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An Information Processing Approach To Understanding Memory Deficits In Individuals With Traumatic Brain Injuries.

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AN INFORMATION PROCESSING APPROACH TO UNDERSTANDING MEMORY DEFICITS IN INDIVIDUALS WITH TRAUMATIC BRAIN INJURIES

by

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A DISSERTATION

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Individuals suffering from traumatic brain injuries (TBI's) frequently suffer from memory deficits. Previous research has contributed little to their understanding. This study employed a learning paradigm wherein subjects learned easy and hard word pairs in two distractor conditions to assess whether TBI memory deficits result from executive impairment or a capacity limitation. Results suggested a capacity limitation in controlled processing is responsible for the TBI memory deficits. Recommendations for future memory assessment are discussed.

Abstract Approved by: Committee Chairman [signature]

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INTRODUCTION

During a typical day, individuals must perform a wide variety of behaviors to complete their normal activities. In order to carry out these functions effectively, people must be able to remember what behaviors they have completed as well as recall other information and events. It is this ability to store and recall data which allows people to benefit from their past experiences, learn new information, and live their lives in an ongoing manner. Without the knowledge of what has occurred to them in the past, people would be forced to live only in the moment, not benefiting from previous experiences or acquiring additional knowledge. Many head-injured individuals have memory deficits such as these, which greatly disrupt their lives (Schacter & Crovitz, 1977). This investigation will focus specifically on the memory deficits which are experienced by individuals who have suffered TBI's. These are closed head-injuries which result from inertial changes on the brain (acceleration, deceleration, and/or rotation).

Auerbach (1986) states that in its broadest sense, memory "refers to the ability to learn new information and to retrieve previously learned information" (p. 6). (While this definition is not meant to be an "all encompassing description" of the processes which occur during learning, it includes the two aspects of memory which will be addressed in this investigation.) This definition implies that there are at least two memory phases where disruption could occur: learning and retrieval.

TBI and Memory Deficits

TBI results in impairment of some aspects of memory while leaving other portions of memory relatively unaffected (Mack, 1986). Much has been written to describe the memory deficits which occur subsequent to TBI (Schacter & Crovitz, 1977; Levin, Benton, & Grossman, 1982; Levin, Papanicolaou, & Eisenberg, 1984). These discussions of memory deficits secondary to TBI have focused on retrograde amnesia, post-traumatic amnesia, and continuing memory deficits as measured by traditional recall methods.

To assess memory deficits subsequent to TBI, measures of recall such as the Wechsler Memory Scale or the Selective Reminding Test are often employed (Mack, 1986). Recall measures such as these provide a standardized descriptive index of memory functioning which can then be used to gauge memory impairment. Although these instruments rate memory performance, they do not indicate the nature of the memory disruption if one exists. Hence, traditional documentation of TBI memory deficits has focused on description of the deficits rather than their theoretical base.

While this approach provided an assessment of the memory disturbance severity, it has not allowed theoretical formulations regarding the nature of the memory deficits. Although information retrieval has been investigated extensively, little attention has been devoted to assessing the learning process in individuals suffering from TBI's (Mack, 1986), a point which will be further discussed below.

In order to better understand these TBI deficits, more recent studies have applied theoretical models of memory functioning. One such study was conducted by Baddeley, Harris, Sunderland, Watts, and Wilson (1987). These investigators administered tests of verbal memory (word recall/recognition and paired associate learning) and procedural learning (fragmented words and primed spelling) to a group 20 TBI individuals, 20 elderly individuals, and 20 normal young control subjects. The procedures and results of these investigations are summarized below.

<u>Word Recall/Recognition</u>

Subjects were shown 72 cards, each containing an object from one of the six following categories: flowers, fruits, birds, four legged animals, metals, and stones. Subjects were asked to classify the object on each card as an animal, vegetable, or mineral. They were instructed to do this at their own pace and told that recall would be tested following the task. After all cards had been shown, subjects were presented with the six category items and asked to recall as many words as they could from each. Results indicated that the control group performed significantly better than the elderly group and TBI group. While there was a tendency for the elderly subjects to perform better than those with TBI's on recall, this tendency did not reach statistical significance.

Paired-Associate Learning

Eight word pairs (four common and four uncommon) were read to subjects. After presentation of the list, subjects were told the first word of the pair and asked to recall the second. This task was repeated a maximum of six times or until each subject had perfect recall for two consecutive trials. Results indicated that control subjects performed significantly better than elderly or head injured. While there was a trend for TBI subjects to perform better than elderly subjects, this trend did not reach statistical significance. Finally, while decreases in recall were noted across time for all groups, there was no evidence of differential forgetting across the groups. These data indicate that the TBI and elderly group forgot the information at the same rate.

Fragmented Words

Subjects were shown cards with the first two letters of a word and they were asked to guess the word. If they were unable to do so, they were shown a card containing the first three letters of the word. If they were still unable to guess the word, they were shown a final card on which the entire word was printed. Each of eight words was presented in this manner until subjects were able to identify the word from a card containing only the first two letters or until they had attempted to do so for a maximum of 12 trials. The test was repeated 1 week later. Five TBI subjects and three elderly subjects failed to reach criteria and were therefore excluded from the analyses. Similar to the previous tasks, control subjects performed significantly better than TBI or elderly subjects, who did not statistically differ from each other. However, the data from this experiment are more confusing because five TBI and three elderly subjects were unable to perform the task, which would suggest that, in contrast to the statistical results, they performed more poorly on the task. Additionally, since subjects learned the task to criterion, the differences 1 week later appear to be from forgetting rather than encoding deficits. It could also be argued, however, that the forgetting resulted from initially poor encoding.

Primed Spelling

Twenty words were primed in each of the subjects by vocalizing the prime in a question which was read to the subjects or by having the answer to the question (which the subject was read) as the prime. Half of these primes were homonyms (words which sound alike but have different meanings, e.g., mane and main) and half were not. When a homonym prime was presented, the less common form was used. After completing the priming, subjects completed a spelling test. During this test, subjects were read 40 words (20 new, 20 old - 20 homonyms, 20 non-homonyms). Results indicated that control subjects spelled significantly more primed words than either the elderly or TBI group, who did not differ from each other.

TBI Memory Deficits Summarized

These data indicate that TBI individuals (and the elderly) acquire information much more slowly than normal control subjects. There is some evidence which indicates that once TBI individuals have satisfactorily encoded some information, they do not forget it faster than individuals who have not sustained TBI's. If other data are found to be in agreement with this finding, it would appear to indicate that the memory deficit which TBI individuals experience results from an encoding problem rather than storage or retrieval deficit. This is consistent with the hypothesis described by Mack (1986) that information processing speed is decreased in individuals with TBI on a variety of tasks.

In order to understand why memory deficits arise as a consequence of TBI, it may be helpful to first review the anatomical bases of memory and the brain structures which incur lesions as a result of TBI. If certain brain areas are necessary for memory functioning and they were lesioned during TBI, then the individual would likely suffer memory dysfunctioning. After reviewing these two sets of brain structures, their overlap will be evaluated for its potential ability to account for the memory dysfunctioning which individuals with TBI experience.

Anatomical Bases of Memory

There is some disagreement regarding the extent to which memory can be localized. Data reviewed by Stein (1988) suggest that memory impairment is more a function of the amount of damage that occurs at any given time than the total amount of destruction to a particular area. Nonetheless, with regard to memory processes, Butters and Miliotis (1985) state that

> Difficulty in learning new material and in recalling remote events arises after hippocampal lesions, e.g., anoxia, herpes encephalitis, cerebrovascular accidents involving the posterior cerebral artery, closed head injuries, and surgical removal. . .atrophy or damage to medial diencephalic structures including the dorsomedial nucleus of the thalamus and the mammillary bodies, e.g., alcoholic neurotoxicity, nutritional deficiencies, cerebrovascular accidents, trauma. . .and lesions of the fornix, e.g., tumors. (p. 403)

It appears that these brain structures are important for normal memory processes and that lesions to them from either trauma or disease can result in profound amnesia (Milner, 1966). Therefore, if these brain areas were damaged as a result of TBI, then memory impairment subsequent to TBI would be anticipated.

Anatomical Lesions in TBI Individuals

TBI's occur as a result of brain displacement within the skull. These injuries are the result of inertial affects: acceleration, deceleration, and rotation. The varying deficits observed after TBI are primarily due to these forces resulting in any of the following adverse affects on the brain: compression or penetration, tensile strains, shearing of neurons, diffuse axonal injury, hemorrhaging, and brain swelling (Genarelli, 1982), which may cause focal and/or disconnection of brain regions. Additionally, when a sudden change in inertia occurs, the brain strikes the inner surface of the skull, and the orbital surface of the frontal lobes, the poles of the frontal and temporal lobes, and the brain stem structures are especially likely to be damaged (Reitan & Wolfson, 1985).

Examination of Overlap Between Memory Structures and TBI Lesions

It has already been indicated that certain brain structures are necessary for memory functioning and that if they are damaged, there is typically subsequent memory impairment. One may therefore suspect that these brain structures must be damaged during a TBI and that lesions to these areas are responsible for the subsequent memory deficit. Inspection of the sets of brain structures thought responsible for memory (Squire, 1986) and the areas which generally incur lesions during TBI indicates that there is not a high degree of overlap. The hippocampus (a brain area important for memory functioning), which lies in the medial temporal lobes, may incur damage during TBI. Temporal lesions sustained during TBI tend to occur in the lateral rather than medial aspect (Auerbach, 1986). While diffuse injury from the TBI may damage brain structures considered important for memory functioning (dorsomedial thalamic nuclei, mammillary bodies, etc.), it may also produce lesions in other areas which are not part of the memory system per se, but rather are structures which are important for general cognitive functioning. This cognitive impairment could result in an encoding deficit even though the memory system was functioning properly. It seems likely that while there may be some memory impairment due to diffuse lesions to anatomical brain structures from TBI, a large portion of the memory performance deficits may result from deficient information processing during the encoding stage of memory rather than from a defective memory.

Sources of Memory Dysfunctioning

In order to isolate unidentified cognitive dysfunctioning which may be responsible for memory impairment in TBI individuals, it might be helpful to survey cognitive information processing literature. If experimental models of memory dysfunctioning could be found, it may be possible to extend these findings to the TBI population. A vast body of literature exists which describes the impact of performing a secondary task while attempting to conduct a memory task (Kahneman, 1973). The results of these investigations have demonstrated that performing a secondary (distracting) task while attempting to learn new material can impair the encoding of information into memory (learning) if both tasks draw from the same cognitive resources (Kahneman, 1973; Shiffrin & Schneider, 1977; Parasuraman & Davies, 1984). These data support the above thesis that impaired performance on memory tests can result from cognitive disruptions in individuals with otherwise unimpaired memory functioning. In order to understand how cognitive processes might impair memory, information processing literature will be reviewed. It may then be clearer how cognitive deficits or defective information processing might result in memory impairment in TBI.

Information Processing

In an influential paper, Shiffrin and Schneider (1977) divided information processing into two general types: automatic and controlled. This distinction was drawn from studies they conducted such as the following. A number of symbols are simultaneously presented in a square for a brief period of time (frame). Before each trial (a given number of frames), the subject is shown several items (memory set) and is required to detect any of these items during the trial. Trials were one of two types: consistently mapped (CM), in which memory set items never served as Distractors, and varied mapping (VM), where memory targets from one trial could also be Distractors on a subsequent trial. Results showed that after practice, subjects were able to determine very quickly whether a target was present in the CM condition regardless of the number of Distractors, whereas they were much slower at making this determination in the VM conditions. The investigators concluded that in the CM condition, subjects were able to analyze the information quickly because they were able to process the information in a parallel form, whereas subjects required the use of a serial search mechanism in the VM condition. They termed the first information processing mode automatic and the second mode controlled (Shiffrin & Schneider, 1977). These two information processing modes have been further supported and elaborated in other contexts (Schneider, Dumais, & Shiffrin, 1984) and with specific regard to memory (Hasher & Zacks, 1979).

