PREDICTION OF MEMORY PERFORMANCE IN LONG TERM SURVIVORS OF SEVERE CLOSED HEAD INJURY

A Thesis

Presented to

the Faculty of the Department of Psychology

University of Houston

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

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by

Keith B. Privett

December, 1988

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ABSTRACT

The Selective Reminding Procedure (SR), the California Verbal Learning Test (CVLT), and the Rivermead Behavioral Memory Test (RBMT) were administered to a group of long term (greater than one year post-injury) closed head injury survivors. As a memory performance measure, patients obtained therapists' signatures on behavioral contracts after each hourly training module over a two week time period. All three memory tests significantly predicted behavioral contract performance. The RBMT, which was designed to reflect real world memory failures in memory impaired individuals, was a significantly better memory performance predictor than the two verbal list learning tasks. CVLT scores were not significantly better than SR procedure scores at predicting memory performance.

Injury severity was significantly correlated with CVLT scores and the memory performance measure but not with RBMT or SR scores. The memory performance measure did not add significantly to the prediction of injury severity over CVLT scores.

Predicting outcome, planning interventions, and

assessing potential for rehabilitation may be best served by using more functionally oriented ecologically valid tests such as the RBMT.

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PREDICTION OF MEMORY PERFORMANCE IN LONG TERM SURVIVORS OF SEVERE CLOSED HEAD INJURY

With the advent of sophisticated brain imaging techniques (CT, MRI, PET), the applied neuropsychologist's role has begun to shift from brain damage diagnosis (presence and location) to the management and treatment of psychological deficits resulting from brain injury (Hart & Hayden, 1986; Loring & Papanicoloau, 1987). Yet neuropsychological assessment techniques have failed to keep pace with this shift from diagnostician to therapist and prognosticator. Traditionally, neuropsychological tests have been validated with reference to the presence, absence or the location of lesions. Assessment tools designed and validated to identify lesion location may not be ecologically valid or appropriate tools to predict everyday cognitive performance. Additionally, neuropsychologists have more recently borrowed and designed assessment tools based upon cognitive psychology memory models that may or may not reflect the true workings of memory in either brain injured or normal individuals. Neither the cognitive approach nor the traditional neuropsychological approach has received adequate empirical verification of its ecological validity.

Ecological validity means generalizing the results of controlled systematic experiments to events occurring outside the laboratory or clinic (Brunswik, 1955). This thesis will address the ecological validity of various tests derived from cognitive psychology memory models in a sample of memory impaired long term survivors of severe closed head injury. First, a review of relevant literature will be offered. Closed head injury, cognitive memory models, memory deficits following closed head injury, ecological validity and assessment will be discussed. Next, an investigational study will be described. Finally, study results will be offered and discussed.

Closed Head Injury

Pathophysiology

The pathophysiology of closed head injury (CHI) is commonly described in relation to the time course of the injury. The primary/immediate mechanism of brain damage resulting from CHI is a diffuse shearing, stretching and tearing of nerve fibers that occurs at the moment of impact (Adams, Mitchell, Graham & Doyle, 1977). Impact to or with the skull causes linear and rotational acceleration of the brain within the enclosed cranial vault (Gurdjian, 1971). This violent movement within the confines of the skull results in stretching of and damage to white matter tracts. Shear strain appears to be greatest in brain areas characterized by structural irregularities, especially frontal and temporal areas (Holbourn, 1943; Ommaya & Gennarelli, 1974). These areas rest on the rough, bony sphenoid wing of the skull. Shear strain occurring in the corpus callosum and midbrain areas is also common (Strich, 1970). The severity of the diffuse brain damage appears to be a more important determinant of the quality of recovery from injury than the presence of a focal brain injury (Adams et al., 1977).

Contusions and lacerations of the brain are also immediate consequences of closed head injury. Gurdjian & Gurdjian (1976) stated that contusions may underlie the site of impact (coup) and occasionally, contrecoup lesions may occur directly opposite the site of impact or to the undersurface of the frontal lobes and tips of the temporal lobes. Contusions may also occur in the white matter and are usually attributed to edema. Laceration of the brain from depressed skull fracture and in sharp bony areas may also occur.

Secondary mechanisms of brain injury occur after the initial impact. Intracranial hemorrhage, swelling, ischemia, raised intracranial pressure, and brain shift and herniation are a few of the delayed effects of CHI (Levin, Benton & Grossman, 1982). Intracranial hemorrhages are space occupying lesions resulting from the tearing of blood vessels. The subcortical white matter, corpus callosum and the orbital surface of the frontal lobe and temporal lobe are common sites for hemorrhage (Strich, 1970). Brain edema, which is excess water in the brain tissue, is usually found in areas of vascular disruption (Levin et al., 1982). The source of excess water is leakage of excess water from cerebral blood vessels. Diffuse cerebral swelling is thought to result from hyperemia which is defined as cerebral blood flow in excess of the metabolic needs of the brain (Levin et al, 1982). Ischemic hypoxia results when cerebral blood flow falls below a critical level. Neuropathological findings suggest that ischemic necrosis is present in about 50% of cases of fatal head injury (Graham & Adams, 1971). Raised intracranial pressure and pulmonary insufficiency are contributors to hypoxic ischemia. Increased intracranial pressure is usually the result of swelling or intracranial hematoma and occurs in more than 75% of patients with severe closed head injury (Miller, Becker, Ward, Sulivan, & Rosner, 1977).

Injury Severity

CHI severity is commonly assessed by coma depth and duration. The Glasgow Coma Scale (GCS), developed by Teasdale and Jennett (1974), evaluates coma depth based upon the patient's best motor response, best verbal response and eye opening. Coma is defined as the absence of eye opening, inability to follow commands, and failure to utter recognizable words. A GCS score of 8 or less indicates coma and is also used as a cutoff score indicating severe closed head injury. A score of 9-12 designates a moderate CHI, while a score of 13 -15 indicates a mild CHI. Plotting GCS scores at regular intervals provides an indication of duration of coma and yields more useful prognostic information than GCS scores at the time of admission (Jennett, Teasdale, Braakman, Minderhoud, Heiden & Kurze, 1979). A less reliable measure of coma duration is the time post-injury until the patient is able to follow verbal commands. This measure is a frequently used injury severity measure due to inconsistencies in plotting GCS's over time (Levin & Goldstein, 1986).

Epidemiology

The incidence of CHI is defined as the number of new cases occurring in a defined population in a specified period of time (usually one year). Prevalence is the total number of cases that exist at any one time. Epidemiological findings are inconsistent due to the problem of classifying mild head injured individuals who may not be admitted to the hospital or may not seek medical attention. At the other end of the spectrum, those CHI's resulting in death may be attributed to some other complication other than the head injury. There is a lack of uniformity across studies with respect to the inclusion of mild head injury. The availability of information about fatally injured patients may be difficult to obtain.

According to Kalsbeek, McLaurin, Harris & Miller (1980) the estimated incidence of head injury in the US is approximately 200/100,000. The incidence per 100,000 was 272 males and 132 females, for an approximate 2:1 ratio. Prevalence was found to be approximately 450/100,000.

The cause of CHI varies as a function of age. Automobile accidents are the most common cause of head injury in young adults, while falls account for a large number of CHI in young children and the elderly. Road traffic accidents account for about one-half of all CHI (Field, 1976). Age is another critical factor with a steep rise in morbidity between the ages of 15-24.

Outcome and Recovery

The Glasgow Outcome Scale (Jennett & Bond, 1975) was developed to categorize CHI patients on the basis of their physical, economic and social reintegration. Four levels of recovery are delineated by the scale including; persistent vegetative state, severe disability, moderate disability, and good recovery. The mortality rate for patients who sustain a severe head injury is somewhere between 30-50%, depending upon the rapidity of effective treatment. The term persistent vegetative state is used to describe those patients who remain speechless and devoid of meaningful contact with other persons (Jennett and Plum, 1972). Widespread injury to the white matter and brainstem have been implicated in this condition. Anywhere from 1-8% of CHI patients will remain in a persistent vegetative state. Severe disability represents 5-18% of CHI patients and is defined as dependent for daily support by reason of physical or mental disability. Moderate disability accounts for approximately 15% of CHI patients and is defined as those patients who can use public transportation, are independent in activities of daily living, and can work in a sheltered environment. Good recovery accounts for 14-27% of CHI individuals.

Gennarelli and colleagues (1982), in a seven center study of severe CHI, found a mortality rate of 41%. They also found that patients with equivalent GCS scores may have markedly different outcomes. The presence of acute subdural hematoma and low GCS (3-5) was associated with a 74% mortality rate and only 8% good recovery. In contrast, those patients with diffuse injury and a GCS of 6-8 had only a 9% mortality rate with 68% experiencing good recovery.

Cognitive Memory Models

Prior to reviewing findings of memory deficits following CHI, it will be necessary to first describe current cognitive memory models. The information processing approach of cognitive psychology provides a useful theoretical framework for investigating disorders of memory, including impairments which follow CHI. The information processing approach uses a computer analogy and purports that memory can be broken down into a set of different stages, processes and systems (Lachman, Lachman & Butterfield, 1979). Different aspects of memory can then be examined in brain damaged patients to provide information about the nature of their memory impairment.

Multiple-stage Model

The multiple stage model of information processing proposed by Atkinson and Shiffrin (1968) distinguishes between the permanent structural features of memory and the transient control processes that are under volitional control. The structural features of the system include a series of stores for the information based upon both temporal ordering and capacity.

