The validity of a model-based procedure for assessing episodic memory.

Michael C. S. Harnadek

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THE VALIDITY OF A MODEL-BASED PROCEDURE FOR ASSESSING EPISODIC MEMORY

by

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A Dissertation
Submitted to the Faculty of Graduate Studies Through the Department of Psychology in Partial Fulfilment of the Requirements for the Degree of Doctor of Philosophy at the University of Windsor Windsor, Ontario, Canada 1993

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ABSTRACT

A recently developed memory assessment procedure provides independent estimates of acquisition and retrieval efficiency, measured using a four-trial learning task. The purpose of the study was to investigate the construct validity of the acquisition measures included within this new procedure. Study participants were left (LT; n = 20) and right (RT; n = 20) temporal lobectomy patients, and control subjects (NC; n = 20), matched for age, education, gender, and intellectual level. Each subject completed verbal and nonverbal memory tests administered and interpreted using the new procedure. In accordance with the material-specific nature of memory disorders, poor acquisition was expected on the verbal test for the LT group, and on the nonverbal test for the RT group. In addition, both patient groups were expected to demonstrate better retrieval than acquisition. In general, the study results supported only the former predictions. Low acquisition estimates for the LT group on the verbal test distinguished them apart from the NC and RT groups. On the nonverbal test, the RT subjects were significantly poorer in acquisition than the NC subjects, but not the LT group. The sensitivity of the acquisition measures in differentiating the LT and RT groups apart from the NC group supports the validity of these parameters. An interesting corollary
finding was that the patient groups also evidenced poor acquisition on tests on which they were expected to do well (i.e., the verbal test for the LT group, the nonverbal test for the RT group). These findings are discussed in terms of a generalized memory inefficiency, in addition to a specific, more severe, acquisition deficit for specific types of material. Finally, contrary to expectation, the LT and RT groups failed to demonstrate better retrieval than acquisition, likely due to an insufficient number of test trials to permit adequate estimation of retrieval efficiency. This finding reveals a serious shortcoming of the new procedure that limits its usefulness in evaluating memory performance. Future research should address: (1) replication of the current results; (2) revision of the four-trial version to permit greater opportunity for retrieval estimation; and (3) evaluation of the validity of the retrieval parameters included in the procedure.
DEDICATION

I dedicate this dissertation to the three most important people in my life: my parents, Mike and Lorraine Harnadek, and my wife, Gloria Grace. All gave selflessly of themselves, in their own way.
ACKNOWLEDGEMENTS

At the completion of this dissertation, I take great satisfaction in writing these acknowledgements. From the inception of this project, through to the final revision, a number of individuals have offered me guidance and assistance. I gratefully acknowledge the cooperation of the Department of Psychological Services at University Hospital in London, Ontario. My appreciation is extended to the subjects who kindly volunteered their time and effort for this study.

I thank the members of my dissertation committee, Drs. Rourke, Namikas, and Morton for their time, effort, and understanding which helped me to successfully complete this project. I also thank my external examiner, Dr. Smith, for her time and thought-provoking questions.

Two persons deserve a special thank you for their collegial support. Dr. Laurie Miller, from University Hospital, ensured my access to the epilepsy patient population at University Hospital. Also, Dr. Mark Howe, of Memorial University, provided unlimited support in helping me to understand and utilize the model that is instrumental to this research. He provided the computer algorithms to conduct the analyses, and patiently helped me to learn and understand the working of this particular mathematical model. I am grateful to Drs. Miller and Howe for their assistance.
I especially would like to thank Dr. Douglas Shore, my dissertation supervisor. Through Dr. Shore, I learned to appreciate the rich relationship between cognitive theory and clinical research. Furthermore, his interest in memory kindled my own interest in this field of study. There was never a moment during this research that he failed to support my efforts, all the while ensuring that I did not lose track of the final goal. I owe him a debt of gratitude, and thank him for serving as my supervisor.