Characteristics of Automatic Processing

Automatic information processing is believed to encode stimulus information such as spatial location, time, and frequency. Automatic processing of material continuously analyzes stimulus attributes regardless of the type of information. Once a process becomes automatic, feedback and practice will no longer improve performance. Automatic processing does not require conscious attention and is conducted in parallel. Hence, processing resources are available to perform other tasks and the information encoded is available for conscious processing. Finally, automatic processes cannot be consciously inhibited. Aside from encoding temporal, spatial, and frequency information about some stimulus, automatic processes also appear to be capable of more complex procedures which appear to result from extensive learning or repeated performance (Hunt, 1978; Shiffrin & Schneider, 1977; Kohlers, 1975). If an individual engages in some procedure repeatedly, the procedure will therefore likely become automated and use little of the individual's conscious processing resources. Hence, people appear capable of learning to perform both simple and complex behaviors over time with little attention or effort.

Characteristics of Controlled Processing

Controlled processes are conducted in a sequential fashion. They improve with practice and require conscious effort to be performed. It is these processes which are thought to "regulate the flow of information into and out of the short term store, as well as between levels" (Hasher & Zacks, 1979, p. 362). In order for information to be satisfactorily encoded, it must be actively processed and with cognitive resources which are then unavailable for the processing of other information. If this model is correct, then performance on a memory task conducted in a controlled processing mode should be impaired by a secondary task which requires the use of the same processing resources. As mentioned earlier, this hypothesis has been confirmed in a number of investigations (Kahneman, 1973; Logan, 1979).

Given this distinction between automatic and controlled information processing, it would appear that cognitive impairment has different affects on information processing, depending on the mode in which the processing was conducted. A distracting task should interfere with controlled processing while not affecting information which was being processed in an automatic mode. The distinction between automatic and controlled information processing may provide a useful dichotomy for classifying cognitive deficits which may potentially result in TBI individuals suffering from memory dysfunctioning. Although controlled processes appear more easily disrupted, it is not known which of the two general types of processing is disrupted in TBI individuals. Fortunately, models of memory exist which may help us further elucidate the effect of the cognitive functioning in both information processing modes.

Working Memory

Baddeley and his colleagues have described a model of memory which operates in a controlled processing mode (Baddeley & Hitch, 1974). His "working memory" model was influenced by earlier models of information processing and the research they generated. Hence, Baddeley's working memory model possesses aspects of the Broadbent (1957) filter theory, the Kahneman (1973) capacity model, and the Craik and Lockhart (1972) levels of processing model. According to Baddeley, working memory is composed of three systems: the articulatory loop, the visuospatial scratchpad, and an executive control system (Baddeley, 1987). Because the visuospatial portion of working memory is not part of this investigation, it will not be further discussed.

The articulatory loop is composed of the articulatory rehearsal component (Vallar & Baddeley, 1982) and a phonological storage buffer (Baddeley, Lewis, & Vallar, 1984). In any situation (again, only verbal processing will be discussed here), the individual will perceive and attend to some information, which will be placed in the phonological storage buffer. This portion of memory is volatile and decay will occur unless some procedure is performed to encode it in a more permanent form. The process by which this occurs is through articulatory rehearsal of the material, which is analogous to subvocally repeating the material. The longer the material is rehearsed, the better encoded it will be. Repeated articulation of this material requires conscious effort and the use of individuals' limited processing resources. It therefore logically follows that working memory necessarily is conducted in a controlled processing mode.

The final aspect of working memory is an executive control system. While Baddeley and his associates have explored the articulatory loop extensively, they have published very little on the nature of its control (by an executive system). As Baddeley (1987) states, "the central executive is a crucial component of working memory" (p. 224). Unlike the articulatory loop, executive functioning is not part of the memory system. Rather, it is the intentional aspect of the conscious mind which guides thought and behavior. Baddeley does not describe the role of such a system in memory functioning. Rather, he applies the Norman and Shallice (1980) model of executive functioning for this purpose.

An Executive Functioning Model

This model has two distinct components: the contention scheduling system and the supervisory attentional system (SAS). Norman and Shallice assume that there are functional units (of thought and behavior) to which they refer as schemata. The contention scheduling system allocates the processing resources according to the demands of the current tasks. This system must select a schema to perform the requirements of the current task(s). If the activation schema requires other schemata, they must also be activated. The contention scheduling system must maintain the schemata until the desired results have been attained. Finally, the progress and accuracy of the schema must be monitored, which is the purpose of the SAS (Norman & Shallice, 1980).

When task demands can be met by the employment of existing schemata, the contention scheduling system is able to perform tasks efficiently with the use of minimal processing resources. Hence, information processing can be conducted in an automatic mode. When the schema fails or there is not an existing schema to process the information, then an alternative approach must be employed. The SAS alters the performance of existing schemata with a general programming system "that can operate on schemata in every domain" (Shallice, 1982). This changes the information processing mode from a rapid, inflexible approach to one that is much slower but flexible and able to emit the necessary responses to perform the task.

Executive Functioning Role in Memory

There would apparently be several functions which the executive system would be required to perform for normal memory functioning. It would select a strategy (or schema) for memorizing the information and would maintain the activation of this strategy until the information was learned. In order to do this, it would be necessary to monitor the learning process. As long as there were existing schemata for the type of learning task in which the individual was attempting to engage, the executive system should be capable of efficiently applying the information processing resources to memorize the information. If no schema was available which would satisfy the task demands, then the SAS would have to employ general processing routines to process the information, and the efficiency of information processing would be greatly reduced.

Memory processes should therefore be satisfactorily conducted as long as 1) there are sufficient information processing resources for the executive system to allocate, 2) there are either existing schemata to control information processing or the SAS employs a general processing approach, and 3) the processing approach is maintained until the information had been satisfactorily encoded (Norman & Shallice, 1980). If there were a breakdown in the executive system, then a subsequent deficit would likely result in strategy selection/maintenance, progress monitoring, and/or control of resource allocation.

It therefore appears that information processing depends on correct operation of an executive functioning system. Without the proper functioning of such a system, the information processing would likely not be properly monitored or controlled. In sum, an executive system is necessary for adequate information processing. If this system is not functioning properly, then information processing deficits which could potentially result in memory dysfunctioning could occur.

The deficits which occur as a result of TBI may be due to executive dysfunctioning or some similar problem which does not interfere strictly with memory functioning but rather with general information processing which results in subsequent memory deficits. If it could be demonstrated that executive functioning was controlled by brain structures which were damaged by TBI's, it would be consistent with the idea that executive dysfunctioning was responsible for the memory deficits observed in individuals with TBI's. To make this determination, the brain structures thought responsible for executive functioning will first be reviewed. Then they will be inspected to determine whether they overlap with the areas which incur damage during TBI.

Localization of Executive Functioning

Attempts have been made to localize areas of the brain which might be responsible for executive functioning. Luria (1973) believed that the frontal lobes were the areas which were most import in executive functioning. He stated that it was the prefrontal division of the brain which played the most "decisive role in the formation of intentions and programmes, and in the regulation and verification of the most complex forms of human behavior" (p. 84). Consistent with Luria's notion, a number of investigators have found impairment in executive functioning in individuals with frontal lobe lesions (Shallice, 1982; Nelson, 1976; Pribram, 1973). As mentioned earlier, frontal lobe dysfunctioning is especially likely to occur in TBI. In a deceleration injury, the prefrontal cortex is forced into the front of the skull and the orbital (basal) frontal lobe is propelled onto the base of the skull (Reitan & Wolfson, 1985). Hence, memory impairment in individuals with TBI may be due to frontal lobe (or other) lesions which interfere with some aspect of executive functioning, including goal formulation, planning, carrying out plans, and/or adjusting performance (Lezak, 1983).

Executive Dysfunctioning in Individuals with Memory Impairment

It has been shown that impairment of executive functioning can be caused by damage to certain areas of the brain such as the frontal lobes. It has been further suggested that impairment of the executive system can result in memory impairment. It may therefore be possible to demonstrate the existence of executive impairment in other individuals with memory problems. One group of people which has memory problems similar to TBI individuals is the elderly (Baddeley et al., 1987). If this group could be shown to have executive functioning impairment, it would further support the argument that the memory deficit in TBI individuals results from executive dysfunctioning.

Several independent lines of evidence support the hypothesis that elderly individuals suffer from a deficit in executive functioning. Rabbit (1981) conducted several reaction time tasks in which subjects were required to adjust their performance. In one study, he had elderly and young subjects scan for the letters A-H. In the first condition, subjects were required to look for the mere presence of the letters in any order while the remainder of the subjects were required to scan for their presence serially (first A, then B, then C, etc.) in a second condition. Both speed and accuracy of responses were recorded. Results indicated that when subjects monitored for the mere presence of one of the target letters, elderly subjects required longer than younger subjects; however, accuracy was similar across the groups (young: errors 1.4%, time 790 msec; elderly: errors 1.6%, time 972 msec). Alternatively, when subjects were required to scan for the presence of letters serially, elderly subjects made a significantly greater number of errors (young: errors 6.3%, time 630 msec; elderly: errors 26.8%, time 896 msec).

Sanford and Maule (1973) required subjects to monitor three locations for the possible presence of a target. Since the probability of a target occurring was much lower for some of the locations, subjects could adjust their strategy and improve performance by spending more time monitoring the high probability locations. While younger individuals used this information to improve their performance, elderly subjects did not. The results of these investigations are consistent with the presence of a deficit one would expect if an individual was suffering from impairment of the executive processing system. When the executive system is impaired, it may require more cognitive resources to perform as well. Sufficient resources will then be unavailable for the actual information processing. Hence, even if the executive system employs a satisfactory approach to processing the information, the individual may be unable to process the information satisfactorily. This is because there are inadequate cognitive resources left with which to control the processing of the information because these resources are being used to do the actual information processing, a point which will be further elucidated below.

In summary, these data are consistent with the hypothesis that TBI is quite likely to result in damage to centers which are responsible for executive functioning. People show deficits on memory tasks when executive functioning is impaired. Individuals who experience memory problems which are similar to those experienced by TBI individuals, at least on some dimensions (the elderly), have also demonstrated deficits in information processing that would be expected if they were suffering from impairment of an executive processing mechanism. Hence, it seems quite likely that the memory deficit which is experienced by TBI individuals is due, at least in part, to an impairment in executive functioning.

Memory Remediation

Because of the disruption which these memory deficits cause TBI individuals, much effort has been devoted to improving their memory functioning with a variety of treatment strategies. These research efforts can be broadly divided into 1) attempts to improve memory functioning through the use of exercises and 2) teaching learning strategies (Glisky & Schacter, 1986). While the use of external aids has also been employed, this has been done with the intent of decreasing the demands upon the amnestic individual's memory rather than improving it and therefore will not be discussed.

