwartz et al.). Primary deficits in learning and memory and the cascade of subsequent social and academic difficulties support the critical role of different aspects of memory in long-term outcome. Moreover, in addition to the aforementioned injury-related variables, family variables have surfaced as vital in predicting long-term outcome. In a study by Schwartz and colleagues, who examined long-term behavioral difficulties in children with moderate and severe TBI compared to an orthopedic control group, severe injury, socioeconomic disadvantage, and pre-injury behavioral difficulties were found to predict elevated behavioral problems. Interestingly, a weakness in working memory as measured by Consonant Trigrams (Paniak, Millar, Murphy, & Keizer, 1997) surfaced as one of the concurrent correlates of those with behavioral difficulties, as did poorer adaptive skills, difficulties with behavior and school competence, and adverse family outcomes.

MANAGEMENT AND EVIDENCE-BASED INTERVENTION FOR MEMORY AND LEARNING IMPAIRMENT

From the preceding review, it is quite clear that successful outcome will depend on a multitude of factors starting with prevention of secondary sequelae and progressing to comprehensive treatment of the chronic cognitive and neurobehavioral deficits of the child while recognizing the impact of family and demographic variables across multiple contexts. The Guidelines for the Acute Medical Management of Severe TBI in Infants, Children, and Adolescents were published in 2003 to address early medical management in this population (Adelson et al., 2003). However, the development of treatment standards and guidelines continues to be emerging across the age at injury and injury severity spectrum.

An essential issue to address as pediatric neuropsychologists embark on a more active role in intervention is for clinicians to be acutely aware of our current ability to evaluate the efficacy of interventions. This is especially critical as neuropsychologists make substantial recommendations regarding treatment across a multitude of domains (e.g., academic, cognitive, behavioral, and psychological) for the child and family. Clinicians should be familiar with criteria established by Chambless and Holon (1998) for "well-established" and "probably efficacious" treatments which are described below:

1. "Well-established" treatments use treatment manuals and specified participant groups, and either of these two characteristics:
   a. Two independent, well-designed group studies demonstrating the treatment to be better than placebo or alternative intervention or equivalent to an established effective treatment.
   b. Nine or more single-subject design studies using robust designs and comparison to an alternative intervention.
2. "Probably efficacious" requires clearly specified participant groups and any of the three characteristics listed below. Treatment manuals are preferable but not required.
   a. Two studies demonstrating better outcomes than a no-treatment control group.
   b. Two strong group studies by the same investigator revealing the treatment to be better than a placebo or alternative treatment or equivalent to an established treatment.
   c. Three or more single-subject design studies that have a strong design and compare the intervention to another treatment.

Neuropsychological intervention for children with moderate–to-severe TBI has typically focused on compensation and environmental alterations as well as pharmacotherapy to address common impairments in attention, memory, speed of information processing, executive functioning, communication, and behavior so that individuals can function optimally at both home and school (Donders, 2007). Neurobehavioral deficits substantially impact emotional and psychosocial functioning, and there appears to be a differential recovery and response to intervention for cognitive and neurobehavioral outcomes. For example, recovery may be more pronounced for cognitive relative to psychosocial adjustment. In contrast, the recently reported modest benefits from psychostimulants may be more evident in altering behavior rather than cognitive functioning (Jin & Schachar, 2004). Contingency management procedures and antecedent-focused procedures such as positive behavior interventions and supports are commonly employed to manage problematic behaviors, although research is needed to examine the efficacy of these methods to generate long-term change. While medication and behavioral management can be successfully used to manage the neurobehavioral consequences following pediatric TBI, treatment specifically geared toward minimizing cognitive deficits such as memory impairment and its impact on academic functioning are often more difficult to implement, and research on generalization and maintenance is often lacking. Nonetheless, during the past couple of decades, there has been increasing evidence that different instructional methods can facilitate learning in individuals with acquired memory impairment (Ehlhardt et al., 2008) and that neuronal plasticity can occur in response to structured input (Gonzalez-Rothi & Barrett, 2006). As such, the past several years have seen a proliferation of excellent articles and reviews addressing educational needs and empirically validated instructional practices in children with TBI (e.g., Ehlhardt et al.; Glang et al., 2008; Kirkwood et al., 2008; Ylvisaker et al., 2005).