Last but not least, I would like to acknowledge the tremendous support that I received from three very special people. First, my parents, Mike and Lorraine Harnadek, who were always supportive of my academic efforts. I love them dearly, and thank them for their sacrifices and encouragement. Finally, I owe a special debt of gratitude to Gloria Grace. She is my colleague, my counsellor, and my confidant. Most importantly, though, she is my friend. Her contributions were many, and I would never have successfully completed this dissertation without her.
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CHAPTER I

INTRODUCTION

Experimental research on normal human memory has a long history, dating back to the late 19th century empirical investigations of Ebbinghaus (Schacter & Tulving, 1982). By comparison, systematic clinical research into memory pathology has emerged within the scientific arena only during the latter half of this century. While important contributions to understanding memory impairment have been realized through the careful observations of late 19th century clinicians, such as Korsakoff (Kolb & Wishaw, 1985; Tulving, 1987), these early investigations were mainly limited to descriptive studies of small groups of patients, or presentations of single cases (Schacter & Tulving, 1982), and did not resemble the controlled, systematic neuropsychological studies that later developed.

Clinical neuropsychologists study memory by examining the brain functions that underlie this behaviour. Interest in memory function by neuropsychologists has broadened our understanding of the neuroanatomical systems that mediate these abilities and the diseases or disorders that can
impair learning and retention. Memory dysfunction has been observed following lesions of neuroanatomical structures located within the temporal lobes (e.g., hippocampus and amygdala), the diencephalon (e.g., mamillary bodies, medial thalamus, fornix, and nucleus basalis of Meynert), and the basal forebrain region (Dusoir, Kapur, Byrnes, McKinstry, & Hoare, 1990; Heilman & Sypert, 1977; L'Hermite & Signoret, 1976; Milner, 1972; Mishkin & Appenzeller, 1987; Squire, 1981). In addition, frontal (Milner & Petrides, 1984; Milner, Petrides, & Smith, 1985; Wirsén & Ingvar, 1991) or temporal-parietal cortical damage (Ojemann & Dodrill, 1985; Warrington, Logue, & Pratt, 1971) has been implicated in memory dysfunction.

A variety of neuropathological conditions have been found to impair memory, including: cerebrovascular disorders, infectious diseases, epilepsy, head trauma, substance abuse, anoxia, systemic diseases (e.g., hepatic, pulmonary, or renal disease), and dementia (Goldberg & Bilder, 1986; Hart & Kreutzer, 1988; Prigatano & Levin, 1988; Squire, 1986; Tarter, Edwards, & Van Thiel, 1988). Disturbed memory function has not only been found to be a concomitant feature of central nervous system disease or damage, but can also be symptomatic of mood and anxiety disorders as well as more severe forms of psychopathology (McAllister, 1981; Squire, 1986).
An important result of clinical research has been the discovery that memory functioning appears to be lateralized within the cerebral hemispheres according to material-specific dimensions (Kimura, 1963; Milner, 1966; 1972; 1978; Patten, 1972). Unilateral damage of memory systems residing within the dominant hemisphere (i.e., the hemisphere that is primarily involved in the processing of verbal and psycholinguistic material) results in the impaired ability to learn and retain mainly verbal types of information. Similar lesions confined to the nondominant hemisphere affect primarily those memory systems that mediate the acquisition and retention of nonverbal and spatial information. Some researchers, however, have questioned the strength of the relationship between nonverbal memory deficits and nondominant temporal lobe lesions (e.g., Chelune, 1991; Lee, Loring, & Thompson, 1989).

Through the examination and study of memory dysfunction in patients, neuropsychologists endeavor to disclose new findings and knowledge about memory function. Implicit in any attempt to understand an impaired ability is an appreciation of how the normal ability operates (Tulving, 1987). Consequently, neuropsychological researchers have generally looked towards the study of normal human memory for their theories, interpretive models, and experimental procedures. In return, the systematic neuropsychological
study of impaired memory processes provides an additional source of knowledge that can be employed in determining the processes involved in normal memory function (Baddeley, 1986; Tulving, 1987). This confluence of knowledge and theory between the cognitive study of normal memory and neuropsychological interest in impaired memory has resulted in a partial integration of cognitive theory into neuropsychology (e.g., Levin, 1986; Schacter, 1989).

A recent development among neuropsychologists has been the abandonment of unitary theories of long-term memory in favour of conceptual frameworks that hypothesize multiple systems (e.g., Squire, 1987; Tulving, 1985; 1987; Weiskrantz, 1987; see also McKoon, Ratcliff, & Dell, 1986 for an opposing view). That is, distinct systems of learning and retaining information have been proposed, that differ not only in the manner in which they are involved in a person's interaction with the environment, but also in the properties that underlie their operation (Tulving, 1987).