The use of memory exercises involves having the individual with a memory deficit repeatedly perform memory tasks. As reviewed by Glisky and Schacter (1986), the theoretical rationale for this procedure appears to have been that the repetitious performing of memory tasks will enhance memory functioning in much the same way as exercising a muscle strengthens it. It is difficult to determine the efficacy of these procedures because investigations have frequently contained methodological flaws such as having low subject numbers and not controlling for severity of the memory deficits. In spite of these methodological problems, it appears that practice exercises such as these do not enhance general memory performance for individuals with TBI or brain lesions of various other etiologies (Godfrey & Knight, 1985; Wilson, 1982; Brooks & Baddeley, 1976). Mnemonic strategies have received the most effort by far as a means of potentially alleviating memory problems in a variety of patient groups (Wilson, 1987). Examples of mnemonic strategies are visual imagery, peg systems, chaining, etc. These strategies are typically taught to the individuals, who then practice using them in a laboratory setting (Crovitz, 1979). The assumption is that strategy usage will spontaneously generalize to other memory tasks and settings.

Glisky & Schacter (1986) state that attempts to improve memory functioning in amnestic individuals have generally been unsuccessful and are likely to continue to be so. They indicate this is because of limited generalizability of the memory strategies to real world applications. Additionally, they cite Cermak (1980), who states that these learning strategies require considerable cognitive effort. Therefore, these strategies would not likely be used because their cognitive requirements likely exceed the availability of information processing resources.

A Capacity Limitation in Information Processing Resources

One interesting aspect of the results of the Rabbit (1981) investigation was the change in reaction time. As can be seen by the times in each group, younger subjects took less time than elderly subjects to perform the task despite the fact that the elderly subjects were capable of responding as quickly. This is what would be expected if the elderly subjects were suffering from a deficit in information processing. Upon further inspection of the results, it can be seen that when the task became more difficult, processing time decreased (i.e., subjects spent less time on the task when it became harder), an effect which may initially appear opposite of what one would expect. It will be recalled, however, that processing capacity is thought to be limited by a finite amount of cognitive resource (Kahneman, 1973). Information processing conducted in a controlled mode (Shiffrin & Schneider, 1977) and the control of cognitive processes for which there are no existing schemata (Shallice, 1982) both appear to require these cognitive resources to process information. If these two mental activities (control of processing by the SAS and actual processing) draw from the same body of cognitive resources, then the efficiency of information processing would be a function of both task difficulty and the extent to which conscious processing of it was required. If a task were harder, it would use more of the limited amount of resources, which would then be unavailable for the SAS to monitor the processing, resulting in more rapid termination of the processing.

As has already been discussed, information processing appears to be partially impaired in TBI individuals from an executive functioning deficit. Because of this impairment, there is either poor allocation of the available cognitive resources, insufficient cognitive resources for the executive processing which would be required by these strategies, or both. These learning strategies which require much effortful processing would not appear to be efficacious techniques to use for enhancing memory performance in TBI individuals. Unfortunately, present understanding of these aspects of controlled processing mechanisms is quite limited. Hence, determining which aspect of controlled processing was impaired would be quite difficult.

Additionally, some memory dysfunctioning may also result from damage to automatic processing mechanisms and cause impairment in the operation of previously existing schemata which automatically processed information. A procedure which made it possible to assess both automatic and controlled information processing may be helpful to understand the nature of these defects.

Shortcomings of Current Memory Assessment Techniques

Although examinations of memory functioning have shown that TBI individuals have memory deficits, the approaches employed thus far to assess memory functioning have not clarified the nature of the memory deficits. The reason for this is that traditional memory assessment techniques test only the outcome of the encoding-storage-retrieval cycle rather than the learning process. If a more thorough understanding of the memory deficits in TBI individuals could be attained, it may be possible to develop alternative approaches for learning information which are better suited to their deficits.

Alternative Memory Assessment Strategies

If a method could be developed which would enable researchers to better understand the nature of memory deficits which resulted from TBI, they may be in a better position to develop treatment strategies. Such a method should be able to assess information processing during the encoding (learning) process and retrieval of the material. Additionally, it should be able to assess whether the information is being encoded in a controlled (by the SAS) or automatic (by the contentional system) mode. If such a measure of information processing could be developed to assess memory functioning, then researchers would likely be able to learn much information about memory processes. One potential approach to developing such a measure might be to employ sets of material which are equally familiar and alike in all respects except for having different frequencies in their association in the past (i.e., two sets of material which have similar characteristics but which differ in how frequently they have been paired). Some measure of processing (e.g., encoding time) for the material could be recorded and used as a way of assessing information processing. Then differences found in information processing (such as the amount of time spent studying the material) would theoretically be attributable to differences in the amount of processing which was conducted by the executive system to encode the information.

One set of material which may be well suited to such as task is word pairs. A list of equally familiar words could be used to compose a set of word pairs, half of which were high and the other half low in associative strength (Noble, 1952). Theoretically, the word pairs with high associative strength (easy) would be processed rapidly (automatically) because of their previous repeated association. As Pollio (1964) puts it, the word pair associations of adults reflect highly overlearned word-word habits. Since these words have been repeatedly associated, there should be a schema which the contention scheduling system can apply to process them. Conversely, word pairs which are low in associative strength (hard) should require longer to process. This is because there is not likely to be an existing schema to process them, so they should require controlled processing under the direction of the SAS. In sum, easy word pairs should be processed in an automatic mode, while hard word pairs should be processed via controlled processes.

A First Attempt at Modeling TBI Memory Deficits

In order to employ a maximally effective learning strategy when presented with lists comprised of both easy and hard word pairs, individuals should spend more time learning the hard than the easy word pairs since hard pairs would require controlled processing (Shiffrin & Schneider, 1977). Additionally, subjects could be made to perform a capacity draining task while simultaneously learning the word pairs. Encoding time could then be used as a measure of information processing and recall errors could be recorded as a measure of learning. The amount of information processing and memory efficacy could then be assessed in both processing modes (controlled and automatic) under both normal and increased load conditions (No Distractor versus simultaneously performing the distracting task). If the executive system was functioning adequately, then it should adjust the processing time for the difficulty level of the word pairs (easy versus hard) and the cognitive load (Distractor versus none). Using this procedure, it should be possible to determine whether individuals with TBI experience memory deficits resulting from executive impairment as hypothesized or if it occurs as a result of a capacity limitation by examining for the following results:

Performance During the No-Distractor Condition

When subjects learn the word-pairs while not engaging in the distracting task, the following results are anticipated. If TBI memory deficits result from impairment of executive functioning as predicted, 1) it is hypothesized that individuals suffering from TBI's will demonstrate smaller encoding time differences between easy and hard word pairs than normal individuals. This is because the executive functioning deficit which TBI subjects experience impairs their ability to adjust their information processing time to the difficulty of the word pairs. Conversely, if TBI individuals suffer memory difficulty from decreased information processing capacity rather than impairment of executive functioning, 2) then it is hypothesized that TBI individuals will have greater encoding time differences between the easy and the hard word pairs than normal individuals. These results should occur because although the TBI subjects have less information processing capacity, executive functioning is working normally. Therefore, their information processing systems are able to adjust to the difficulty level of the stimulus material and they subsequently spend longer learning the word pairs. Whether TBI memory impairment is due to executive impairment or a capacity limitation, 3) it is hypothesized that normal and TBI subjects will make an approximately equal number of recall errors for easy word pairs; however, TBI subjects will make a greater number of recall errors on the hard word pairs. This performance difference between the TBI and normal subjects is predicted for the hard word pairs because the hard word pairs are encoded via a controlled processing mode which is impaired in TBI subjects.

Performance During the Distractor Condition

When subjects learn the word pairs while simultaneously engaging in the distracting task, the following results should be obtained. If TBI memory deficits result from the predicted impairment in executive functioning, 4) it is hypothesized that encoding time differences between easy and hard word pairs will be smaller than the differences found in the no-Distractor condition. Normal individuals will have greater encoding time differences when learning the word pairs in the distraction condition. This should occur because the distracting task further impairs an already taxed executive system in TBI subjects and makes their SAS' even less able to adjust to the word pair difficulty level. If, however, the TBI memory deficit results from diminished processing resources, 5) then it is hypothesized that, although both normal and TBI subjects will increase their encoding time differences between the easy and hard word pairs, the increase in encoding time differences should be greater for TBI subjects. Finally, whether TBI memory deficits result from executive functioning or decreased capacity, 6) it is hypothesized that TBI and normal subjects should make a similar number of recall errors for the easy word pairs while the TBI group should have a differentially greater increase in recall errors for the hard word pairs.

Summary of Experimental Hypotheses

In sum, if TBI individuals suffer memory difficulty because of executive dysfunctioning, then they should show smaller differences in encoding times between easy and hard word pairs than normal individuals, an effect which should be enhanced when learning is done while simultaneously engaging in the distracting task. Again, this is because the impairment of the SAS prevents appropriate adjustment of information processing time based on task difficulty. If TBI memory deficits result from a capacity limitation, then there should be a greater difference in encoding time between the easy and hard word pairs for the TBI group than for the normal individuals, an effect which should be magnified when the word pairs are learned during the distracting task. This is because there is less available capacity with which to process the material, but the executive system is functioning properly. Therefore, information processing time is appropriately adjusted based on the difficulty level of the stimulus material.

Preliminary Investigations

Pilot Study #1

To develop and test the methodology for this experiment, six pilot studies were conducted on university undergraduate and graduate students. For the first pilot study, a computer program was written which presented two sets of easy and hard word pairs to verify that subjects spent more time processing the hard word pairs than the easy word pairs (a detailed explanation of how these word pair lists were generated is presented in the materials portion of the methods section).

Subjects were presented the word pairs and were instructed to press the spacebar to display the next word pair after they had learned the current one. After the first 24 word pairs were presented, recall was tested. During this portion of the test, subjects were shown the first word in the pairs (in the order in which they were initially presented). After seeing it, subjects attempted to recall the word with which it was paired initially. When they were able to do so, they said the word aloud and the experimenter pressed a button on the mouse, which then displayed the next word pair. After recall was tested on the first 24 word pairs, the second set of words was presented in the same manner as the first set. After learning the second set of words pairs, recall was then tested in a manner similar to the initial set.

Data were collected on three individuals. Analysis of the encoding times for the word pairs indicated that subjects spent an average of 4.29 and 3.97 seconds on the hard word pairs and 5.92 and 4.22 seconds on the easy word pairs, in the first and second word sets, respectively. Results therefore indicated that subjects spent longer encoding the easy than the hard word pairs. In other words, subjects took longer to learn the word pairs which should have been easier. Unfortunately, the meaning of the data was confounded by the subjects requiring more explanation once the procedure had begun. Since there were more easy word pairs at the beginning, it tended to be these during which they paused for further explanation. The results of the first pilot study therefore suggested the need for a practice section and gave some information regarding specific items which should be included in the instructions.

Pilot Study #2

To address these problems in the next pilot study, a practice set of words was presented before each of the test sets of words to demonstrate the procedure to the subjects. Additionally, questions which the pilot subjects asked the experimenter during the first pilot study were addressed in the instructions for the next set of pilot data which was collected.

In addition to these changes, a capacity demanding Distractor task was added to the second set of word pairs. This Distractor task involved subjects viewing a different five character random letter sequence before each word pair. They were instructed to say the sequence aloud and then press the spacebar to view the word pair. After pressing the spacebar, they continued repeating the Distractor character sequence while learning the word pair.

Data were collected for two individuals. These data were not analyzed because the test clearly overwhelmed the subjects. They were unable to remember the character sequences while attempting to learn the word pairs. Additionally, subjects found the procedure quite aversive and complained bitterly. Much effort had to be put forth to persuade these individuals to complete the test. Finally, approximately halfway through the procedure, they adopted an ineffective response style and began pressing the spacebar approximately twice as fast to complete the procedure. Results of this investigation therefore indicated that a less demanding Distractor task was needed.