The sensory register is preattentive and is the initial stage of information processing. It is concerned with the immediate registration of the stimulus within the appropriate sensory modality. The capacity of the sensory register is large, the trace duration is very short (1-2 seconds) and information is lost through decay.

Short-term store (STS) refers to "working memory" and is that information currently receiving conscious attention. Information is retained in STS through rehearsal and is coded in a phonemic fashion. Capacity is small, approximately seven bits of information may be handled at any point in time. Information is lost through decay or possibly through interference. Trace duration may last up to approximately 30 seconds.

Long-term store (LTS) differs from the sensory register and STS in that information does not decay or become lost in the same manner. LTS comprises our general fund of information or semantic network. It contains word meanings, rules and facts. There is no known limit or capacity and possibly no information loss. Deficient LTS may be the result of inaccessible information or interference. Trace duration can last for years and information retrieval utilizes various retrieval cues and search processes.

Control memory processes act upon material within the memory stores and can modify and/or integrate this information. Control processes of the memory system include the transfer of information between stores, memory schemes, coding techniques, and mnemonics. These processes are under voluntary control of the individual and are transient in that they are altered through the experiences of the individual. Transfer of information can occur through either a conscious or unconscious process (Lachman et al., 1979). Conscious transfer occurs when the individual deliberately tries to remember something. This may be referred to as controlled processing and includes the use of several techniques, such as rehearsal strategies and mnemonics (Hirst, 1982). Automatic processing is faster and does not require conscious effort and lacks the flexibility of controlled processes in that it cannot be consciously modified. Input into or retrieval from LTS can occur through automatic or controlled processes.

Criticisms of the multiple store or stage model of memory include: a lack of evidence for multiple stores (Craik & Lockhart, 1972), the problem of information transfer from one store to another (Tulving & Patterson, 1968), and the idea that information must necessarily pass through STS to enter LTS (Shallice & Warrington, 1970).

Craik and Lockhart (1972) question the notion of capacity in the Atkinson and Shiffrin model. It is unclear whether capacity limitations refer to processing or storage capacity or an interaction between the two. They also criticize the notion of how information is coded in each memory store. The commonly held view states that information in STS is coded acoustically while LTS information is coded semantically. Craik and Lockhart assert that STS can be coded visually or acoustically and possibly semantically. Therefore, they posit that a distinction of stores based upon coding is unsatisfactory. Finally, Craik and Lockhart (1972) state that forgetting has not been invariant across the different paradigms and experimental conditions used to support a multiple-stage memory model.

While the multiple stage model provides a good linear conceptual model of memory functioning, it appears to be weak in its explanations of the processes involved in memory processing.

Levels of Processing

Craik and Lockhart (1972) offer a "levels of processing" model of memory which suggests that "trace persistence is a function of the depth of analysis, with deeper levels of analysis associated with more elaborate, longer lasting and stronger traces." The levels of processing model is heirarchicacal with greater depth implying a greater degree of semantic elaboration or cognitive analysis. Longer lasting or stronger traces are processed more deeply.

A central feature of the levels of processing model is a flexible central processor that may be deployed to one of several encoding dimensions. This central processor can only deal with a limited number of items at a given time. Items are kept in consciousness or in primary memory by rehearsal at a fixed level of processing. The depth at which primary memory operates will depend both upon the usefulness to the subject of continuing to process at that level and also upon the amenability of the material to deeper processing. Thus, speed of analysis does not necessarily predict retention. Retention is a function of the depth of processing.

The levels of processing model of information processing provides a useful conceptual framework for memory. Trace persistence lies on a continuum depending upon the amount or degree of cognitive or semantic elaboration. Stores or stages are unnecessary in this model. The processes used by memory are this model's focus. A criticism of this model is the circularity of reasoning of trace persistence. If the trace is stronger, then it must have been processed more deeply. If the information was processed more deeply, then the trace must be stronger. Logically, it would seem that one cannot be experimentally dissociated from the other.

Episodic and Semantic Memory

Tulving (1972) made an additional distinction between two different memory systems, episodic and semantic. Episodic memory is a record of those events which have occurred during the individuals life that continue to maintain temporal and/or spatial tags. It is autobiographical in nature and includes memories of specific experiences. In contrast, semantic memory is a store of abstract and symbolic information which is no longer tied to specific episodes from the individual's past. It is the individual's fund of information and includes knowledge of words, facts and rules. While amnesics generally display impaired episodic memory, semantic memory is usually spared. Demented patients appear to have impairments in both episodic and semantic memory (Weingartner, Grafman, Boutelle, Kay & Martin, 1983). A deficit in semantic memory may also lead to an associated impairment in episodic memory since episodic memory depends upon information stored in semantic LTM. Access to material in semantic memory may be necessary for the proper encoding and organization of new information.

This semantic/episodic distinction would represent two different components of LTS in the multiple store model of memory by Atkinson and Shiffirin. It is unclear how it would fit into a levels of processing model or which one, episodic or semantic, would represent deeper processing.

Encoding Specificity

Tulving (1979) also formulated an "encoding specificity" principle of memory which states that the nature of the encoding operations performed at input directly determines the probability of gaining access to that item in the future. This theory ties in well with the levels of processing model. Semantic and associative cues at input would be the most likely cues to stimulate subsequent recall. Encoding and retrieval operations are thus accounted for by encoding specificity and levels of processing.

Memory and Closed Head Injury

Pathophysiology

Two regions of the brain, the medial aspect of the temporal lobe and the diencephalic midline, have been linked to human amnesia for nearly a century (Squire, 1987). Diencephalic structures implicated in memory include the mammillary nuclei, the medial-dorsal nucleus of the thalamus and neural pathways in the vicinity of the mediodorsal nucleus (Squire, 1987). Temporal lobe structures thought to play a significant role in memory processing include the hippocampus and the amygdala (Mishkin, 1978). With CHI, the temporal lobes are predisposed to focal contusions and hematomas by their structural irregularity and the bony protrusion of the sphenoid wing. In addition, bilateral shearing and tearing of fiber tracts within the temporal stem may disrupt afferent and efferent connections of the temporal cortex and the amygdala (Levin et al., 1982). Thus, memory deficits following CHI may be the results of temporal lobe or diencephalic dysfunction.

Memory deficits and CHI

Memory deficits associated with closed head injury may be best examined in relation to the time course of the injury. The loss of memory for events prior to injury is called retrograde amnesia. Coma refers to the period of loss of consciousness immediately following injury. Anterograde amnesia includes both post-traumatic amnesia (PTA) and residual memory deficits. PTA is a period of variable length following closed head trauma during which the patient is confused, disoriented, suffers from retrograde amnesia, and seems to lack the capacity to store and retrieve new information (Schacter & Crovitz, 1977). Residual memory impairments are the persistent memory deficits that remain after resolution of PTA. Each of these "phases" of memory impairment will be explained further and research findings will be reviewed.

Retrograde Amnesia

In 1882, Ribot stated that memories become increasingly resistant to disruption as a function of their age and repetition. His reasoning was based upon observations of retrograde memory loss for events occurring shortly before non-missile head injury with sparing of very remote memories. In some head injured patients, retrograde amnesia initially extends to events several years in the past and gradually resolves beginning with the oldest events until a point is reached contiguous in time to the injury which remains as a gap in memory (Levin et al., 1985; Benson & Geshwind, 1967; Russell, 1935; Russell & Nathan, 1946).

The nature of retrograde amnesia may be attributed to a retrieval failure for the more remote memory loss (Benson & Geshwind, 1967) or a disruption of memory consolidation explaining the more recent memory loss (Russell, 1946). Benson and Geshwind (1967) reasoned that retrograde amnesia must be a retrieval deficit because memories have already been coded and stored. If retrograde amnesia is a problem with retrieval then it would seem likely that all previously stored memories would be affected. The shrinking nature of the retrograde amnesia may suggest that older memories are more consolidated or more firmly established and therefore less susceptible to disruption, whereas newer memories have not been stored or consolidated as well and are more prone to disruption. From a neuroanatomical perspective, recently acquired memories are presumed to be more vulnerable because the neural changes that anchor them have not had sufficient time to be completed (Corkin, Hurt, Twitchell, Franklin & Yin, 1987).

Besides a relative sparing of more remote memories, the resolution of retrograde amnesia occurs in a "shrinking" fashion. Access to more remote memories tend to resolve more rapidly or before more recent memories (Benson & Geshwind, 1967; Russell, 1932; Russell & Nathan, 1946). The phenomena of shrinking retrograde amnesia suggests that different brain mechanisms are altered in the transient as compared to the lasting retrograde amnesia (Corkin, et al., 1987).

The methods of investigation used to study retrograde amnesia have evolved from the subjective and unstructured questioning of patients about pre-injury events (Russell, 1935; Russell & Nathan, 1946) to standardized techniques using public events that have previously occurred such as television program titles, public events, and faces of prominent persons (Albert, Butters & Levin, 1979; Warrington & Sanders, 1971; Squire & Slater, 1978).

The investigations of Russell and coworkers (1935, 1946) were retrospective in nature and consisted of asking the patient about personal or autobiographical pre-injury events. They stated that retrograde amnesia is relatively short, (i.e., less than 24 hours duration) and that the duration of retrograde amnesia is not proportional to the duration of total amnesia, even though long periods of retrograde amnesia are usually associated with long term amnesia. Retrograde amnesia resolves in a shrinking manner, with older memories available prior to newer ones, and a permanent retrograde amnesia is usually very short.