The fragmentation of memory into component systems is not entirely novel. Neuropsychologists have long realized a functional dissociation between short-term and long-term memory processes following the emergence of a double dissociation between patients who are impaired in the formation of new, permanent memories, but who evidence normal short-term retention of material (e.g., Baddeley &
Warrington, 1970; Milner, 1966; 1972; Squire, 1982; 1987), and others who perform poorly on tests of short-term retention despite essentially unimpaired long-term memory function (e.g., Shallice & Warrington, 1970; Warrington, Logue, & Pratt, 1971; Warrington & Shallice, 1969). Patients who conform to the former description, were found to have lesions affecting mesial-temporal and diecephalic neuroanatomical structures (Milner, 1966; 1972; Squire, 1982; 1987) while those fitting the latter depiction showed evidence of parietal-occipital cortical damage (Warrington et al., 1971).

Considering long-term memory, the conscious (i.e., requiring directed attention) learning and recollection of information, often referred to as declarative (Squire, 1987) or explicit (Schacter, 1987) memory, is frequently regarded as separate from learning that occurs outside of conscious awareness. This latter form of learning, often denoted as procedural (Squire, 1987; Tulving, 1985) or implicit (Schacter, 1987) learning, proceeds without the requirement of conscious attention (Tulving, 1987). Yet evidence that it has occurred is readily apparent from the facilitation in task performance that results from previous exposure. Examples of procedural learning include skill acquisition, priming effects on certain learning tasks, and the development of stimulus-response type associations (Tulving,
Perhaps the memory classification scheme most widely accepted among neuropsychological researchers has been Tulving's (1983; 1985; 1987) distinction between procedural, episodic and semantic memory systems. Procedural memory has been largely described above, but it should be added that within this system, learning occurs slowly. The episodic system permits one to recollect specific personal past events, and is therefore dependent upon temporal or spatial cues, or both, for retrieval. Semantic memory, on the other hand, is totally independent of contextual cues, and reflects general knowledge of the world (Tulving, 1983). Patients' recall of general facts, vocabulary and the names of familiar objects are examples of tasks that are dependent upon semantic memory. Tulving proposed that these memory systems are functionally independent, but correlated with each other. In addition, he has hypothesized that the three systems share a phylogenetic relationship, with procedural emerging first and episodic appearing last during evolution; furthermore, this order is recapituated ontogenetically during human development (Tulving, 1987).

The relevance of Tulving's classification scheme to the neuropsychological study of memory is apparent from the neuropsychological literature. Evidence is accumulating that some systems of learning are spared in cases of
amnesia. Initial findings of spared memory in amnesia were reported for the famous patient, H.M., who had become densely amnesic following bilateral hippocampal surgery (Kolb & Wishaw, 1985; Milner, 1966; 1972). Despite his virtual inability to acquire and retain new information, H.M. is competent at tasks requiring new skill acquisition, such as mirror drawing (Kolb & Wishaw, 1985; Milner, 1966). As characterized here, the memory difficulties of H.M. appear to be constrained to episodic learning, with procedural memory spared.

In recent years, some clinical investigators have suggested that impairments in acquiring and learning new information represent a selective deficit of episodic memory (Kinsbourne & Wood, 1987). Although not all researchers affiliate themselves with this theory (e.g., Zola-Morgan, Cohen, & Squire, 1983), the trend towards fractionating anterograde memory into multiple forms suggests that neuropsychologists may have to refine their notion of amnesia in order to better diagnose and discriminate between different patient populations.