Pilot Study #3

To correct this problem, the Distractor was dropped to three characters and each character was separated by a space. This made the Distractor character sequence easier to read and learn. Pilot data were then collected on three more individuals. Examination of the data indicated that mean encoding times were 5.11 and 7.58 for the easy word pairs, and 9.82 and 11.87 for the hard word pairs in the first (No Distractor) and second (Distractor performed) conditions, respectively.

Therefore, unlike the first pilot study, subjects spent longer encoding the hard word pairs, as predicted. Contrary to the hypothesized results, subjects increased more from the No Distractor to Distractor condition for the easy word pairs than the hard word pairs. This is the type of finding which would be expected if executive functioning was impaired. These data were collected from normal individuals who were not known to suffer executive dysfunctioning. Therefore, they should have demonstrated greater encoding time increases for hard words than easy words.

While it is difficult to determine why the Distractor task had this effect, it may in part be due to its large verbal memory component. Not only did the task require controlled processing resources, it also likely required the same system resources necessary to learn the word pairs. Hence, the memory system was impaired, not because of a decrease in general processing resources but because the system which was necessary to process the word pairs was being used by the Distractor. Hence, rather than assessing the efficacy of the SAS under increased load conditions, the pilot study merely demonstrated that subjects could not simultaneously memorize two different sets of material. A Distractor task which required processing by the SAS was therefore needed which did not occupy working memory.

Baddeley (1987) had elderly and young subjects generate one random letter every second. He found a strong age effect, with elderly subjects saying "an extremely high proportion of stereotyped responses" (p. 249). Therefore, elderly subjects experienced difficulty generating sequences of random numbers (they tended to repeat the same numbers). It seems unlikely that there should be an existing schema to conduct this task. Also, other data have indicated that elderly individuals suffer from an executive deficit (Rabbit, 1981). Hence, this task appears to have been under the direction of the executive system and therefore requires controlled processing.

Although Baddeley had subjects generate random sequences of letters in this experiment, it appears to be more common for experimenters to require subjects to verbalize characters which are not of the same type being used in the memory task (Baddeley, 1987). Keeping the stimulus material different for the items to be memorized and the Distractor seems to be done to minimize the interference between memory items and Distractor (Wickens, Born, & Allen, 1963). This task would therefore appear to require controlled processing resources while having a much lower working memory component. Since requiring subjects to generate a random number every second (as Baddeley did) seemed excessive to the experimenter, this internumber interval was varied from 1-5 as a between subjects factor to test the effect at each rate.

Pilot Study #4

The fourth set of pilot data was then collected. This group was comprised of 20 subjects, with four individuals at each of the five intervals between random numbers (with two on counterbalancing order 1 and two on counterbalancing order 2). Encoding times for easy and hard word pairs are presented in Table 1. Along with encoding times, this table also presents three summary scores: 1) the difference between encoding times of easy word pairs with and without Distractor, 2) the difference between encoding times of hard word pairs with and without Distractor, and 3) the difference between these two scores. It was predicted that subjects would spend more time encoding the hard than the easy word pairs, a result which was found for every group. Additionally, it was hypothesized that there should be a greater difference in the encoding times for hard word pairs than easy word pairs for normal individuals. As can be seen in Table 1, this occurred for all except two groups: the ones generating random numbers every second and every 5 seconds. Hence, the remainder of the groups demonstrated greater encoding time increases for the hard word pairs when the Distractor task was added, as was expected. The reason subjects performing the 1 and 5 second variations showed an opposite effect is presently unclear.

Additionally, the experimenter realized that there were also problems with this Distractor task. While it was superior to the previous task in that it required less working memory capacity, it also theoretically interfered with the articulatory loop buffer (Baddeley, 1987) by requiring the subjects to verbalize words. It was therefore decided that a Distractor task was needed which could be performed at the same time that the word pairs were being encoded, which did not displace words from the articulatory loop buffer.

A third Distractor task was therefore developed. This Distractor task involved presenting the subject with one of three numbers (1, 2, or 3) every second. Their task was to look at the number and press the first mouse button if the number was a 1, the second if it was a 2, and the third button if it was a 3. When the button was pressed the number was cleared. If the subject either failed to respond to the number (by pressing the mouse button within 1 second from the time of its presentation) or pressed the wrong button, then the computer beeped to indicate an error. This beep served as immediate auditory feedback regarding their performance on the Distractor task. Hence, while this task still required active processing, it posed a much lower demand on the articulatory loop buffer.

Pilot Study #5

The fifth pilot study was then conducted. A summary for encoding time and the number of errors for both word pair types (easy and hard) under conditions of Distractor and No Distractor is presented in Table 2. As can be seen from this table, there was a greater increase in the hard word pairs than in easy word pairs between the Distractor and No Distractor conditions. These results support the hypothesis that normal individuals are able to adjust their behavior in response to task demands. Although they increased their encoding times, recall of hard word pairs learned in the Distractor condition was very poor. Subjects were able to recall an average of only two words. Hence, although they adjusted their behavior, the changes they made proved insufficient to adequately store the material. Since recall errors were so high, it was decided that the procedure was too demanding. Hence, the final change made in the procedure was to decrease the total number of word pairs in the test sets from 20 to 16 word pairs to make the procedure less demanding without altering the nature of the test. These word pairs were then added to the practice sets, increasing them from four to eight word pairs.

Pilot Study #6

The final pilot study was then conducted. This study was conducted for two reasons. First, since the number of test word pairs was changed, it was important to assess the effect of this modification. Second, data indicated that male head-injured individuals outnumber female head-injured individuals by a ratio of approximately 5:1. Hence, it was necessary to determine whether females and males would perform differently on the test. Data were collected on 30 males and 30 females. A Mixed MANOVA was conducted with two between group factors, sex (male vs female) and order (No Distractor followed by Distractor vs Distractor followed by No Distractor), and with two within group factors, word pair type (easy vs hard) and distraction condition (distraction vs none), on two sets of independent variables: encoding time as well as recall errors. Results indicated significant multivariate main effects for word pair type [$\underline{F}(2,55)=207.70$, $p<.0001$] and distraction condition [$\underline{F}(2,55)=141.58$, $\underline{p}<.0001$]. Follow-up analyses indicated that distraction condition had significant univariate effects on both encoding time [$F(1,56)=93.38$, $p<.0001$] and recall errors [$F(1,56)=116.47$, $p<.0001$] and that word pair type also had significant univariate effects on both encoding time [$F(1,56)=80.75$, $p<.0001$] and recall errors [$F(1,56)=267.58$, $p<.0001$]. A significant multivariate interaction was also found between distraction condition and word pair type [$F(2,55=29.96$, $p<.0001$]. Follow-up analyses again indicated significant univariate effects of the interaction on both encoding time [$F(1,56)=11.21$, $p<.005$] and recall errors [$F(1,56)=47.85$, $p<.0001$]. To further understand the nature of these interactions, simple effects tests were conducted on word pair type for each distraction condition and each distraction condition for word pair type for both encoding time and recall errors. Simple effects analyses for encoding time revealed that while subjects spent more time in the Distractor than the No Distractor condition on both the easy word pairs [$F(1,56)=24.73$, $p<.001$] and the hard word pairs [$F(1,56)=47.50$, $p<.001$], there was a significant increase in encoding time across word pairs only in the Distractor condition [$F(1,56)=14.14$, $p<.001$]. Conversely, analyses of simple effects for recall errors showed significant differences only between easy and hard words in the Distractor condition [$F(1,56)=8.85$, $p<.005$] and between distraction conditions only for hard words [$F(1,56)=16.21$, $p<.001$]. No other main effects or interactions were found to be significant. Since no effect was found for sex, there was no support for the idea that potential differences found between the TBI and control groups would be attributable to gender differences. Consistent with those of pilot study 5, these results demonstrated that subjects had higher encoding times and more recall errors for the hard than the easy words and that these differences were greater in the Distractor condition than in the No Distractor condition.

Pilot Study Results Summary

This progressive series of investigations allowed for the testing and development of a procedure with which to assess information processing during learning and its subsequent effect on memory performance. Results of the pilot studies now appear to support the experimental hypotheses. When individuals with unimpaired executive functioning learn word pairs, they spend more time encoding hard than easy word pairs. Additionally, when they simultaneously perform a distracting task, they increase their encoding time more for the hard words. If individuals with TBI's do not show increases in information processing similar to normal individuals, then it would appear to support the contention that TBI memory deficits are the result of executive impairment.

Proposed Investigation

This study will attempt to further the understanding of memory deficits observed in individuals with TBI. Rather than using a traditional paradigm which only assesses for the presence of memory deficits, this investigation will attempt to directly assess information processing by examining encoding time and recall errors. It is hypothesized that individuals with TBI's suffer from executive impairment and therefore will not appropriately increase their encoding times across distraction conditions as much as individuals with unimpaired executive functioning.

METHOD

Subjects

One control and one TBI group was recruited to participate in this study. Potential subjects were informed that their data would be examined only in group form and that their performance would remain strictly confidential. Each group contained 26 individuals, making the total participant number 52 subjects. Potential control group subjects were administered a brief screening questionnaire to assess for possible psychiatric and/or neurological problems that may have confounded the results (See Appendix A). The final group was comprised of spouses, siblings, and parents of head-injured individuals who reported no psychological disorder or neurological event which caused dizziness, coma, or nausea, or caused them to visit a physician. These individuals also rated their subjective level of depression on a seven point scale. The mean rating (1 = sad, 7 = happy) was 5.92. This particular control group was used so that the memory performance of the TBI group could be compared to a group of individuals similar on demographic factors (e.g., background and education) who were not experiencing memory deficits.

The TBI group was comprised of a heterogeneous sample of head-injured individuals recruited from social support groups, rehabilitation facilities, and assessment clinics. Only subjects who had loss of memory for the event and either coma or post-traumatic amnesia (determined by self-report) were included. Duration of coma ranged from 0 to 120 days (mean = 27.08). Post-traumatic amnesia ranged from 0 to 365 days (mean = 78.50). Days post-injury ranged from 104 to 7788 days (mean = 1611.04).

In addition to these criteria, only those head-injured individuals who scored 1 standard deviation below the mean on at least two of the three memory screening tests (described below) were included. Individuals with insignificant memory disruption would not have been useful TBI subjects because they lacked the deficits that this investigation was attempting to explore. Specific types of TBI may result in different forms of memory impairment. While this is undoubtedly the case, there is little understanding of the type of memory deficits in which specific forms of TBI would result. Therefore, the only injury characteristic requirement was that it resulted in a TBI (as specified by the aforementioned criteria). Of all potential subjects who completed the memory screening tests, 2 refused to participate, 6 had no evidence of TBI, 9 were unable to perform the test, and 15 did not meet the memory deficit criteria.

The first two memory screening tests were subtests taken from the Wechsler Memory Scale (WMS). The first WMS subtest was Logical Memory (LM), a test that provides an assessment of memory for information in context. Average number of items immediately recalled was examined on this test. The second WMS subtest was Paired Associates (PA), which provides an assessment of how subjects perform on a standardized word pair task. The final memory screening test that was administered is the Selective Reminding Test (SRT). This test is a list learning task that provides an assessment of memory for verbal material that is not in context. Consistent long term recall scores from this test were recorded. These tests are well established measures and are frequently used to assess memory functioning (Mack, 1986).

Materials

A Toshiba T1600 Laptop (AT class) computer was used to run a memory test program that was written specifically for this investigation. A Logitech C-7 serial mouse was installed in the computer and used by both the experimenter and subject to provide input during the test. The computer program collected demographic information, presented stimulus material (word pairs) with and without a distractor, and recorded reaction time. It also recorded study time, recall time (for both correct and incorrect responses), and whether the response was correct.