Objective measures of retrograde amnesia probe into memory of acquired knowledge, rather than into memory of experiences of one's life. Levin, High, Meyers, Von Laufen, Hayden and Eisenberg (1985) used a revision of Squire and Slater's (1975) TV test of remote memory to assess acquired knowledge in patients both during and after post-traumatic amnesia. They found a partial amnesia for events which occurred in the preceding decade in both groups. They also found impaired remote memory for events in the public domain and for life events. Secondly, they found that remote memory for life events was impaired in head injury patients who were still exhibiting disorientation and marked anterograde amnesia when compared to patients with head injuries of comparable severity who had emerged from post-traumatic amnesia. Furthermore, there was no temporal gradient on TV test measures of acquired knowledge. However, a temporal gradient was found for autobiographical memories. The authors suggested that repeated reminiscence of early personal events incorporated these memories into a semantic structure that becomes relatively invulnerable to retrograde amnesia.

Coma

Depth and duration of coma have long been viewed as the most useful indicants of brain damage severity (Levin et al., 1982). Prior to the development of scales to assess coma, unconsciousness was rated qualitatively and the end of coma was equated to the presence of eye opening, speech generation and the beginning of purposeful movements (Teasdale & Jennett, 1974). Teasdale and Jennett (1974) developed the Glasgow Coma Scale (GCS) which quantifies levels of consciousness. The scale measures the stimulus required to produce eye opening; the best motor response; and the best verbal response. According to these criteria, coma is defined as the absence of eye opening, inability to obey commands, and failure to utter recognizable words. This definition of coma corresponds to a quantitative GCS score of 8 or less.

During coma, memories are not being formed. Therefore, for the period of coma, there are no recollections. The use of coma depth and/or duration as predictors of memory deficits has revealed that coma duration and length of post-traumatic amnesia are not necessarily correlated. Also, coma depth at hospital admission is associated with a wide range of coma duration (Levin, Grossman, Rose & Teasdale, 1979).

Levin et al. (1979), investigated neuropsychological outcome following severe CHI (GCS score of 8 or less at admission). They found that all severely disabled patients and several moderately disabled patients exhibited unequivocal cognitive and emotional sequelae after long follow-up intervals (approximately 1 year). Memory deficits occurred in both storage and retrieval for about one third of the patients studied. The authors also found that good recovery was generally associated with a relatively brief period of coma.

Stuss, Ely, Hugenholtz, Richard, LaRochelle, Poirier and Bell (1985), found only minimal correlations between GCS scores and neuropsychological results in patients with good recovery from closed head injury. Furthermore, neuropsychological effects of mild head injury (GCS score 13 - 15) have shown no conclusive evidence of cognitive impairment one month after trauma (Gentilini, Nichelli, Schoenhuber, Bortolotti, Tonelli, Falasca & Merli, 1984).

Posttraumatic Amnesia

According to Schacter and Crovitz (1977), PTA refers to a period of variable length following closed head trauma during which the patient is confused, disoriented, suffers from retrograde amnesia, and seems to lack the capacity to store and retrieve new information. The term, post-traumatic amnesia, was introduced by Russell and Nathan (1946) and proposed to be a measure of severity of closed head injury. This interval was measured by subjective accounting by the patient as to when he "woke-up" and included the time from initial injury. This time period included the combination of coma and the confusional phase of recovery (Levin et al., 1982). Russell and Smith (1961) later refined the definition of PTA as the length of the interval during which current events have not been stored. Self-report continued to be the method of investigation.

Quantitative methods of assessing PTA have proven more reliable than retrospective accounts (Teasdale, Knill-Jones, & Van Der Sande, 1978; Gronwall & Wrightson, 1980). Also, Russell's method of including coma and clouded consciousness would tend to equate a patient with two days of coma and eight days of PTA to another patient with eight days of coma and two days of PTA, though injury severity may be quite different. Quite often, a very short period of coma can be followed by a very long duration of PTA (Levin et al., 1982).

Russell (1932) found that the likelihood of residual memory disturbances was directly related to PTA duration. A significant correspondence between PTA duration and outcome has also been reported by Jennett (1976).

The relation of PTA to subsequent neuropsychological deficits is inconsistent due to differences in measurement of PTA and outcome variables. According to Levin et al. (1982) "the magnitude of the correlation between posttraumatic amnesia duration and residual cognitive ability has been modest and has rarely accounted for more than 25% of the variance in test scores."

The GCS provides a useful quantitative measure of coma. The Galveston Orientation and Amnesia Scale (GOAT) (Levin, O'Donnell & Grossman, 1979) was developed to serially assess consciousness during the subacute stage of recovery from CHI and measures patient orientation. GOAT scores were found to be highly related to GCS scores. Duration of PTA, as defined by serial assessment using GOAT scores, were highly predictive of long term level of recovery. According to Schacter and Crovitz (1977), there is a general tendency for PTA duration to be correlated with degree of later memory difficulties. However findings are inconsistent and confounded by factors such as injury to test interval and subject age. Memory deficits are more likely to be found when earlier testing is conducted.

Gronwall and Wrightson (1981) studied simple CHI and found that a deficit in the ability to place material into long-term store was related to PTA duration, while the ability to retrieve material once stored was not predicted by PTA. Brooks (1976) found a significant correlation between PTA duration and Wechsler Memory Scale (WMS) scores. PTA of at least 2 days was required for subject inclusion. Those patients with PTA duration of one week or less were much less affected on memory performance than were other, more severely injured patients. Mandleberg (1975) assessed cognitive recovery during PTA following severe CHI (PTA less than 1 week) using the Wechsler Adult Intelligence Scale (WAIS). He found that verbal abilities were relatively intact during PTA while performance or non-verbal skills were significantly deficient. Mandleberg (1976) further found that verbal IQ and PTA were related at three months post-injury while performance IQ was related to PTA at both three and six months post-injury. No such relationships were found at twelve and thirty months post-injury.

Longitudinal investigations of patients with CHI have affirmed the prognostic significance of PTA duration (Levin et al., 1979). Prolonged periods of PTA have been predictive of neurological sequelae and persistent disability.

Can patients actually store and retrieve new information during PTA? "Islands of intact memory" during PTA have been reported (Russell, 1932; Russell & Nathan, 1946; Gronwall & Wrightson, 1980). This information may be clinically significant with respect to the timing of therapeutic interventions. Procedural memory is commonly referred to as the "knowing how" of task performance without "knowing that". Procedural memory is not accessible as specific facts, data, or time-and-place events. It is the memory contained within learned skills or modifiable cognitive operations (Squire, 1987). Procedural memory is spared in amnesia, including CHI patients (Ewert, 1987) and includes both motor learning and cognitive skills acquisition.

Priming, the facilitation of performance by prior exposure to words or other materials (Shimamura, 1986), is also preserved in most amnesic groups (Warrington & Weiskrantz, 1970; Baddeley, 1982; Weiskrantz, 1978). However, Baddeley (1987) was unable to find facilitation of fragmented word recognition in patients with CHI. He also was unable to demonstrate facilitation of word recognition using a homonym word priming task. The degree and utility of procedural memory and priming requires further investigation in

CHI patients.

Persistent Memory Deficits

Amnesia has an acute onset and resolves at varying rates. For this review, persistent memory impairments are those that continue following the resolution of PTA. Russell and co-workers (Russell 1932, 1971; Russell & Smith, 1961) indicate that persistent memory deficits are very frequent sequelae of CHI. Levin et al. (1982) state that anterograde amnesia is probably the most consistent clinical feature of closed head injury.

Verbal Short Term Memory

Verbal short-term memory, frequently referred to as "working" or "primary" memory, remains relatively intact following CHI (Levin et al., 1982). Brooks (1975), using a free recall memory task with patients following PTA found a strong recency effect in CHI subjects, just as he did in normals. The recency portion of word list recall is said to represent auditory-verbal STM. When a delay was interspersed prior to list recall, the recency component was much less for the CHI group when compared to controls. Since the effects of STM were supposedly eliminated by the delay, Brooks concluded that a deficit in LTM was responsible for the poor performance in injured patients. Brooks also found no significant difference between head injured subjects and controls on a digit span task, again supporting relatively intact short-term memory in head injured patients. However, digit span reversed was significantly worse in the head injured individuals. Digits reversed requires complex cognitive operations and cannot be considered as evidence for deficits in STM.

Verbal Episodic Long Term Memeory

According to Levin et al. (1982), "disturbances of long-term storage and retrieval for verbal material are a frequent result of a closed head injury that produces mass lesions or diffuse injury. Focal involvements of the left temporal lobe and diffuse cerebral swelling suggested by CT findings are associated with early long-term memory impairment, whereas the severity of diffuse brain injury reflected by acute neurologic deficits, low scores on the GCS, and residual cerebral atrophy reflected by CT findings are related to persistent memory deficit (p. 115)."

Brooks (1976) analyzed WMS performance in patients following severe CHI (PTA greater than two days). He found that patients continued to display marked memory deficits months after injury. PTA associated with diffuse brain damage was an important prognostic sign for residual memory impairment. Focal damage was found to be relatively insignificant in the genesis of memory deficits. Recovery of memory to stable but low levels may occur within six months post injury.