As an example of how Tulving's classification has been incorporated within clinical research, consider several studies that have compared the memory deficits associated with Huntington's and Alzheimer's dementias. The memory impairment for both groups look remarkably similar when
unitary measures, such as memory quotients, are compared (Butters, 1984). Nonetheless, the two patient groups are readily distinguishable when storage and retrieval are assessed within the contexts of episodic and semantic memory performance. A general retrieval defect, affecting episodic and semantic information, has been shown to underlie the memory difficulties of Huntington's dementia (Cummings & Benson, 1992; Butters, Granholm, Salmon, Grant, & Wolfe, 1987; Butters, Salmon, Heindel, & Granholm, 1989; Hodges, Salmon, & Butters, 1990). Acquisition is thought to rarely be affected to the extent that retrieval is impaired, but the results of several studies have suggested that inefficient acquisition may also play a role in the memory impairment in Huntington's dementia, particularly in the latter stages of the disease (Caine, Ebert, & Weingartner, 1977; Polstein, Brandt, & Polstein, 1990; Wilson, Como, Garron, Klawans, Barr, & Klawans, 1987). A much different clinical picture has been reported for cases of Alzheimer's dementia. Poor recall, which reflected severely impaired storage of episodic material, and disorganization in the structure of semantic knowledge was reported (Cummings & Benson, 1992; Butters, Granholm, et al., 1987). With progression, patients with Alzheimer's dementia eventually develop impaired retrieval, in addition to their acquisition deficits (Moss & Albert, 1988).
The remainder of this section will focus upon episodic memory, particularly upon the evaluation of acquisition and retrieval functioning on episodic learning tasks. An approach that is commonly used in clinical research will be discussed. Following this, an alternative assessment procedure for episodic memory will be proposed. The final part of the introduction will outline a study to investigate the validity and utility of the proposed procedure.

Assessment of Acquisition and Retrieval in Episodic Memory

In its simplest form, episodic learning can be thought of as the acquisition of an item-to-be-remembered, that is coded in terms of a spatial or temporal tag, and which is later retrieved. Remembering, therefore, is described as the occurrence of two sequential events, acquisition followed by retrieval. These two memory processes are unobservable to the researcher who must instead infer their involvement from test performance. A common procedure for making such inferences is to employ an assessment method that will be labelled the "different-task comparison" procedure. This approach will be described, followed by the presentation of a recently developed alternative procedure.

Different-task comparison approach.

Assessment procedures that correspond to the different-task comparison approach utilize two memory tasks that are presumed to make equal demands upon acquisition while
requiring either lesser or greater involvement of retrieval functioning. By comparing performance on the two tasks, the effect of the additional retrieval demands upon memory performance can be observed. Often, free recall and recognition learning\(^1\) tests are used for comparison, with recognition performance presumed to be only minimally dependent upon retrieval efficiency (Buschke, 1984; Lezak, 1983). A fundamental assumption in the different-task approach is that if poor memory is the result of deficient acquisition then additional prompting, through recognition testing or cuing, will not facilitate the retrieval of these "lost" memories (Squire, 1980). Free recall and recognition both require that information be initially acquired, and when different learning lists are utilized, the tests are implicitly assumed to be equivalent in acquisition difficulty. The two methods differ in that free recall, unlike recognition, is also largely determined by, and is considered a measure of, retrieval efficiency. Poor free recall and adequate recognition suggests that a retrieval deficit may exist, while poor free recall and recognition tests implies that acquisition is impaired.

The use of the different-task comparison approach to evaluate acquisition and retrieval function may appeal to

\(^1\) Cued-recall has also been assumed to make fewer demands upon retrieval function than free recall (Buschke, 1984; Squire, 1980).
researchers who value its direct methodology and utilization of familiar testing methods. Unfortunately, several shortcomings are associated with this paradigm, and these can have a detrimental effect upon the accuracy with which acquisition and retrieval are interpreted.

Squire (1980) described a logical flaw in the assumption that poor recall and better recollection through recognition testing reflects a retrieval deficit. Any impairment in acquisition will necessarily make retrieval more difficult. In addition, Squire commented:

Partial improvement after prompting could be interpreted either as evidence for the reduction of a retrieval defect or as evidence for incompletely stored information that provides an insufficient basis for recall but a sufficient basis for some recognition. Thus...in this context storage and retrieval defects are difficult to distinguish in an unambiguous way (p. 369).

The different-task comparison procedure assumes that conditions of learning prior to recollection are constant for free recall and recognition tasks. However, retrieval of learned information has been found to be dependent upon the reconstruction of the context that existed at the time of acquisition (Tulving, 1985). Thus, if different cognitive strategies are employed during acquisition on the
two memory tasks, then the assumption of constant conditions prior to recollection would not be valid (Smith, 1980). In this case, different patterns of performance on the free recall and recognition tasks may reflect the initial differences in acquisition strategy, and not differences in retrieval performance (Smith, 1980).