All subjects were also administered the first portion (page) of the Shipley-Hartford Institute of Living Scale. This portion is a vocabulary measure and allowed the two groups to be compared on their overall vocabularies to verify that they were not different.

Word pairs were selected that were assumed to require either a controlled (the hard word pairs) or an automatic (the easy word pairs) mode of processing. In order to control processing requirements, three selection criteria were used to choose the word pairs. First, word pairs that were of equal familiarity to subjects were used. This was done to help prevent memory performance being affected by word familiarity rather than the strength of the association between the words. The second selection criterion was that half of the word pairs were high in associative strength (the easy set) while the remaining half (the hard set) were low in associative strength (Cramer, 1968). The final criterion in selecting the word pairs was that no word was used twice so as not to cause interference between word pairs. The word pairs were taken from Postman (1970) to satisfy these criteria.

In the Postman (1970) study, the first word in each of the word pairs was taken from one of the two sets of words which Thorndike and Lorge (1944) classified as high in familiarity. Postman presented these words (from both of the Thorndike and Lorge two highest frequency categories) and had subjects generate associations for each of them. To select the easy word pair set for this investigation, every other word (half of the total words) was selected from the Thorndike and Lorge two most familiar categories. The most common association which subjects generated for the words in the Postman (1970) investigation was selected as its pair. For the selection of the hard word pairs, the remainder of the words in the Thorndike and Lorge (1944) study's two most frequently used word categories was extracted and a pair was selected for each word from Postman's (1970) lowest frequency category for which there was no readily apparent association. Forty-eight word pairs (24 easy and 24 hard) were thus generated. These word pairs were divided into two practice sets of four pairs each (four easy / four hard) and two test sets of 16 (8 easy / 8 hard) word pairs (See Appendix B).

Procedure

At the beginning of the experiment, subjects were asked to participate in an experimental research project to assess the effects of head-injury on memory functioning. TBI subjects who were willing to participate were administered the WMS-LM, WMS-PA, and the SRT. Those individuals with TBIs were screened for study participation by their performance on these three memory tests. Their scores were examined and those who scored at least 1 standard deviation below the mean on two of the three tests were eligible to participate. Control subjects were administered the brief screening questionnaire (see Appendix A). All subjects were also administered the first portion of the Shipley-Hartford to assess for group vocabulary differences.

The experimental computer memory test was then administered. At the beginning of this test, a screen was presented to collect subject information. The experimenter asked the subject the following questions (subjects were not asked the questions regarding experimental conditions) and typed in this information: first and last name, age, education, gender, counterbalancing order (distraction/no distraction or no distraction/distraction), subject group (TBI group or control group), and phone number (in case future information is required).

After this information was collected, the screen cleared and the phrase "Motor Response Time Test" appeared on the center of the computer screen. The subject was asked to place the fingers of his or her non-dominant hand on the spacebar and hold them there throughout the remainder of the test. When the experimenter pressed the middle mouse button, the first portion of this program began. This was a reaction time task to assess whether there were reaction time differences between the two groups. During this portion of the test, the subject watched the center of the screen. Ten times, at different intervals (7, 2, 12, 4, 9, 15, 6, 10, 3, and 8 seconds) that were unknown to subjects, an "x" appeared in the center of the screen. When the "x" appeared, he or she pressed and released the spacebar on the computer keyboard. This cleared the screen, recorded reaction time, and started the count-down for the next time an "x" would appear. The first five of these were practice, and reaction time was based on the average of the last five. Instructions for this portion of the test are located in Appendix C.

As soon as the motor response time test ended, the phrase "Number Tracking Test Practice" appeared on the computer screen. The subject was read the instructions and the test was started when he or she pressed the middle button. Once every second during this test, the computer displayed a 1, 2, or 3 in the middle of the screen. After this number appeared on the screen, the subject had 1 second to press the appropriate button on the mouse with the dominant hand to indicate which number was displayed (left button for 1, middle button for 2, and right button for 3). The number was erased as soon as any button was pressed, and the next number was displayed 1 second after the last one was initially presented. If a subject either failed to respond within 1 second or pressed a wrong button, the computer emitted a .5 second 1000 Hz. tone to indicate an error. Instructions for this procedure are located in Appendix D. This test was chosen as the Distractor test because it is assumed to require active processing by the executive system (because no schemata are likely to be available to conduct the task). Additionally, it minimized verbal processing by requiring only a motor response. Therefore, this task should have impacted only on the articulatory loop and verbal processing mechanisms via its use of the executive system, or what Shallice (1982) has termed the SAS.

After completing the number tracking test, the subject completed one of two portions of the test, which differed only in whether the number tracking task was performed while learning the word pairs in the first or second distraction condition. The number tracking task was administered in a counterbalanced fashion across the two sets of word pair lists so that each consecutive subject (in both groups) received the alternate order. The instructions which subjects received for these two portions are presented in Appendix E for counterbalance order 1 and Appendix F for counterbalance order 2.

Aside from engaging in the number tracking task, which was thought to occupy the SAS, on one of these two portions of the test, the same procedure was followed both times. This procedure was as follows. When the number tracking task was completed, the screen was cleared and the phrase "Part 1 - Display - Practice" appeared on the screen. The subject was then read the instructions presented in Appendix E or Appendix F (depending on which counterbalancing order he or she was in). Before presenting test items, a practice set was given. When the subject was ready begin, the experimenter pressed the left button on the mouse and the first word pair was presented. The subject's task was to learn the word pairs as they appeared on the screen so that later, when only the first word was presented, he or she could recall its pair. Once the subject had learned the pair, he or she pressed the spacebar. When the spacebar was pressed, encoding time (information processing time) was recorded for that word pair, the screen was cleared, and the next word pair was presented.

After all eight practice word pairs were presented, the phrase "Part 1 - Recall - Practice" was written to the screen and the subject was read the instructions for that portion of the test (specified in Appendix E and Appendix F). When the subject was ready to begin recalling the word pairs, the experimenter pressed the middle mouse button to begin the recall section. The first word of the pair appeared on the screen. The subject watched the screen and, when the word appeared, tried to recall the word that went with it. Once he or she recalled the word (or made a best guess if they were unable to remember it), the subject said it aloud and simultaneously pressed the spacebar. When it was pressed, the word was cleared from the screen and the recall time was recorded. Then the experimenter pressed the left mouse button if the answer was correct and the right mouse button if the response was incorrect. After the mouse button was pressed, the first word of the next pair appeared on the screen. The test proceeded in this manner until recall of all eight word pairs was tested.

After recall was tested, the phrase "Part 1 - Display" was written on screen. The next portion of the test was conducted in a fashion identical to the Part 1 - Display - Practice portion of the test. When the subject was ready to begin, the experimenter pressed the middle mouse button, and the first word pair was displayed. Each successive word pair was presented and the encoding time was recorded after each press of the spacebar. The test proceeded in this manner until all 16 word pairs had been presented.

At that time, the phrase "Part 1 - Recall" was displayed, and when the subject was ready to begin recalling the pair of each of the words, the experimenter began the recall portion of the test. This portion of the test was conducted in a manner identical to the Part 1 - Recall - Practice section. The first word of each of the 16 successive pairs was displayed, and the recall time and whether the response was correct were recorded.

Part 2 of the test was then begun. In a manner similar to Part 1, the same four portions of the test were conducted: Part 2 - Display - Practice, Part 2 - Recall - Practice, Part 2 - Display, and Part 2 - Recall. The only difference between these two portions of the test was that the distracting task was given during one of them (determined by counterbalance order). During the part of the test in which the distracting task was performed, the subject kept track the numbers as they appeared on the screen by pressing the appropriate mouse buttons while they learned the word pairs. After completing both parts of the memory test, the subject was thanked for participating and any questions he or she had regarding the procedure were answered.

RESULTS

The purpose of the first analysis was to determine whether the control and TBI groups differed on measures which could have affected their performance on the memory test. Six univariate ANOVA's were conducted to examine whether the groups differed on vocabulary, age, education, reaction time, and performance on the distractor task. Results indicated that the two groups differed only on age [$F(1,50)=16.05$, $p<.0005$] (TBI mean = 29.88 years, control mean = 43.58 years) and reaction time [$F(1,50)=6.11$, $p<.05$] (TBI mean = .55 sec., control mean = .46 sec.). Hence, the TBI group was younger and slower.

Next, to investigate the six experimental hypotheses, a Mixed MANOVA was conducted with two between group factors, group (TBI vs control) and order (No Distractor followed by Distractor vs Distractor followed by No Distractor), and two within group factors, word pair type (easy vs hard) and distraction condition (Distractor vs No Distractor), on two sets of dependent variables: encoding time and recall errors. Results indicated significant multivariate main effects for group [$F(2,47)=15.96$, $p<.0001$] word pair type [$F(2,47)=172.30$, $p<.0001$] and distraction condition [$F(2,47)=85.29$, $p<.0001$]. Follow-up univariate ANOVAs indicated that group had significant effects on both encoding time [$\underline{F}(1,48)=12.17$, $\underline{p}<.005$] and recall errors [$\underline{F}(1,48)=23.33$, $\underline{p}<.0001$], word pair type had significant effects on both encoding time [$\underline{F}(1,48)=52.80$, $\underline{p}<.0001$] and recall errors [$\underline{F}(1,48)=281.53$, $\underline{p}<.0001$], and distraction condition also had significant effects on both encoding time [$\underline{F}(1,48)=104.14$, $\underline{p}<.0001$] and recall errors [$\underline{F}(1,48)=63.44$, $\underline{p}<.0001$]. Main effects on encoding time and recall errors are presented in Table 3.

MANOVA results also showed two significant two-way interactions: group by distraction condition [$\underline{F}(2,47)=3.78$, $\underline{p}<.05$] (see Figure 1) and word pair type by distraction condition [$\underline{F}(2,47)=4.02$, $\underline{p}<.05$] (see Figure 2), and one three-way interaction: group by word pair type by distraction condition [$\underline{F}(2,47)=5.28$, $\underline{p}<.01$] (see Figure 3). Follow-up univariate ANOVAs indicated that the group by distraction condition interaction had significant effects only on encoding time [$\underline{F}(1,48)=7.09$, $\underline{p}<.05$], word pair type by distraction condition had significant effects only on encoding time [$\underline{F}(1,48)=6.07$, $\underline{p}<.05$], and group by word pair type by distraction condition had significant effects only on recall errors [$\underline{F}(1,48)=9.71$, $\underline{p}<.005$].

Simple effects analyses were then conducted to further examine the nature of these univariate interactions. The Satterthwaite approximation for simple effects analyses of repeated measures was employed to estimate the degrees of freedom for each F-test (Winer, 1971).