In a recent manuscript published by the TBI Practice Guidelines Subcommittee, which was established by the Academy of Neurologic Communication Disorders, the instructional research literature relevant to teaching individuals with acquired memory impairment was reviewed (Ehlhardt et al., 2008). This review was not specifically geared toward children, but its intent was to generate practice guidelines for individuals working in the field of cognitive rehabilitation. In addition, a review of the strategies will serve as a backdrop for the remainder of this section for which the review of intervention for memory and learning difficulties is intended. Fifty-one studies spanning from 1986 through 2006 were examined in the review; however, only two of these studies involved children from 8 to 11 years of age. Two instructional categories surfaced from this review: (1) systematic and (2) conventional instructional methods (e.g., errorful learning/trial and error). Systematic instructional methods use explicit faded models or prompts, while conventional methods focus on the recall of information or a procedure without prompts. Systematic instructional methods include techniques such as: (a) errorless learning, (b) method of vanishing cues (MVC), and (c) spaced retrieval. According to the authors, errorless learning is a strategy for which the goal is to eliminate errors during initial acquisition through the provision of models (Baddeley & Wilson, 1994). Patients are not encouraged to guess. MVC is a form of chaining for which the individual is provided either stronger or weaker cues following attempts to recall information or a procedure (Glisky, Schacter, & Tulving, 1986). This method is based on the premise that complex procedures can be taught if they are broken into smaller and simpler elements and if explicitly trained. Spaced retrieval or expanded rehearsal is a form of practice that allows individuals to practice at successfully recalling information during extended time intervals (Melton & Bourgeois, 2005). Favorable learning outcomes using systematic instructional methods were reported in 89% of the studies of TBI. However, it is important to note that only two pediatric studies met criteria for inclusion, and one study reported positive outcomes while the other reported negative outcomes. Only errorless learning was used in the study with negative outcome, while a systematic instructional practice was used in the former.

Though the aforementioned review focused on instructional techniques geared specifically toward neurogenic memory deficits, it is critical to recognize that these deficits occur within the context of everyday functioning, and for children, this means within the complex educational and home environments. Indeed, historically, the cognitive rehabilitation approach for individuals with TBI included client-delivered, discrete, cognitive exercises that were often presented through computer programs within inpatient and outpatient rehabilitation settings. However, research during the past several decades has revealed the limits of this decontextualized, discrete-trial approach. Direct restorative memory retraining has shown essentially no impact on functional skills or generalization. In fact, as noted by Ylvisaker and colleagues (2005), it is often the lack of executive control over other cognitive processes such as attention and memory that underpins the limits in functioning, so targeting a specific process such as memory may result in diminishing benefit. Moreover, concomitant problems associated with executive impairment often intensify as the child ages. In fact, a context-sensitive approach for which treatment is rooted in routines of everyday life and that incorporates opportunities for generalization and maintenance of skills to foster the acquisition and learning of new information is currently supported by the literature (Glang et al., 2008; Ylvisaker et al., 2005). Table 2 outlines specific research-based instructional strategies associated with pediatric TBI (Ylvisaker et al., 2005).