Levin et al. (1979) found an impairment in verbal episodic LTM in patients following CHI. They administered the verbal selective reminding test (Buschke & Fuld, 1974), which was designed to measure LTM encoding and retrieval processes. Levin and Eisenberg found that CHI patients often perform poorly on this test. Continuous word retrieval was impaired in patients with diffuse damage, damage to the left temporal lobe or bilateral lesions. The storage of material into LTM was also found to be deficient in these patients. In general, an association was found between deficits in verbal LTM and damage to the left temporal lobe. They retested all of their patients at least six months after the initial assessment. Unlike their previous results, they found storage and retrieval deficits resolved in many patients. Residual memory deficits were most severe in patients with diffuse brain damage. Therefore, the process of diffuse injury seems to be a necessary prerequisite for the persistence of verbal LTM memory deficits.

Levin, Grossman, Rose and Teasdale (1979) investigated the long-term neuropsychological outcome of severe CHI patients (GCS score of 8 or less upon hospital admission). Their findings revealed that intellectual level, memory storage and retrieval, linguistic deficits and personal and social adjustment corresponded to overall outcome. Medium follow-up at testing was one year. Using the selective reminding procedure, they found that about one-third of the patients exhibited a deficit in memory storage and retrieval. Disruption of LTM processes and inefficient screening of intrusive errors were found in patients with moderate or severe disability as measured by the Glasgow Outcome Scale.

Gronwall and Wrightson (1981) examined the effects of head injury and subsequent memory performance. In one experiment, a factor analytic approach was undertaken to examine WMS scores, the PASAT, and Quick Test performance in 71 patients who had simple head injuries (no skull fracture, intracranial hematoma, localizing neurological signs or complications). Three factors were identified. Factor 1 loaded most highly on PASAT scores and WMS Mental Control and was determined to be an indicator of attention, concentration and information processing capacity. Factor 2 had to do with learning and memory and loaded most highly on WMS Associate Learning. Factor 3 could be identified as a general knowledge or verbal competence measure and loaded most highly on the Quick Test and WMS Information and Orientation. Surprisingly, the learning and memory factor showed a very low loading on duration of PTA.

In a second experiment, Gronwall and Wrightson (1981) used 20 patients with PTA duration longer than one hour. They were given the PASAT, the selective reminding task, and a visual sequential memory subtest from the Illinois Test of Psycholinguistic Abilities. The selective reminding procedure was administered because it purports to allow separate analysis of storage and retrieval mechanisms. No significant correlations were found between PASAT scores and memory scores while PTA was correlated with several memory scores. As a group, patients did not show a significant deficit in their ability to store items into LTM, but the number of items they stored was significantly related to the duration of PTA. The authors concluded that the inability to place material into LTS may persist to a diminishing degree after PTA has ended.

More recently, Levin and Goldstein (1986) examined verbal episodic memory in 12 severe closed head injured patients using a levels of processing model of memory functioning. Depth of processing is related to the persistence of the memory trace and requires semantic memory for the encoding and organization of new material (Tulving, 1983). Three levels of words, each representing a different level of semantic organization, were used. These lists consisted of either completely unrelated words, related but unclustered words, or related words presented in clusters. The related words consisted of items from several different semantic categories (house parts, fruits, animals). Patients were found to have inferior recall when compared to controls on all three lists. Recall was better for both groups when words were presented in a clustered format. However, controls were able to impose a strategy for clustering on the related and unclustered list while patients did not. The CHI patients were found to use ineffective strategies resulting in poor semantic clustering and decreased word recall. CHI subjects made use of semantic organization when the list was structured but were incapable of effectively organizing the information when they had to generate structure on their own. This "passive" approach to learning resulted in impaired free recall.

It appears that patients have access to information in semantic memory, but they do not make good use of it for organizing and processing new material. Another explanation for their memory deficits could be a deficit in retrieval from semantic long-term memory.

<u>Verbal Semantic Long Term Memory</u>

Patients with CHI may have difficulty accessing information from semantic LTM (Levin & Goldstein, 1986). Sunderland, Harris & Baddeley (1983) found evidence for a semantic retrieval deficit in CHI patients. Using a list of obviously true and obviously false statements, they found that head injured subjects were slower than controls in correct identification of statements even when the confound of motor speed was controlled. Verbal fluency tasks (word association) also appears to reflect poor access to semantic information. Poor performance on verbal fluency tasks has been reported with CHI subjects (Sarno, 1980).

Although access to semantic information is not completely eliminated in CHI, the diffuse damage of closed head injury may result in a reduction in the efficiency with which semantic information is retrieved. One result of this semantic inefficiency could be a deficit in episodic LTM.

<u>Mild CHI and memory</u>

The results of investigation into residual memory deficits following mild CHI has produced equivocal results. Gentilini and colleagues (1985), in a study of 50 consecutive cases of mild CHI and 50 matched controls, reported no conclusive evidence that mild CHI causes cognitive impairment at one month after the trauma. Barth, Macchiocchi, and Giordani (1983), using the Halstead-Reitan Battery to study cognitive performance in 70 patients with mild CHI, found a moderate to severe impairment in 22 patients, a mild deficit in 22 patients and minimal impairment in 26 patients. At three months, two-thirds of their patients demonstrated mild to severe cognitive impairments and one-third were unemployed. Gronwall and Wrightson (1974) found that almost all of their mild CHI patients (PTA less than 24 hours) reached normal information processing (PASAT scores) 35 days post-injury.

Levin and colleagues (1987), in a three center study of neuropsychological outcome of mild CHI patients, found significant differences in patients when compared to controls at baseline on the GOAT, digit span, memory for word lists, visual reproduction of geometric figures, digit symbol, PASAT and a structured interview. At one month follow-up, performance on most measures had improved to comparable control levels. Furthermore, at three months, the pooled data from the three centers disclosed no difference in neuropsychological performance between controls and head injury groups. Also, gain in performance between one and three months did not reach significance for any of the test measures.

Visual memory

Few studies have examined visual memory deficits in CHI patients. Brooks (1976) found that patients performed more poorly than controls on the Visual Reproduction portion of the WMS. This impairment was associated with focal neurological signs. There was also a relationship between PTA duration and tasks performance. Gronwall and Wrightson (1981) found that visual memory was most highly loaded on a factor associated with learning and memory. The same subtest also had a moderate loading on a factor reflecting attention and concentration. In general, patients with CHI do worse than controls on tests requiring the reproduction of visual designs. However, attentional factors appear to make a significant contribution to task performance. Performance on visual reproduction tests may be affected by deficits in either attention or memory processes. The relationship between visual memory impairment and the type of pathology is unclear. One possibility is that performance on these tasks can be disrupted by either localized or diffuse brain damage.

Visual recognition memory deficits have been demonstrated in CHI patients using signal detection analysis of patient responses (Brooks, 1974; Hannay, Levin, & Grossman, 1979). Hannay et al. (1979) found that head injured subjects had lower overall levels of memory efficiency and applied a lower response criterion. Head injured patients were less cautious than controls in identifying previously seen stimuli. No relationship was found between performance and lesion laterality. This finding may imply that diffuse damage is responsible for the decrease in memory efficiency.

Ecological Validity of Memory Assessment

Questionnaires and checklists are designed as methods of assessing real world memory performance and are usually completed by the subject, an immediate family member or by rehabilitation therapists. The construction of these instruments may be based upon observations of memory performance or dysfunction of select patient populations. Research has found that responses to questionnaires are reliable but that they correspond only moderately with a person's memory performance (Sunderland et al., 1983). Two explanations may illuminate these findings. Some patient populations may be unaware of their memory failures and secondly, the criterion used to validate memory performance may be inadequate (criteria are memory tests validated in regards to organicity).

Sunderland et al. (1983) developed a twenty-seven item questionnaire used to assess memory failure in severe CHI patients. The questionnaire may be completed by the patient, a relative or a third party familiar with the patient. There are 9 possible ratings based upon frequency of occurrence of memory failures. The statements were developed through interviews with CHI patients and relatives and were selected based upon their ability to discriminate between patients (severe CHI) and controls (mild CHI). Relatives' ratings were more valid than the patient's inaccurate self-assessment when compared to performance on traditional clinical memory tests. Relatives' questionnaires' greatest correlations with other memory measures were with story recall, then paired associates, and finally facial and pattern recognition tasks.

The Rivermead Behavioral Memory Test (RBMT) is a recently developed memory test designed to assess everyday memory performance, therefore reflecting ecological validity (Wilson, 1986). The RBMT consists of a series of memory tasks which reflect memory deficits commonly seen following traumatic brain injury (Sunderland et al., 1983). The test includes prospective memory tasks (remembering an appointment, remembering placement of a belonging, associating a name with a face for future recall, and remembering a route) as well as tests of discourse memory, orientation, and object and face recognition. According to Wilson (1986), "the RBMT provides more information than the usual standardized test since it is assessing skills necessary for adequate functioning in normal life rather than performance on experimental material" (p. 4). Preliminary results indicate that the RBMT correlates well with other memory tests. Correlations between the RBMT screening score and therapist's ratings of CHI subject's memory failures was 0.75 indicating a good measure of memory performance.