To further analyze the group by distraction condition interaction, simple main effects tests were conducted on group at each distraction condition and across distraction conditions for each group. Results indicated that while there was a significant increase in encoding time across distraction conditions for both the TBI group [$F(1,82)=24.39$, $p<.001$] and the control group [$F(1,82)=8.42$, $p<.01$], there was a significant difference in encoding time between groups only in the Distractor condition [$F(1,82)=9.59$, $p<.005$]. To further analyze the word pair type by distraction condition interaction, simple effects analyses were conducted across word pair types at each distraction condition and across distraction conditions for each word pair type. Results indicated that while encoding times increased significantly from easy to hard words in both the Distractor [$F(1,48)=35.58$, $p<.001$] and the No Distractor [$F(1,48)=7.45$, $p<.01$] distraction conditions, there was only a significant difference between distraction conditions on the hard word pairs [$F(1,48)=11.08$, $p<.005$]. Finally, to examine further the effect of the group by word pair type by distraction condition interaction, simple effects analyses were conducted separately for each group across word pair types for both distraction conditions and across conditions for both word pair types. Results for the control group indicated that while there were significant increases in recall errors from easy to hard words for both the Distractor [$F(1,144)=41.77$, $p<.001$] and the No Distractor [$F(1,144)=16.51$, $p<.001$] distraction conditions, there was a signficant difference in recall errors across distraction conditions only on the hard words [$F(1,144)=13.19$, $p<.001$]. Similarly for the TBI group, there were significant increases in recall errors from easy to hard words in both the Distractor [$F(1,144)=28.04$, $p<.001$] and No Distractor conditions [$F(1,144)=37.15$, $p<.001$]; however, significant differences across distraction conditions were found only for the easy word pairs [$F(1,144)=5.45$, $p<.05$]. Cell means and standard deviations of encoding times and recall errors for this analysis are presented in Appendix G.

As was previously mentioned, the control group was approximately 14 years older than the TBI group. It would be anticipated that this age difference would increase encoding time and recall errors in the control group. Although this would make rejecting the null hypothesis more difficult (indicating the groups were the same on the dependent variables), it would not change the capacity limitation pattern of the TBI group. Nonetheless, since group was correlated with age, it was desired to test whether the group effects resulted from explanation of variance which was shared with age. Hence, two post-hoc

Mixed MANCOVA's (identical to the one described above except that age was included as a covariate) were conducted to assess group effects after controlling for age. Results of these two Mixed MANCOVA's indicated that group effects were not affected by the inclusion of age as a covariate. Therefore, while age was unequal between groups, this age difference was not responsible for group differences on the dependent measures.

Although the TBI group performance on the experimental memory test supported the capacity limitation hypothesis, it was possible that some of the individuals in this group displayed an executive dysfunctioning pattern which was masked by mean performance. A capacity limitation pattern would differ from an executive functioning pattern in that subjects manifesting a capacity limitation pattern would increase their encoding time difference between the easy and hard words from the no distractor to the distractor condition. In order to test whether a subset of the TBI group displayed an executive dysfunctioning pattern, encoding time of the easy words was subtracted from encoding time of the hard words in both the Distractor and No Distractor conditions. The difference of the No Distractor condition was then subtracted from the Distractor condition difference. This is summarized by the following equation: ((Distractor Hard encoding time - Distractor Easy encoding time) - (No Distractor Hard encoding time - No Distractor

Easy encoding time)). If the equation equalled a positive number, then the subject was compensating for the distractor task and manifesting a capacity limitation pattern. Alternatively, if the value was less than or equal to 0, then the individual was displaying an executive functioning pattern by not increasing his or her encoding time despite the addition of a distracting task. On the basis of this equation, 10 subjects displayed an executive dysfunctioning pattern while the remaining 16 subjects displayed a capacity limitation pattern. Likewise, in the control group, 12 individuals displayed a capacity limitation pattern while the 14 remaining subjects performed in a manner consistent with executive functioning impairment. A Chi-Squared indicated there was no difference between groups on these two patterns.

After conducting the statistical analyses to explore the primary concern of the investigation, two other issues were explored: 1) the relationship between encoding time and recall errors, and 2) whether subject characteristics related to performance on the experimental memory test for the TBI group.

To address the first issue, correlations were computed between encoding time and subsequent recall errors for both word pair types in both distraction conditions. No correlations for either the TBI or control group for either word pair type in either distraction condition were significant.

The final issue explored was whether there was a relationship between subject variables and overall performance of the TBI group on the experimental memory test. To answer this question, age normed scores on the three memory tests (PA, LM, and SRT) were transformed to Z-scores. These scores were then added to the Mixed MANOVA described above, along with days post-injury, length of post-traumatic amnesia, length of coma, the transformed Shipley-Hartford vocabulary score (Z-transformed for the univariate test described above), age, performance on the distractor, reaction time, and education. The group variable was removed from the analysis because only the TBI group was being analyzed. Hence, two Mixed ANCOVAs were conducted, one on encoding time and the second on recall errors. Both had one between group factor, order (No Distractor followed by Distractor vs Distractor followed by No Distractor), and two within group factors, word pair type (easy vs hard) and distraction condition (distraction vs none), and the following covariates: days post-injury, length of coma, length of post-traumatic amnesia, age, performance on the distractor, reaction time, education, and Z-transformed Shipley-Hartford vocabulary scores, PA, LM, and SRT scores. Results indicated significant multivariate effects on encoding time for the Z-transformed Shipley-Hartford vocabulary score [$\underline{F}(4,10)=3.73$, $\underline{p}<.05$], Z-transformed SRT [$\underline{F}(4,10)=4.15$, $p<.05$], and reaction time [$\underline{F}(4,10)=4.11$, $\underline{p}<.05$]. To further examine these effects, correlations were computed between these three variables and encoding time of both word pair types in both distraction conditions (see Table 4). In general, these correlations showed a positive relationship between Z-transformed SRT scores and encoding time, and an inverse relationship of encoding time with Z-transformed Shipley-Hartford vocabulary scores and reaction time. Examination of this table, however, reveals only one significant correlation. Therefore, it appears these signficant MANOVA findings may have resulted from suppression effects. None of the remaining variables had a significant multivariate effect on encoding time. No significant multivariate effects were found for recall errors.

DISCUSSION

Much has been written regarding the memory problems which arise as a consequence of TBI. It is now well known that TBI can result in post-traumatic amnesia, retrograde amnesia, and lasting deficits which impair learning and memory (Schacter & Crovitz, 1977). Despite the vast amount of descriptive literature which has been published on memory deficits secondary to TBI, this impairment is not theoretically well understood. This investigation was an initial attempt at applying Shiffrin and Schneider's (1977) concepts of automatic and controlled processing to TBI memory deficits. A memory test was constructed to measure whether the memory disruption occurs in an automatic or controlled mode as well as to determine the nature of a potential controlled processing deficit.

Results indicated that the easy word pairs did not appear to be processed in automatic mode since their encoding times were affected by the distraction conditions (Hasher & Zacks, 1979). Hence, it is not possible to determine whether TBI memory deficits result from disruption of automatic information processing. However, there was support for the idea that TBI memory deficits result from a disruption of controlled information processing.

Having found a controlled processing deficit was at least partially responsible for the memory impairment, the investigator decided that the next question was to determine whether this deficit is the result of a capacity limitation or executive dysfunctioning. This decision was made by examining whether the TBI group was able to adjust their information processing to increased environmental demands (i.e., whether they were simultaneously performing a distracting task). Results indicated that all subjects (both TBI and normal) had greater encoding times when learning words while simultaneously conducting the distracting task.

This increase in encoding time in response to increased environmental demands would be expected of normal individuals. It indicates that the task in which they are engaging has become more difficult and the executive system is therefore compensating by increasing encoding time. In order for subjects to compensate for these increased environmental demands, their executive systems must monitor the progress of their information processing and maintain the application of learning schemata until the material has been satisfactorily encoded (Norman & Shallice, 1980). The fact that they spend longer encoding the material suggests that the executive system is applying the schemata longer because the material is not being as rapidly encoded. Because encoding duration is based on learning progress, the more difficult the material is to learn, the longer the executive system should maintain encoding. Therefore, TBI does not appear to affect the executive system.

In sum, TBI memory deficits do not appear to result from an executive deficit which impairs controlled processing. TBI subjects increased their encoding times in response to task demands in a manner similar to normal individuals, although in an accentuated manner. Although they compensated in their encoding of the material, memory functioning was still impaired. Therefore, TBI memory deficits appear to result from a capacity limitation of the controlled information processing system.

These results have potential impact on memory rehabilitation. It seems likely that memory deficits resulting from executive impairment would result in greater disruption than memory difficulties resulting from a capacity limitation. This is because executive dysfunctioning impairs the normal regulation of information processing (i.e., it damages the ability to adjust to environmental demands and exert more effort when appropriate). Therefore, TBI subjects would likely benefit little from a memory enhancement strategy requiring increased cognitive effort (Cermak, 1980) because it (the strategy) would require them to engage in the very process (compensating their amount of cognitive effort) that they will not spontaneously perform.

Memory deficits that result from a capacity limitation would be different, however. This deficit theoretically results from decreased efficiency of the memory system. A capacity limitation memory deficit theoretically occurs because, although these individuals do compensate, they do not do so to a sufficient degree. Although individuals with memory deficits of this nature adjust their amount of information processing, it is not sufficient for them to learn the material. Therefore, it may be helpful to teach these individuals new approaches to learning complex material. If more effective learning strategies could be developed and taught to these individuals, they would likely use the strategies.

Presently, however, there is little convincing evidence that attempts at memory remediation have been successful. Glisky and Schacter (1986) stated that this is not likely to change because of the lack of applicability of the approaches outside the laboratory. This implies that it is the strategy, not the limitations of those who fail to benefit from it, that is at fault. TBI subjects may therefore be able to benefit from strategies that are more applicable to learning situations they encounter.

Currently, no such strategies have been shown to be effective at relieving these memory deficits. Because there are no procedures currently which have been shown to be effective, it is difficult to speculate what characteristics of a strategy might be efficacious. Some results, however, may be suggested by the results of this investigation. TBI subjects performed generally more slowly on information processing measures. While much of this was likely compensation for their limitation in capacity, it may also indicate that they process information more slowly than normal individuals. TBI memory impairment, then, may be alleviated to some extent by teaching TBI individuals to process smaller amounts of material at a time. Learning curves could be examined to determine whether optimal rates for presentation of material could be established. Environmental cues and restructuring will also likely continue helping individuals with memory impairment. Rehabilitation efforts could be focused on teaching individuals to use memory aids (e.g., lists) to decrease memory requirements. Additionally, environments could be altered so that commonly used items are readily found or summaries made to describe their location.

There were methodological problems in the present study that may have affected the sensitivity of the results. The distracting task appeared to be too demanding. When subjects were attempting to memorize the hard word pairs while performing the distracting task, learning was almost totally disrupted. While this appeared to occur for both TBI and normal subjects, it seemed to be especially true for TBI subjects (see Table 3). Because recall errors appeared to reach a ceiling effect, it is not possible to determine how recall would have differed between the two groups in this condition. It seems likely, however, that the TBI group would have recalled significantly fewer words.

Another issue which could affect the interpretation of the results is the TBI group which was used. Although the group was heterogeneous with respect to variables like length of coma, days post-injury, etc., all were selected for having memory impairment. Hence, subjects were not tested who did not meet the criteria of being 1 standard deviation below the mean on two of the three memory tests. Because TBI individuals who did not meet these criteria were not tested, it is not possible to determine whether the obtained results would generalize to this group. Additionally, because subjects were selected on the basis of their memory performance on these tests, there was decreased variance on these variables. This decreased variance may have been partially responsible for some of the lack of association between the experimental memory test and other variables (e.g., the standardized memory tests). Further research into this issue will need to be conducted to determine this.

In sum, this was an initial attempt to understand the nature of TBI memory deficits. Results demonstrated that these deficits appeared to be the result of a capacity limitation rather than of impairment in the executive functioning system. These findings are encouraging because they suggest that if effective learning strategies that are applicable outside the laboratory could be developed, they may be helpful in alleviating TBI memory deficits.