Likewise, it is becoming increasingly evident that TBI-specific assessment and intervention may also have its shortcomings, as there is significant variability in individual outcome based on a multitude of factors previously discussed, supporting the need for individualized educational programming. That is, given the lack of evidence for specific instructional strategies from which only children with TBI benefit, educators should focus on best practice and methods shown to be successful for students with special needs in general (Glang et al., 2008; Kirkwood et al., 2008). Glang et al. recently reviewed two general instructional methodologies that were shown to be effective with several populations of children: (1) direct instruction and (2) cognitive strategy intervention (e.g., self-regulated strategy, graphic organizers). Glang and colleagues cited a recent meta-analytic study that examined the effectiveness of instructional components in special education. They concluded that a combined cognitive strategy coupled with an explicit instruction model such as direct instruction was the most efficacious, regardless of the etiology of the learning difficulties. Direct instruction is a systematic instruction method that uses two interrelated components: carefully designed curriculum materials and enhanced delivery, with a goal of ensuring high rates of success. Components of direct instruction that have errorless learning as the goal include task analysis, modeling, prevention of guessing, and gradual fading of prompts. On the other hand, cognitive strategy interventions which include compensatory instruction and executive function/meta-cognitive intervention have been reported to be evidence-based practice for adult brain injury rehabilitation (Cicerone et al., 2005). Unfortunately, in a recent review of cognitive rehabilitation strategies for children with TBI (Limond & Leeke, 2005), no clear conclusion emerged in terms of clinical recommendations due to an insufficient number of high-quality studies.

TABLE 2
Research-Based Cross-Population Instructional Strategies Related to Characteristics of Many Students with TBI*

TBI Characteristic	*Instructional Strategy*	*Description of Method*
• Variable attention and concentration • Decreased speed of information processing	Appropriate pacing	Acquisition of new materials is improved by presenting information in small increments and requiring responses at a rate consistent with a student's processing speed. Pacing may need to be fast, even for a student with slowed processing, if they are familiar with the routine and fluctuations in attention demand faster delivery.
• Memory impairment (associated with need for errorless learning) • High rates of failure	Method that ensures high rates of success	Acquisition and retention of new information tend to increase with high rates of success, facilitated by errorless teaching procedures.
• Organizational impairment • Inefficient learning	Task analysis and advance organizational support	Careful organization of learning tasks, including systematic sequencing of teaching targets and advanced organizational support (e.g., graphic organizers), increases success.
• Inconsistency • Inefficient learning	Sufficient practice and review of each lesson as well as cumulative review	Acquisition and retention of new information is increased with frequent review, as well as with both massed and distributed learning trials.
• Inefficient feedback loops • Implicit learning of errors	Errorless learning combined with nonjudgmental corrective feedback when errors occur	Students with severe memory and learning problems benefit from errorless learning. When errors occur, learning is enhanced when those errors are followed by nonjudgmental corrective behavior.
• Possibility of gaps in the knowledge base	Teaching to mastery rather than criterion	Learning is enhanced with mastery at the acquisition phase.
• Frequent failure of transfer • Concrete thinking and learning	Facilitation of transfer/generalization	Generalizable strategies, wide range of examples and settings, and content- and context-embeddedness increase generalization; cognitive processes should be targeted *within* curricular content.
• Inconsistency • Unusual profiles	Ongoing assessment Flexibility in curricular modification	Adjustment to teaching on the basis of ongoing assessment of students' progress facilitates learning. Modifying the curriculum facilitates learning in special populations.

Adapted from Ylvisaker et al. (2005).
*TBI indicates traumatic brain injury.

CONCLUSION

Substantial progress has been made during the past several decades in the diagnosis and treatment of memory and learning impairment in pediatric TBI. The development of acute methods of screening to more appropriately gauge severity of injury and the proliferation of standardized instruments and batteries specifically designed for children have allowed us to more adequately describe changes in cognition in the acute, subacute, and chronic phases of the injury. Moreover, there have been recent attempts to characterize potentially more ecologically valid facets of memory such as prospective and procedural memory, though these methods remain experimental. It has become increasingly apparent that the persistence of long-term deficits in memory and learning and its impact on the acquisition of new skills and abilities is multifaceted and dependent upon a host of variables including, but not limited to, severity, age at injury, premorbid functioning, comorbidity, socioeconomic status, family expectations and adjustment, and post-injury care. Rigorous investigations regarding the efficacy of intervention for memory and learning deficits in pediatric TBI are sorely lacking, despite its prevalence. However, there has been a recent surge of research suggesting that best practice includes systematic instructional methods in a context-sensitive approach for which treatment is rooted in routines of everyday life and incorporates opportunities for generalization and maintenance of skills.

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