Assessment

Ecological Validity

Ecological validity means generalizing the results of controlled systematic experiments to events occurring outside the laboratory or clinic (Brunswik, 1955). In neuropsychology, strictly diagnostic issues are becoming less important and the prediction, management and treatment of psychological disorders are becoming more important. According to Hart and Hayden (1986),

"the neuropsychologist must now be able to: (1) predict the effects of dysfunction on activities of daily living, educational performance and vocational success; (2) express these predictions using concepts and terms that are understandable to the patient, the family, and other lay persons; and (3) plan programs of rehabilitation which have a significant impact on neuropsychological deficits as they are expressed in activities important to the patient and his family."

Currently used neuropsychological and cognitive theoretical tests have not been validated as performance predictors in these three areas.

To predict behavior or plan interventions, a thorough assessment of spared and impaired performance is required, yet current assessment procedures lack ecological validity confirmation. Neuropsychological literature lacks a substantial database connecting test scores and specific present or future real world performance (Hart & Hayden, 1986). This statement holds true for neuropsychological tests assessing brain pathology and cognitive psychological tests assessing memory components according to cognitive theoretical models. Neither was designed or empirically verified as ecologically valid.

Another difficulty with memory tests developed through cognitive psychology is that new theories of cognition, information processing and memory are formulated so frequently that standard measurement of these functions may be reliable, but may not be measuring what they propose to measure (Cermak, 1986). If the theories are incorrect, the batteries designed to assess such disorders are incorrect as well.

Memory Tests

Selective Reminding

The selective reminding (SR) procedure developed by Buschke (1973) and Buschke and Fuld (1974) and the California Verbal Learning Test (CVLT) developed by Delis, Kramer, Ober, and Kaplan (1986) are attempts to ground verbal memory assessment within the context of contemporary information-processing theory.

The SR procedure reflects the multiple-stage model of memory as proposed by Atkinson and Shiffrin (1968) and attempts to differentiate retention, storage and retrieval. According to the Atkinson and Shiffrin model, memory is comprised of stores and processes including the sensory register, short term store (STS) and long-term store (LTS). The sensory register is the initial perceptual stage and is pre-attentive with very rapid decay. STS refers to working or conscious memory, has a limited capacity, is maintained through rehearsal and decays rapidly or is lost through interference. LTM has an unlimited capacity and is generally thought to be long lasting.

The rationale of the SR procedure is that the subject is provided the opportunity to recall words spontaneously, presumably demonstrating long term memory recall (Loring & Papanicolaou, 1987). The SR procedure purports to parcel memory into long-term storage (LTS), long-term retrieval (LTR), consistent long-term retrieval (CLTR), and short-term recall (STR). Studies using the selective reminding procedure have typically found high correlations for these memory performance measures in both clinical and control samples, suggesting that these measures are assessing similar constructs (Kenisten, cited in Kraemer, Peabody, Tinklenberg, & Yesavage, 1983; Loring, cited in Loring & Papanicolaou, 1987). Furthermore, the distinction between storage and retrieval is arbitrary and has dubious construct validity (Loring & Papanicolaou, 1987).

California Verbal Learning Test

The CVLT has a strong grounding in cognitive psychology (Loring & Papanicolaou, 1987) and was designed to reflect a "cognitive process" approach to neuropsychological assessment. This approach maintains that a patient's performance is multifactorially determined and requires a test with a scoring system capable of quantifying both spared and impaired cognitive abilities (Kaplan, 1983). CVLT scores reflect cognitive psychology procedures or paradigms that have been beneficial in differentiating patient populations based upon memory performance. The amnesias are as heterogeneous as the apraxias and the agnosias and show distinctive deficit patterns when a broad range of memory capacities are assessed. (Butters, Miliotis, Albert & Sax, 1984). Differentiation of the amnesias is a primary goal of the CVLT.

The CVLT moves away from the distinction of memory stores and seeks to quantify memory processes. The CVLT has greater utility in addressing a "levels of processing" (Craik & Lockhart, 1972) conceptualization of memory, given the inherent semantic structure of the word lists used. The levels of processing approach to memory states that trace persistence is a positive function of the depth to which the stimulus has been analyzed (Craik & Lockhart, 1972). Depth pertains to the degree of semantic or elaborative analysis of the stimuli. Thus, memory is viewed as a continuum from the transient product of sensory analysis to the highly durable products of semantic-associative operations (Craik & Lockhart, 1972).

The CVLT assesses semantic processing by using a 16 item word list that comprises four distinct semantic categories. The subject may impose a strategy or "chunk" information into semantic categories reflecting deeper levels of processing which should aid recall. The CVLT may be better equipped to predict everyday memory performance since the CVLT stimulus words permit the subject to impose a semantic strategy for word recall. Depth of processing can be evaluated by this organizational or planning memory component. The association of CVLT word list items may provide additional predictive power of real-world memory requirements over the list of unrelated words used in the SR task.

Although the SR procedure provides information about memory stores and the CVLT provides information regarding memory processes, neither provides information about the implications of spared and impaired performance reflected in its scores. The CVLT may better discriminate amnesic populations since it was designed to provide scores that have been shown to discriminate different amnesic populations. Neither measure may be a valid indicator of everyday memory performance for individuals with known memory disorders. The tests' ecological validity has not been investigated.

Rivermead Behavioral Memory Test

A memory test designed to assess everyday memory performance and therefore reflecting ecological validity has recently been introduced by the Rivermead Rehabilitation Center (Wilson, 1986). The Rivermead Behavioral Memory Test (RBMT) consists of a series of memory tasks which reflect memory deficits commonly seen following brain injury (Sunderland et al., 1983). The test includes prospective memory tasks (remembering an appointment, remembering placement of a belonging, associating a name with a photograph, remembering a route) as well as tests of discourse memory, orientation, and object and face recognition. While providing information regarding visual and verbal memory, the RBMT does not attempt to factor memory failure based upon any theoretical cognitive memory model. It also does not attempt to address the existence or locus of brain injury. According to Wilson (1986), the RBMT provides more information than the usual standardized test since it is assessing skills necessary for adequate functioning in normal life rather than performance on experimental material. Preliminary results indicate that the RBMT correlates well with other memory tests (Wilson, 1986). As previously reviewed, correlations between the RBMT screening score and the number of memory failures as reported by rehabilitation therapists was 0.75 indicating a good measure of memory performance during hospitalization (Wilson, 1986).

Study Rationale and Hypotheses

The ecological validity of the SR procedure and the CVLT has not been established. However, these tools are frequently used by neuropsychologists to plan rehabilitation interventions and to predict functional memory outcome. Therefore, this study will attempt to establish the ecological validity of each memory measure (SR, CVLT, RBMT). Next, a comparative analysis of incremental predictive power will be undertaken. Finally, the study will attempt to establish the relationship between memory measures and injury severity. Specific hypotheses are as follows:

Hypothesis 1: CVLT scores will better predict memory performance than will SR scores.

Hypothesis 2: RBMT scores will better predict memory performance than will CVLT and SR scores.

Hypothesis 3: The memory performance score will best predict injury severity when compared to each memory test score (RBMT score, CVLT score and SR score).

The CVLT and SR procedure are both verbal learning tasks. In viewing memory through a "levels of processing" approach, the unrelated SR procedure words would be processed at a more "shallow" level. In contrast, CVLT words are semantically related and therefore may be processed at a "deeper" level. Since functional memory appears to work through contextual cues and associations (deeper processing), the CVLT (deeper processing) would be a more ecologically valid indicator of functional memory performance than the SR procedure.

In contrast to both word list tasks, the RBMT is comprised of tasks that more closely simulate everyday memory requirements. The RBMT would therefore appear to be less artificial than word list learning tasks and more deeply processed. RBMT scores should be more ecologically valid indicators of everyday memory than either list learning task.

Impaired memory performance is a frequent sequela of CHI. One would expect that injury severity should be reflected in the severity of the memory deficit. Therefore, memory scores will be used to predict injury severity using the rationale that the more ecologically valid the memory measure, the greater its predictive power. Thus, the memory performance measure should be most highly related to injury severity.

METHODS

Subjects

The sample consists of 35 long term survivors (greater than one year post-injury) of severe CHI (estimated GCS of 8 or less) enrolled in The Transitional Learning Community (TLC), a residential rehabilitation facility in Galveston, Texas. While these subjects were selected for their rehabilitation potential, they lacked the capacity for independent living and do not reflect the entire spectrum of CHI.

Exclusion criteria for this study included residents who were older than 50 or younger than 14 years of age at the time of their injury. Residents with previous neurologic or psychiatric diagnosis were excluded. Subjects were free of aphasic deficits at the time of testing as determined by clinical judgment and by the results of neuropsychological test data.

Tables 1 and 2 provide demographic and clinical characteristics for each CHI subject.