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Table 1 - Pilot Study #4 Encoding Time Means

Sec.	No Distractor Easy	No Distractor Hard	Distractor Easy	Distractor Hard	Easy Diff.	Hard Diff.	Easy-Hard Diff.
1	6.12	11.14	6.64	9.67	0.52	1.47	-1.99
2	2.97	4.93	7.41	10.72	4.44	5.79	1.35
3	2.33	2.99	4.68	6.01	2.35	3.02	0.67
4	3.02	4.89	8.01	10.81	4.99	5.92	0.93
5	3.42	5.93	8.06	10.30	4.64	4.37	-0.27

Word Pair Type
Easy: Easy Word Pairs
Hard: Hard Word Pairs

Distraction Condition
Distractor: Simultaneous concurrent task
No Distractor: No simultaneous concurrent task

Summary Scores
Sec. - Number of seconds at which number appeared for simultaneous distractor task
Easy Diff. - Difference of encoding times for easy words across distraction conditions
Hard Diff. - Difference of encoding times for hard words across distraction conditions
Easy-Hard Diff. - Difference of encoding time differences scores for easy and hard words across conditions

Note: All encoding times are in seconds.

Table 2 - Pilot Study #5 Results

Encoding Times and Recall Errors With and Without Distractor	Counter-Balancing Order #1	Order #2
Easy Words (No Distractor)		
Encoding Time	3.17	4.13
Number of Errors	2.00	1.75
Hard Words (No Distractor)		
Encoding Time	4.55	6.04
Number of Errors	5.50	3.50
Easy Words (Distractor)		
Encoding Time	6.33	7.16
Number of Errors	5.00	3.00
Hard Words (Distractor)		
Encoding Time	8.22	9.68
Number of Errors	9.00	7.50

Table 3 - Main Effects

Main Effect For:	Mean	S.D.	Mean	S.D.
Group	TBI		Control	
Encoding Time	8.79	5.79	5.92	3.58
Recall Errors	5.01	2.30	3.49	2.58
Distraction Condition	No Distractor		Distractor	
Encoding Time	4.64	2.69	10.07	5.32
Recall Errors	3.57	2.48	4.93	2.45
Word Pair Type	Easy Words		Hard Words	
Encoding Time	6.16	4.21	8.54	5.46
Recall Errors	2.54	1.64	5.96	2.13

Table 4 - Follow-up Manova Correlations

	No Distractor		Distractor	
	Easy	Hard	Easy	Hard
Z-Transformed Shipley-Hartford Scores	-.28	-.34	-.24	-.47*
Z-Transformed SRT Scores	.27	.16	.06	.18
Reaction Time	.03	-.07	-.10	-.17

* Significant at the .05 level

APPENDIX A - CONTROL GROUP SCREENING QUESTIONNAIRE

Please write your name ______________________________
Please write the name of the patient you are here with

____

On the line below, please state your relationship to the patient and explain how you met him/her if he/she is not related to you.

____
____

Have you ever suffered a serious accident which resulted in loss of consciousness or for which you went to see a doctor? If so, please explain the circumstances on the lines below.

____
____

Have you ever (or are you now) seeing a doctor for physical or mental health problems? If so, please explain the circumstances on the following lines.

____
____
____

Please list all medications you are currently taking (or have taken in the past) and your reason for taking them.

____
____

Please rate your present mood on the scale below by circling the number which best describes how you are feeling.

Sad 1 2 3 4 5 6 7 Happy

APPENDIX B - WORD PAIRS

Practice Set 1

Mortgage-House
Oyster-World
Leather-Rifle
Circus-Clown
Welfare-Preamble
Author-Book
Country-Farm
Window-Life

Test Set 1

Biscuit-Foot
Garden-Flower
Business-Later
Presence-Here
Order-Spend
Shoulder-Fluff
Glory-Flag
Problem-Math
Tennis-Ball
Doctor-Starch
Sidewalk-Distance
Morning-Night
Answer-Question
Table-Chair
Letter-Penny
Drama-Lights

Practice Set 2

Trouble-Bad
Moment-Levers
Device-Gadget
Wisdom-Magazine
Panic-Bridge
Figure-Long
Belief-Religion
Reason-Why

Test Set 2

Woman-Abrupt
Candle-Race
Region-Area
Message-Particle
Dinner-Food
Husband-Wife
Story-Value
Sofa-Wood
Color-Hill
Highway-Road
Office-Work
Paper-Dwindle
Tourist-Travel
Oven-Hot
Building-Tall
Forest-Deep

APPENDIX C - REACTION TIME TASK INSTRUCTIONS

This program is a test to help us understand individual differences in memory processes. Before we begin the memory test though, there is going to be a brief section see how quickly you respond to the questions. Are you right handed or left handed? I want you to the put the fingers of your (non-dominant) hand on the spacebar and keep them there until the test is done. When I start the test, the screen will go blank. I want you to watch the middle of the screen because after a little while, an x is going to appear there. When the x appears, I want you to gently press the spacebar and then let it back up as quickly as you can. As soon as you press the spacebar, the x will disappear and pretty soon, another x will appear there. This will happen ten times. Each time, just press down the spacebar and then let it all the way back up as quickly as you can. Do you have any questions? Are you ready?

APPENDIX D - RANDOM NUMBER GENERATION TASK INSTRUCTIONS

During the next portion of the test, you are going to see one number appear on the screen every second. The number will be a 1, a 2, or a 3. If it is a 1, I want you to press this button (pointing) on the mouse. If it is a 2, I want you to press this button (pointing), and if it is a 3, I want you to press this button (pointing). After the number appears on the screen, you will have one second to press the right button. If you either do not press the right button within one second or if you press the wrong button, the computer will beep to let you know you made a mistake. Do you have any questions? Are you ready?

APPENDIX E - INSTRUCTIONS FOR COUNTERBALANCING ORDER 1

Part 1 - Display - Practice

We're now going to begin the memory portion of this program. There will be two parts to this test. Before you do the actual test in either part, though, you will complete a few warm-up items so that you see exactly what you are going to be doing and get some practice doing it.

On this part of the test, you will see pairs of words appear in the center of the screen. I want you to look at the word pair and learn it, so that later, when only the first of the two words is presented, you can recall the one that went with it. Once you have learned the word pair and are ready to go on to the next one, quickly press and release the spacebar, just like you did during the first test. Do you have any questions? Are you ready?

Part 1 - Recall - Practice

In the next part of the test, you are going to see the first word from each of those word pairs appear on the screen. When you see the word, think of the one that went with it. As soon as you remember it, say the word out loud and press the spacebar at the same time. If you are not sure what the word was, make your best guess and press the spacebar at the same time. After you press the spacebar, the word will disappear from the screen. Then, after I press a button on the mouse, the next word will appear and we will keep going like that until we have gone through all the word pairs. Do you have any questions? Ready?

Part 1 - Display

Now that you've practiced learning and recalling the words, we are going to begin the actual test. It will be done exactly like the practice test. When I start the program, you will see pairs of words appear on the screen, one at a time. After the word pair appears, memorize it and then press the spacebar. There will be 16 word pairs in all. Any questions? Ready?

Part 1 - Recall

Now we are going to begin the recall portion of the test which we will do just like we did during the practice portion. You'll see the first word from each pair appear on the screen. As soon as you remember the word that went with it, say it out loud and press the spacebar at the same time. Again, if not sure what the word was, make your best guess and press the spacebar. Ready?

Part 2 - Display - Practice

Now we are going to see pairs of words again and I want you to learn the word pairs, just like before, so that later, when only the first of the two words is presented, you can recall the one that went with it. Additionally, while you are looking at each of the word pairs, you will also see a 1, a 2, or a 3 appear on the screen every second. As the numbers appear, I want you to press the buttons on the mouse that correspond to them, just like you did during the second test. If you press the wrong button or don't press it in time, the computer will beep. So while you are learning the word pairs, you will be tracking the numbers, too. Press the spacebar to go on to the next word pair once you have learned the current one and press the buttons on the mouse that correspond to the numbers as they appear on the screen. We'll do a few practice examples to show you what it's like. Do you have any questions? Ready?

Part 2 - Recall - Practice

Now we are going to do the recall portion, just like we did before. You'll see the first word from each pair appear on the screen. As soon as you remember the word that went with it, say it out loud or make your best guess and press the spacebar at the same time. Ready?

Part 2 - Display

Now that you've had some practice at learning the words while you were tracking the numbers and then recalling the words, we are going to begin the next part of the test. It will be just like the practice session. When I start the program, you will see pairs of words appear on the screen, one at a time. While you are learning the word pairs, you will also have to keep track of the numbers as they appear on the screen by pressing the appropriate mouse button.

When you are ready to go on to the next word pair, press the spacebar. There will be 16 word pairs in all. Any questions? Ready?

Part 2 - Recall

Now we are going to begin the last portion of the test. This will be just like what you did before. You'll see the first word from each pair appear on the screen. As soon as you remember the word that went with it, say it out loud or guess what the word was and press the spacebar at the same time. Ready?

APPENDIX F - INSTRUCTIONS FOR COUNTERBALANCING ORDER 2

Part 1 - Display - Practice

We are now going to begin the memory portion of this program. There will be two parts to this test. Before you do the actual test in either part, though, you will complete a few warm-up items so that you see exactly what you are going to be doing and get some practice doing it.

On this part of the test, you will see pairs of words appear in the center of the screen. I want you to look at the word pair and learn it, so that later, when only the first of the two words is presented, you can recall the one that went with it. Once you have learned the word pair and are ready to go on to the next one, quickly press and release the spacebar, just like you did during the first test. Additionally, while you are looking at each of the word pairs, you will also see a 1, a 2, or a 3 appear on the screen every second. As the numbers appear, I want you to press the buttons on the mouse that correspond to them, just like you did during the second test. If you press the wrong button or don't press it in time, the computer will beep. So while you are learning the word pairs, you will be tracking of the numbers too. Press the spacebar to go on to the next word pair once you have learned the current one and press the buttons on the mouse that correspond to the numbers as they appear on the screen. We will do a few practice examples to show you what it's like. Do you have any questions? Ready?

Part 1 - Recall - Practice

In the next part of the test, you are going to see the first word from each of those word pairs appear on the screen. When you see the word, think of the one that went with it. As soon as you remember it, say the word out loud and press the spacebar at the same time. If you are not sure what the word was, make your best guess and press the spacebar at the same time. After you press the spacebar, the word will disappear from the screen. Then, after I press a button on the mouse, the next word will appear and we will keep going like that until we have gone through all the word pairs. Do you have any questions? Ready?

Part 1 - Display

Now that you've had some practice at learning the words while you were tracking the numbers and then recalling the words, we are going to begin the actual test. It will be just like the practice session. When I start the program, you will see pairs of words appear on the screen, one at a time. While you are learning the word pairs, you will also have to keep track of the numbers as they appear on the screen by pressing the appropriate mouse button. When you are ready to go on to the next word pair, press the spacebar. There will be 16 word pairs in all. Any questions? Ready?

Part 1 - Recall

Now we are going to begin the recall portion of the test, which we will do just like we did during the practice portion. You'll see the first word from each pair appear on the screen. As soon as you remember the word that went with it, say it out loud and press the spacebar at the same time. Again, if not sure what the word was, make your best guess and press the spacebar. Ready?

Part 2 - Display - Practice

Now we are going to see pairs of words again and I want you to learn the word pairs, just like before, so that later, when only the first of the two words is presented, you can recall the one that went with it. However, this time, no numbers will appear on the screen. I want you to just learn the word pair and when you are ready to go on to the next one, press the spacebar. We'll do a few practice examples to show you what it's like. Do you have any questions? Ready?

Part 2 - Recall - Practice

Now we are going to do the recall portion just like we did before. You'll see the first word from each pair appear on the screen. As soon as you remember the word that went with it, say it out loud or make your best guess and press the spacebar at the same time. Ready?