Procedures

Subjects were administered the CVLT, the SR

TABLE 1

Demographic and Clinical Characteristics

Age (in years)	
mean	21.1
sd	4.24
range	18-37
Education (in years)	
mean	12.3
sd	1.79
range	10-16
Sex	
male (n)	24
female (n)	11
Injury-test Interval (in years)	
mean	3.44
sd	2.56
range	1-12
Accident type	
automobile (n)	19
other (n)	16
Injury type	
focal and diffuse (n)	29
diffuse (n)	6
Cranial nerve signs	
presence (n)	17
absence (n)	18
Paresis	
presence (n)	24
absence (n)	11
Surgery	
yes (n)	9
no	26

TABLE 2

Individual Neuropathology and Demographics

subject	sex	age	educ	time post	accident type	injury type	cranial nerve
DA	F	30	16	4	auto	focal	yes
LB	F	19.5	11	1.5	auto	focal	no
JB	M	28	14	6.5	auto	diffuse	yes
MB	M	23	12	3	other	focal	no
TB	F	27	12	2.5	auto	diffuse	no
KB	F	22	12	4	auto	focal	no
AC	F	22.5	12.5	3.5	auto	focal	yes
DC	M	27	15	2	auto	focal	no
TC	F	21	12	1.5	auto	focal	yes
SE	M	24	11	3.5	other	focal	yes
JF	M	25	12	2	other	focal	yes
TH	M	26	14.5	1	auto	diffuse	yes
RH	F	28	13.5	8	other	focal	yes
TK	M	21	10	6	other	focal	yes
SK	F	29	11	12	auto	focal	yes
JL	M	24.5	15.5	2	other	focal	no
VL	M	31	13	1.5	auto	focal	yes
ML	M	28	10	8	other	focal	no
ML	F	20	12	2.5	auto	focal	no
DM	M	26	12	1.5	other	focal	no
CN	M	20.5	11	1	other	focal	yes
PR	M	18	11	1	other	focal	no
GR	M	26	12	3.5	auto	focal	yes
LR	M	20	13	1	other	focal	yes
AR	F	20	10	4	auto	diffuse	no
GS	M	26	15	1.5	auto	focal	no
KS	F	37	16	3.5	auto	diffuse	no
PS	M	21	12.5	2	auto	focal	yes
SS	M	26.5	9	9	other	focal	yes
PT	M	19	11	2	other	focal	no
JT	M	22	11	2.5	auto	focal	yes
KW	M	28	13.5	5	auto	focal	no
BW	M	18	10	3	other	focal	no
MY	M	24	12	2	other	diffuse	no
RH	M	32	12	3.5	other	focal	no

TABLE 2 (con't)

Individual Neuropathology and Demographics

subject	LOC days	GCS	surgery	seizures	paresis
DA	16	4	no	no	right
LB	1	6	no	no	left
JB	21	<8est.	no	yes	left
MB	120	4	yes	no	left
TB	2	<8est.	no	no	right
KB	90	<8est.	no	no	both
AC	28	6	monitor	no	left
DC	21	<8est.	no	no	right
TC	20	<8est.	no	no	none
SE	30	7	monitor	no	left
JF	35	<8est.	no	no	none
TH	19	5	no	no	none
RH	42	<8est.	no	no	none
TK	90	<8est.	shunt	no	both
SK	21	<8est.	no	no	right
JL	7	<8est.	yes	no	none
VL	28	<8est.	no	no	left
ML	7	<8est.	no	no	none
ML	35	<8est.	no	no	right
DM	2	<8est.	no	no	right
CN	14	<8est.	no	no	left
PR	13	8	yes	no	none
GR	25	<8est.	no	yes	none
LR	2	<8est.	no	yes	none
AR	37	<8est.	no	no	right
GS	21	4	no	no	right
KS	30	<8est.	no	no	left
PS	21	<8est.	yes	yes	right
SS	49	<8est.	no	no	both
PT	60	<8est.	no	no	none
JT	8	<8est.	no	no	right
KW	18	<8est.	no	no	none
BW	45	<8est	yes	no	left
MY	1	<8est.	no	no	right
RH	2	<8est.	yes	no	left

Note. est. = estimated score

procedure, and the RBMT in a private room on the TLC campus as part of a standard neuropsychological evaluation. The evaluation was scheduled for two four-hour sessions on different days. The two word-list memory tests (CVLT, SR) were not administered on the same day to prevent interference between word lists. Delays on word list learning tests were filled with the assessment of so called "non-verbal" abilities. The RBMT was administered during either testing session.

The CVLT is patterned after the Rey Auditory Verbal Learning Test (Rey, 1964; Lezak, 1983), and is comprised of two sixteen word shopping lists, a Monday list and a Tuesday list. Both lists have four categories of shopping items with four members in each category. The Tuesday list shares two semantic categories with the Monday list. All sixteen words on the Monday list are presented for immediate recall for five consecutive trials. The Tuesday list is then presented for immediate recall as an interference trial. The subject is then asked to recall the Monday list items. Next, the subject is cued with the semantic category name for recall of the category items from the Monday list. A twenty minute delay occurs next, during which tasks of a non-verbal nature are administered. After the delay, the subject must again freely recall the Monday list. Then a cued recall trial is given. Finally, a recognition test for Monday items is administered. The recognition list includes the sixteen Monday list items and a host of distractors including: Tuesday list items of both shared and unshared semantic categories; prototypical distractors; phonemic distractors; and non-related words.

The SR procedure consists of twelve unrelated words presented for free recall after which the subject is reminded of only those words that were not recalled on the previous trial. Perfect free recall of the list occurring on two consecutive trials or completion of twelve trials is necessary for task completion.

The RBMT contains tests of discourse memory, prospective memory, recognition memory and orientation. The discourse memory paragraph is broken into twenty-one units of information. One point is scored for each detail recalled word perfect, one point for a close synonym, and 1/2 point for a partially correct recall or approximate synonym. Prospective memory measures include remembering a name, a personal object and where placed, an appointment, a route around the room, delivering a message and a delayed recall of the discourse memory paragraph. Scores were combined on these measures to give a global memory measure called the RBMT profile score.

The memory performance score was based upon a memory component of a behavioral contract that the subjects were required to keep as part of their rehabilitation program. The subject carried his contract at all times and had to remember to ask for a signature from the therapist after each hourly rehabilitation module. During the first two weeks of residence, this is the only component of the behavioral contract. There is no reward for performance during the first two weeks, but thereafter, the subject must progress through a series of stages to successfully move through the rehabilitation program. Correct contract performance percentages and failures to initiate signatures were reported each week and used for feedback and reinforcement in a group meeting with all residents present.

Variables

A preliminary correlational analysis of scores within each test and the memory performance score were used to determine the most appropriate score for each test. Three separate scores were analyzed from the CVLT; the Monday list total recall score, the delayed recall score and the semantic cluster score. The total recall score is the total number of words correctly recalled on the first five recall trials. The delayed recall score is a free recall trial which occurs approximately 20 minutes after the short delay cued recall. The semantic cluster score is a ratio calculated over the initial five free recall trials. The semantic cluster ratio is an observed/expected ratio derived to indicate the degree to which the examinee uses a semantic strategy in recalling the word list. For the observed semantic cluster score, one point is given each time the subject reports a correct word after another correct word from the same semantic category. The expected score indicates chance clustering. The ratio of 1 indicates chance clustering and a ratio of >1 indicates the increasing imposition of a semantic strategy for word recall.

Three scores were used from the SR procedure: long term storage (LTS), continuous long term retrieval (CLTR), and delayed recall. LTS is defined as recalling a word on two consecutive trials. It is assumed that the word has entered long term storage on the first of the two trials since the subject recalls the word without a reminder. Once the word has entered LTS, it is considered to be in permanent storage and the word is scored on each subsequent trial regardless of the subject's recall. When the subject begins to recall a word in LTS consistently on all subsequent trials, it is scored as CLTR. Delayed recall is the total number of words freely recalled after a thirty minute delay.

Only the total profile score was used from the RBMT. Included in this score are all the component parts of the RBMT including discourse memory, prospective memory, orientation, and recognition memory. Scores from each component part were added together to form the profile score.

The memory performance score was the number of failures to initiate therapist signatures during the first two weeks of TLC residence. Each TLC resident had to remember to have their contract with them at all times. Next, they must ask for therapists signatures at the end of every training module, after each meal, and upon morning wake-up. A total of 12 signatures per day was possible. Eight of the subjects were residents of TLC prior to the institution of the behavioral contract and their memory performance scores will be the number of times they failed to initiate the therapists' signature during the first two weeks after the institution of the behavioral contract system.

As an estimate of injury severity, length of impaired consciousness (LOC) is defined as the length of time, in days, post-injury, until the subject was able to follow simple verbal commands. LOC was estimated by retrospectively analyzing the subject's acute medical records.

Demographic variables including age, sex and education were analyzed descriptively. Also, correlations were computed with memory variables to investigate possible relationships.

A neuropathological variables table provides injury information for each subject. Variables include the presence or absence of: focal lesion; hemiparesis; cranial nerve signs; seizures and whether surgery was conducted.

Data Analysis

First, a preliminary correlational analysis was performed to assess the relationship of the memory performance measure with memory test scores to determine the score within each memory test with the largest correlation to the memory performance score. These scores were used in subsequent analyses. Correlations of demographic variables (age, sex, time post-injury, and age at injury) were also computed. Next, multiple regression analyses of the contributions of RBMT, CVLT, and SR scores were undertaken in order to assess their utility and incremental validity in predicting memory performance. First, a simple regression analysis was performed using the RBMT profile score to predict memory performance. Next, a stepwise multiple regression analysis of scores within each cognitive psychology based memory test was used to predict memory performance. First, the CVLT total recall score, delayed recall score and semantic cluster ratio were used to predict everyday memory performance. Then, LTS, CLTR and delayed recall scores of the SR procedure were used to predict everyday memory performance.