Part 2 - Display

Now that you've had some practice at just learning the words and then recalling them, we are going to begin the next part of the test. It will be done exactly like the practice test. When I start the program, you will see pairs of words appear on the screen, one at a time. After the word pair appears, memorize it and then press the spacebar. There will be 16 word pairs in all. Any questions? Ready?

Part 2 - Recall

Now we are going to do the recall portion, just like we did before. You'll see the first word from each pair appear on the screen. As soon as you remember the word that went with it, say it out loud or make your best guess and press the spacebar at the same time. Ready?

APPENDIX G - CELL MEANS FOR MIXED MANOVA TESTING HYPOTHESES

Group	Word Pair Type	Distraction Condition	Encoding Time Mean	Encoding Time S.D.	Recall Errors Mean	Recall Errors S.D.
TBI	Easy	No Dist.	4.50	2.67	2.50	1.10
TBI	Easy	With Dist.	10.53	5.06	3.96	1.59
TBI	Hard	No Dist.	6.23	3.29	6.31	1.64
TBI	Hard	With Dist.	13.89	6.18	7.27	0.72
Control	Easy	No Dist.	3.00	0.95	1.46	1.03
Control	Easy	With Dist.	6.63	2.49	2.23	1.68
Control	Hard	No Dist.	4.83	2.33	4.00	2.58
Control	Hard	With Dist.	9.21	4.28	6.27	1.66

Figure 1

Group By Distraction Condition Interaction

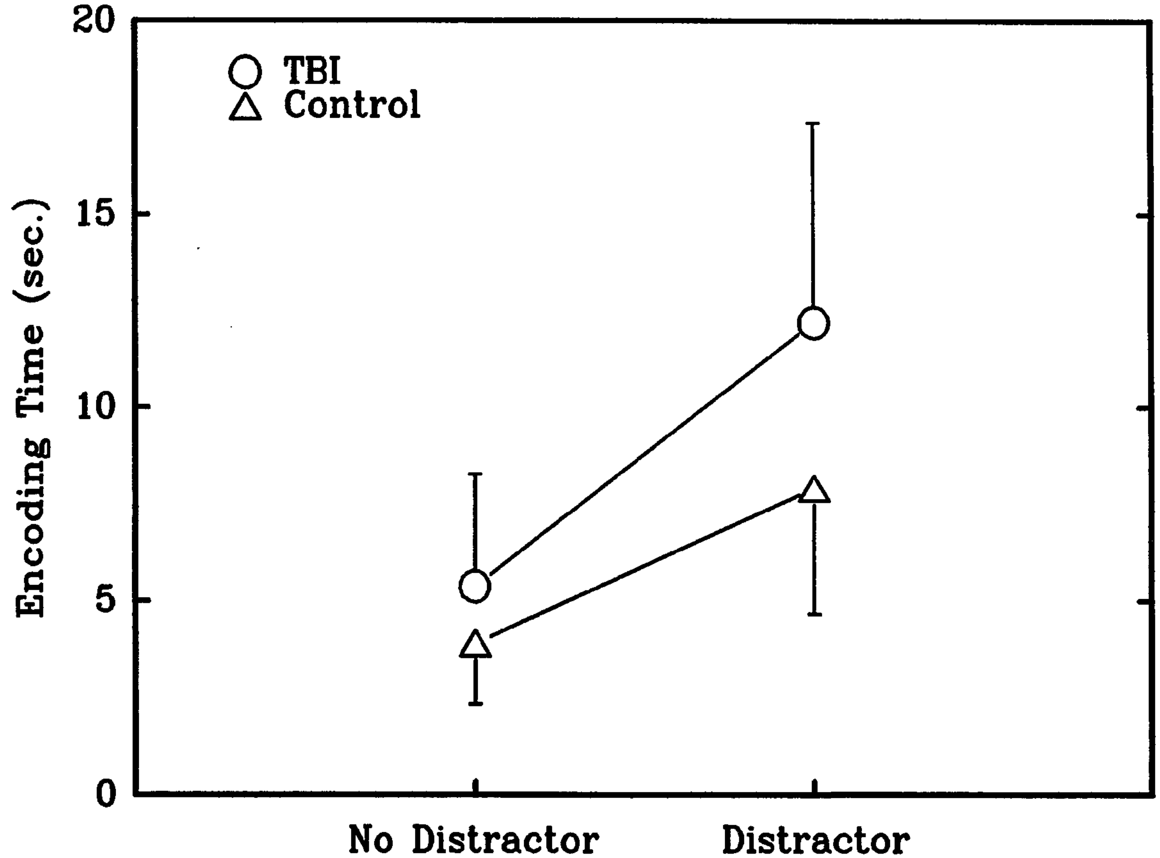


Figure 2

Word Pair Type By Distraction Condition Interaction

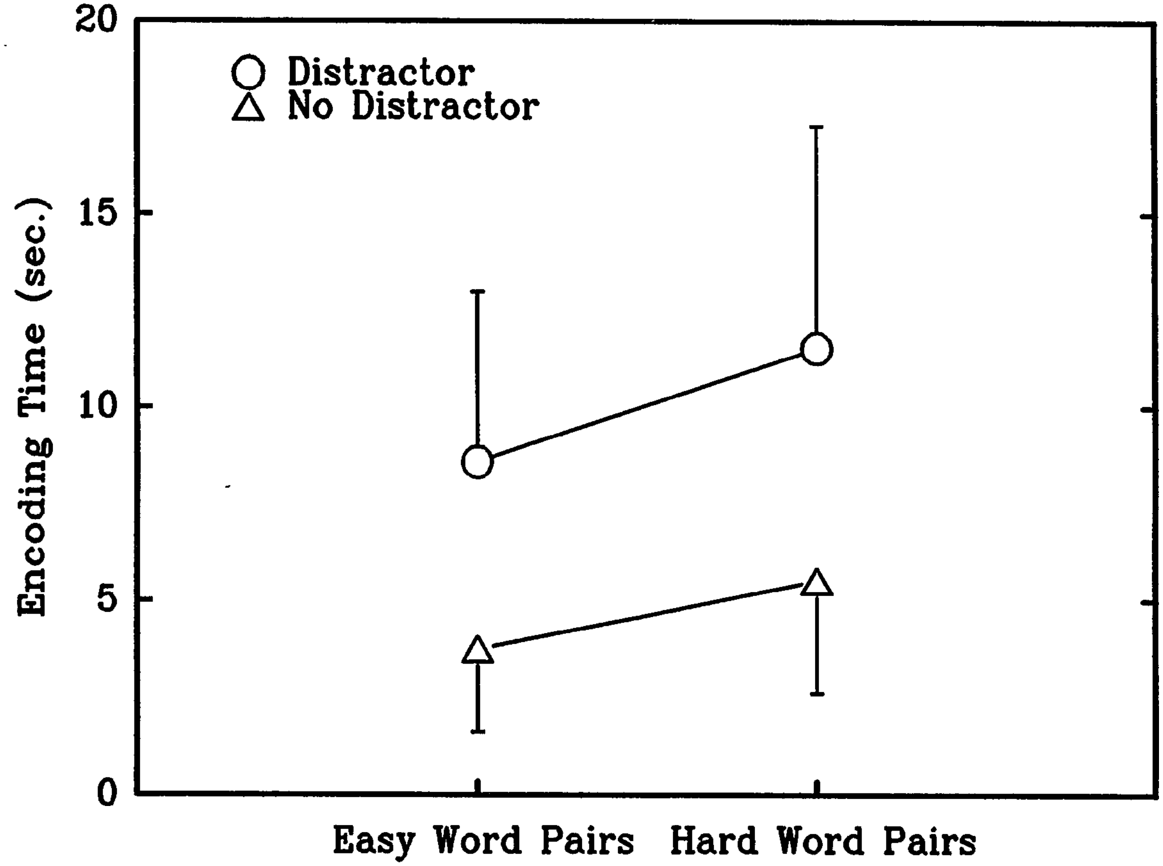
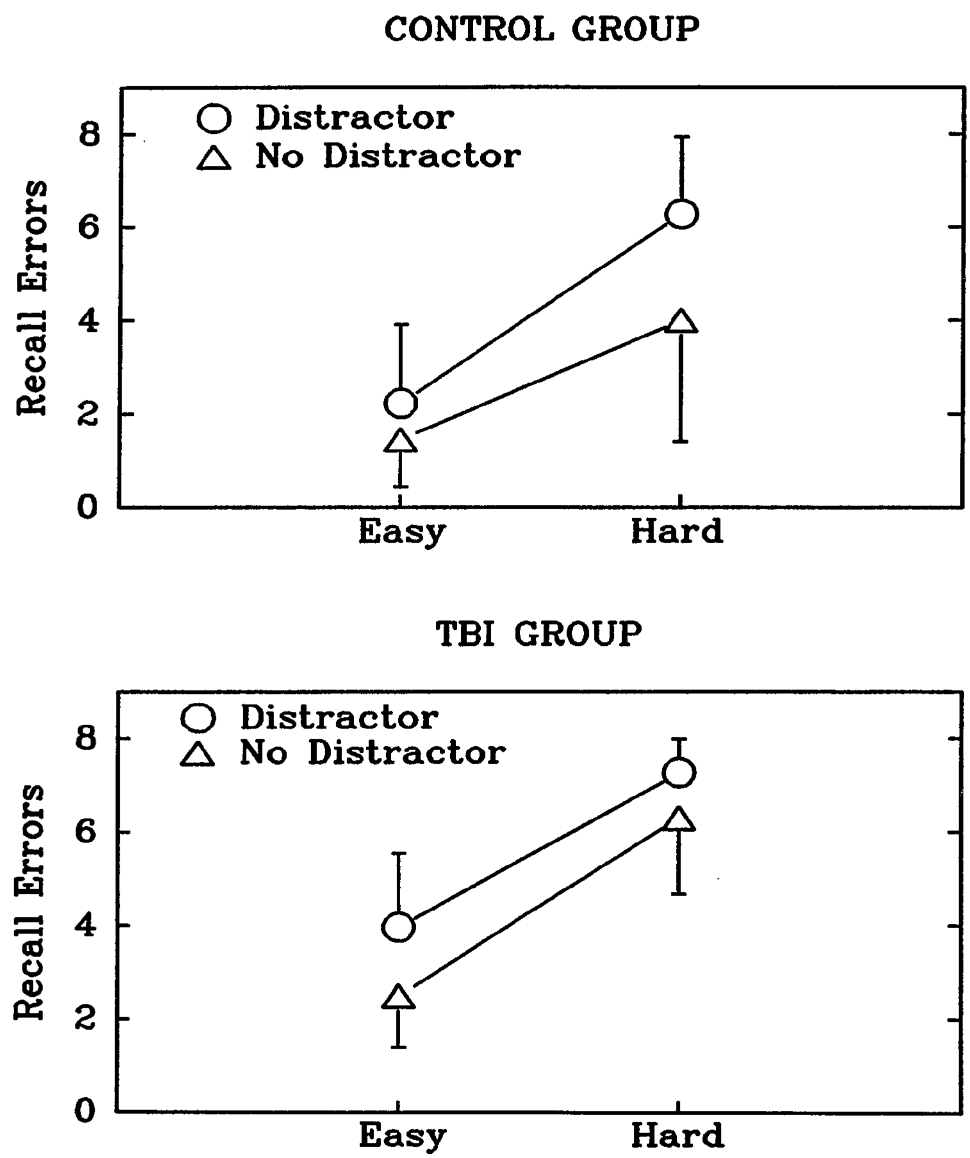


Figure 3

Group by Word Pair Type by Distraction Condition Interaction



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