The most highly correlated scores to memory performance within each test were then used to assess the incremental power of each test in predicting memory performance by testing for the significance of R square change. The hypothesized regression equations were as follows:

Equation 1: SR + CVLT = Memory performance score

Equation 2: SR + CVLT + RBMT = Memory performance score

Equation 1 provides information regarding any additional predictive ability of the CVLT over the SR procedure. This equation tests the hypothesis that the CVLT provides better predictive power than the SR procedure due to the inherent semantic organizational strategy of the CVLT. Equation 2 tests the hypothesis that the memory test designed to reflect ecological validity, the RBMT, provides additional predictive power over the two list learning tasks, the CVLT and SR procedure. Testing the significance of R square change provides this information.

Finally, memory scores were analyzed as predictors of injury severity. Multiple regression analyses using each separate memory test score (RBMT, CVLT, and SR) with the memory performance score were undertaken to predict injury severity. The memory performance measure should best predict injury severity.

The number of subjects that have been administered the RBMT is 13 less (22 subjects) than the number having taken the CVLT and the SR procedure. Equations using the RBMT will therefore include fewer subjects.

RESULTS

Hypothesis 1 was not supported. The CVLT did not add significantly to the prediction of memory performance scores over the SR procedure, F (2, 32) = 2.87, p > .05. The RBMT did provide significant incremental validity of memory performance over the SR procedure and the CVLT, F (2, 19) = 6.54, p = .017, supporting hypothesis 2. This hypothesis stated that the RBMT would be a better predictor of the memory performance measure than the SR procedure and the CVLT. Hypothesis 3 stated that the memory performance measure would be most highly related to injury severity. Only the memory performance measure and the CVLT score were correlated with injury severity. However, when combined into a single regression equation, statistical significance was not obtained in predicting injury severity, R = .15, p = .07, therefore, further analysis was not conducted.

Table 1 provides demographic and clinical characteristics of the CHI subjects. Demographically, the mean age of the CHI subjects used in this study was 21 years. There was an approximate 2:1 sex ratio with

24 males and 11 females. Mean educational achievement was 12.3 years, ranging from 10 to 16 years.

In addition to the grouped data in table 1, table 2 provides individual neuropathological information for each subject. An examination of these tables shows that clinically, the injury to test interval averaged 3.44 years. Nineteen subjects were involved in automobile accidents, while 16 subjects suffered a CHI from motorcycle accidents and falls. Twenty-nine of the subjects showed focal neurological damage on CT and/or MRI scans, while only six subjects had negative images. Brain stem involvement was present in approximately 50 percent of the subjects. Seventeen subjects displayed abnormal cranial nerve signs acutely, and eighteen had normal cranial nerve findings. Twenty-four subjects demonstrated either a hemiparesis or quadriparesis while eleven subjects did not. Surgery was performed on nine subjects, while 26 subjects did not require surgery.

The memory performance score was not related to the basic demographic variables of age, sex or education. Clinical characteristics were also unrelated to the memory performance score. However, the injury severity measure was correlated with age at injury, $\underline{r} = .34$, $\underline{p} <$

.05, with a younger age associated with a more severe injury.

Table 3 provides correlations of memory test scores and the memory performance measure. Based upon the most highly significant correlations between memory test scores and the memory performance measure, the SR delayed recall score, *r* = .48, *p* = .003, and the CVLT long delay free recall score, *r* = .53, *p* = .001, were chosen for use in further analyses. The RBMT profile score was also highly correlated with the memory performance measure, *r* = .69, *p* = .0004. Table 3 provides correlations of memory test scores and the memory performance measure.

Injury severity was significantly correlated with the memory performance measure, *r* = .35, *p* = .04, and the CVLT, *r* = .33, *p* = .05. The SR procedure and the RBMT were both unrelated to injury severity. Table 4 contains correlations of memory measures and injury severity.

Appendix A provides the raw data for each subject, while appendix B provides scatter diagrams for visual inspection of raw data correlations. Due to the skewed shape of the distribution of the dependent variable

TABLE 3

Correlations of Memory Test Scores and Memory Performance Measure

Test		n	r	p
SR	LTS	35	.38	.03
	CLTR	35	.33	.06
	delay	35	.48	.003
CVLT	total	35	.47	.006
	semantic	35	.27	.13
	delay	35	.53	.001
RBMT	profile	22	.69	.0004

TABLE 4

Correlations of Memory Measures and Injury Severity

Test	n	r	p
Memory Performance Score	35	.35	.04
SR delay	35	.17	.33
CVLT delay	35	.33	.05
RBMT profile	22	.31	.17

TABLE 5

Memory Performance Measure Prediction: 22 Subjects

(raw data)

Test	n	F	df	p
SR + CVLT	22	4.85	2,19	.07
SR + CVLT + RBMT	22	6.54	3,18	.02
(log transformation)				
SR + CVLT	22	5.02	2,19	.02
SR + CVLT + RBMT	22	4.70	3,18	.10
(square root transformation)				
SR + CVLT	22	5.17	2,19	.06
SR + CVLT + RBMT	22	6.62	3,18	.02

(memory performance scores), various transformations were conducted to attempt to normalize the distribution. Table 5 provides results using only those 22 subjects who were administered all three memory tests. The CVLT did not significantly to the SR procedure at predicting memory performance when using the raw data or a square root transformation. However, the CVLT did add significantly to memory performance prediction when a log transformation was performed, $F\ (2,\ 19) = 5.02$, $p = .02$.

Post-hoc analyses comparing RBMT performance with each word list learning test individually, using both raw and log transformed data, yielded consistently significant results. The RBMT added to the SR procedure at predicting memory performance, $F\ (2,\ 19) = 9.78$, $p < .01$. Using log transformed data, results were also significant, $F\ (2,\ 19) = 6.11$, $p < .01$. The RBMT was also a significantly better predictor than CVLT scores in predicting the memory performance measure. The raw data yielded an $F\ (2,\ 19) = 7.89$, $p < .01$, while the log transformed data provided an $F\ (2,\ 19) = 6.05$, $p < .01$. Table 6 provides results of memory performance prediction.

TABLE 6

Memory Performance Measure Prediction: All Subjects

(raw data)

Test	n	F	df	p
SR + CVLT	35	2.87	2,32	>.05
SR + RBMT	22	9.78	2,19	<.01
CVLT + RBMT	22	7.89	2,19	<.01
(log transformation)				
SR + CVLT	35	1.54	2,32	>.05
SR + RBMT	22	6.11	2,19	<.01
CVLT + RBMT	22	6.05	2,19	<.01

DISCUSSION

RBMT scores provided for greater incremental validity over and above either the CVLT or SR procedure in predicting memory failures in long term severe closed head injury survivors. Both the SR procedure and the CVLT are word list learning tasks that may not be as efficient in determining real world memory performance as the RBMT. The RBMT was designed based upon the types of memory failures commonly seen in memory impaired head injured patients. Sunderland and colleagues (1983) developed a questionnaire to assess common memory failures in CHI patients. They found that relatives' ratings were more reliable than patients' ratings. They also found greater reliability of this questionnaire with long term CHI survivors than with acutely injured subjects. The RBMT was designed based upon this questionnaire and provides an instrument that may be reliable with both acute and chronically memory impaired patients.

The SR procedure and the CVLT were both highly correlated with the memory performance score. However, neither test individually or combined were as effective as the RBMT in predicting the actual memory performance measure. Both the SR procedure and the CVLT are cognitive memory model based tasks. As such, each has its own theoretical underpinning that attempts to explain memory functioning. The SR procedure is based upon the Atkinson and Shiffrin (1968) multiple stage model of memory, while the CVLT is more related to a levels of processing approach to memory functioning (Craik & Lockhart, 1972). These theoretical models provide good conceptual frameworks to guide our thinking about memory processing. However, everyday memory performance is multi-factorially determined and tasks more closely resembling real world memory requirements may be more ecologically valid.

A levels of processing explanation could account for the findings of this research. The more important the information is to the subject the more deeply processed and the more likely it is to be recalled. Obtaining behavioral contract signatures would appear to be more important to these individuals than their performance on memory tests and would be most deeply processed. Next, the RBMT uses situations reflecting real world memory requirements and would be more deeply processed than would verbal list learning tasks.

Injury severity was related to the memory performance measure and to CVLT scores, but not to RBMT and the SR procedure performance. Furthermore, the memory performance score did not add significantly to the relationship of injury severity and CVLT scores. Group homogeneity with respect to injury severity may account for these findings. All subjects were long term severe CHI survivors who were residents of a rehabilitation facility. Residents were accepted into this program based upon their potential for competitive employment following program completion. With an average of three and one-half years time post injury, most of these subjects have not been able to function adequately outside the medical environment.

It is interesting to note that within the cognitive based memory measures the delayed recall scores were most highly correlated with the memory performance measure. Delayed free recall after 30 minutes proved to be the most highly related SR procedure score, while a 20 minute delayed free recall CVLT score provided the most highly correlated measure. The prospective nature of the memory performance measure appears more closely related to delayed recall on verbal list learning tasks. The RBMT has many prospective memory components which may account for its providing greater incremental validity.

Analyses of results using transformed scores yielded contradictory results. Using the raw data and a square root transformation of the memory performance score, the RBMT added significantly to memory performance prediction over a combination of the SR procedure and CVLT scores. However, the RBMT only approached statistical significance, $\underline{p} = .10$, when a log transformation was used. Outlyers may have influenced raw data analyses in such ways to give spurious results, while the log transformed may have provided more normally distributed data.

When comparing only the SR procedure and the CVLT in predicting memory performance, there was no statistically significant differences using raw data or the square root transformation. However, when using a log transformation, the CVLT added significantly to the SR procedure in predicting memory performance. These results were obtained using only the 22 subjects who received all three memory tests. When all 35 subjects were used, no statistical significance was obtained.

The memory performance score is an artificial measure of everyday memory and therefore may not be a sufficient indicator of real world memory requirements. The environment in which the data were collected is also artificial. A rehabilitation facility provides close supervision of its patients. Verbal cues by therapists or other patients may have triggered the initiation of obtaining contract signatures used as the memory performance measure.

Length of impaired consciousness was used as a measure of injury severity. This was the number of days following the injury until the subject was able to follow verbal commands. The information is retrospective in nature and was obtained by reviewing patients' acute medical records. Estimations were used when definite information was not available. Therefore, this measure may not be as accurate an indicator of injury severity as prospective measurement using length of post traumatic amnesia or Glasgow Coma Scale scores.

The RBMT appears to be a more ecologically valid tool for predicting outcome than word list learning tasks, at least in chronic brain injured memory impaired subjects. The assessment of rehabilitation potential and the planning of interventions would appear to be best evaluated using the

RBMT. The cognitive based memory measures may adequately provide a framework for thinking about normal memory, but their utility in predicting real world memory performance appears to be limited. A functional approach to assessing patient performance in as close to real world circumstances as possible will provide better information in predicting patient performance in specified situations.

Future research investigating the ability of memory tests to predict outcome in memory impaired patients should take a longitudinal research approach. Detailed and accurate measurement of injury severity and serial assessments of subject's memory performance combined with functional outcome measures will provide better information regarding memory tests' clinical utility and ecological validity. Measures such as the ability to return to previous employment, to live independently, or success in rehabilitation may be better criterion measures than behavioral contract signatures. The use of memory questionnaires completed by individuals with close patient contact would also provide important criterion measurement. These functional outcome measures would probably be more closely related to RBMT performance than with verbal list learning tasks.

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Appendix A

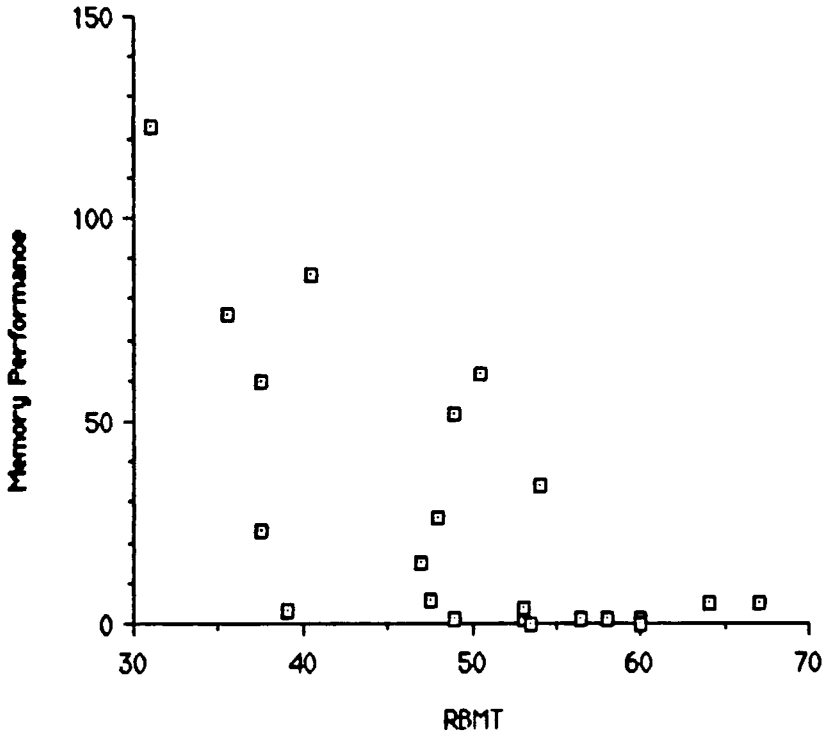
Memory Raw Data

Subject	LOC	MP	RBMT	CVLT	SR
DA	16	0	53.5	10	1
LB	1	26	48	7	7
JB	21	20	-1	3	5
MB	120	60	37.5	1	0
TB	2	6	47.5	7	3
KB	90	3	39	2	3
AC	28	76	35.5	0	1
DC	21	1	49	5	2
TC	20	7	-1	8	6
SE	30	62	50.5	3	5
JF	35	1	60	2	5
TH	19	0	-1	2	2
RH	42	26	-1	11	4
TK	90	52	49	5	6
SK	21	1	58	11	9
JL	7	15	47	8	0
VL	28	1	53	0	5
ML	7	0	60	10	7
ML	35	1	-1	13	12
DM	2	1	56.5	10	7
CN	14	5	64	7	7
PR	13	8	-1	0	0
GR	25	86	40.5	0	0
LR	2	4	-1	10	8
AR	37	34	54	3	2
GS	21	4	53	0	1
KS	30	66	-1	1	1
PS	21	0	-1	9	5
SS	49	123	31	0	0
PT	60	5	67	7	6
JT	8	0	-1	16	12
KW	18	23	37.5	2	0
BW	45	0	-1	8	9
MY	1	1	-1	12	8
RH	2	20	-1	5	2

Notes. -1 = missing data; LOC = length of impaired consciousnes; MP = memory performance score.

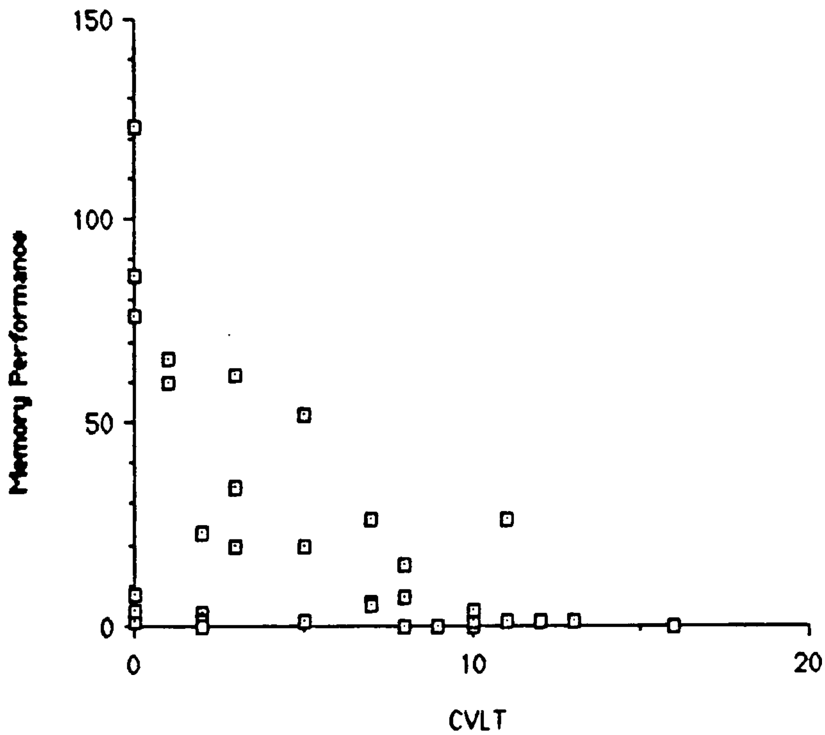
Appendix H

Scatter Diagrams



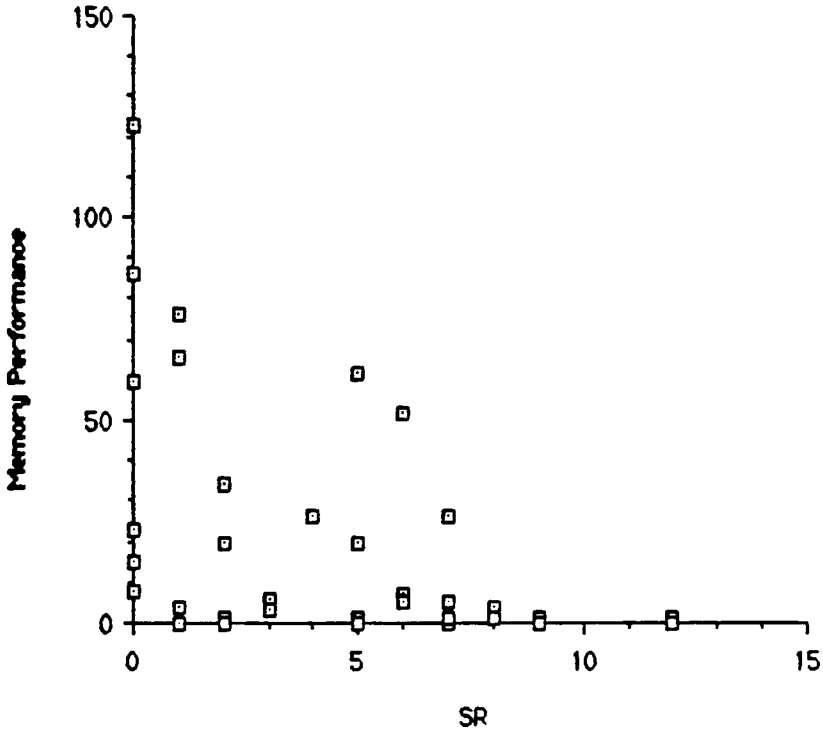
Appendix B

Scatter Diagrams



Appendix B

Scatter Diagrams



Appendix E

Scatter Diagrams