A further difficulty of the different-task comparison approach is that it does not permit an adequate investigation of both memory processes under all possible patterns of performance. For example, a finding that recognition and free recall are both deficient, which would be interpreted as consistent with an acquisition deficit, relates little information about the adequacy of retrieval functioning. Clearly, what is needed is an interpretive approach that permits an independent appraisal of both memory processes.

An additional obstacle to interpretation results from the need to utilize more than one test measure. A failure to equate tests for reliability can result in a faulty appraisal of memory functioning since the less reliable task will be less sensitive to group differences than the more reliable task (Knight & Woolfes, 1980). In addition, failing to control for task difficulty can lead to ceiling and floor effects at the time of testing. Furthermore, memory performance is known to be dependent upon attention,
cognitive strategy, and related processing skills (Buschke, 1984). To the extent that a more difficult memory test introduces greater demands for these associated skills than does an easier test, performance discrepancies may be accentuated beyond mere differences in memory ability.

The different-task comparison procedure can further be criticized for its absence of explicit scaling rules for the tests involved. Scaling rules are the quantitative definitions of how two or more theoretical constructs, in this case acquisition and retrieval, relate to one or more observable facts, such as a memory test score (Brainerd, 1985b; Howe, 1988). Two relationships are described by scaling rules. One relationship outlines the manner in which trace "strength" (or memorability) improves with the adequacy of acquisition and with ease of retrieval. This relationship essentially maps changes in acquisition and retrieval to memory potential. The second description elucidates the relationship between memory potential and performance on the memory test being used. This function maps trace strength onto actual test data. Algorithms that describe these two relationships comprise the scaling rules. Evaluation of the scaling rules for a procedure may provide findings that suggest an alternative relationship between acquisition and retrieval. The important consideration, however, is that the rules are explicit and open to
falsification.

The different-task comparison paradigm does not provide descriptions of these two relationships. The most that can be assumed using this approach is that acquisition and retrieval share a simple monotonic relationship with test performance. That is, increases in either process will result in a better score on the two memory tasks employed (Brainerd, 1985b; Howe, 1988). Whether the tests utilized in the different-task comparison approach actually conform to this assumption is speculative.

Brainerd and colleagues (Brainerd, 1985a; Brainerd, Howe, & Desrochers, 1982; Brainerd, Howe, & Kingma, 1982) have developed an alternative assessment paradigm, suitable for use with episodic memory tasks, that remedies several of the criticisms mentioned above. A synopsis of the procedure, and the model on which it is based, will be described below.

Model-based procedure.

Researchers have observed that many types of anterograde learning tasks are well described as a two-stage process: the formation of a memory trace followed by learning to retrieve the trace in a reliable fashion (Bower, 1967; Brainerd, 1985b; Brainerd, Howe, & Desrochers, 1982; Brainerd, Howe, & Kingma, 1982; Greeno, 1968; Halff, 1977). The assessment paradigm developed by Brainerd and colleagues is based upon a mathematical model of two-stage learning
that was developed by Greeno (1968). Because this assessment approach is founded upon a particular model, it will be referred to herein as the model-based procedure. The model-based procedure may be distinguished from information processing characterizations of memory by its focus upon the pattern of test performance that occurs on learning tasks rather than the cognitive processes hypothesized to be involved.

An explanation of the model-based procedure begins with the definition of two patterns of responses that can occur when, over repeated test trials, a subject learns an item (e.g., word, sentence, visual design) to a criterion. The subject may learn the item immediately and will produce only the criterion series of correct responses. Alternatively, the subject may require several trials to learn the item, and a sequence of inconsistent error and correct responses, culminating in the criterion series, results. These patterns of learning performance describe three states in which the item being memorized can reside at the beginning of any learning trial: an initial, unmemorized, state where only errors occur \( (U) \); an intermediate, partially-learned, state where both errors and correct responses occur \( (P) \); and a final memorized state where only correct responses occur \( (M; \text{Brainerd, 1985a; Greeno, 1968}) \). By definition, an item that is unmemorized cannot be correctly remembered (i.e.,
probability of recall is zero). A partially-learned item will be recalled inconsistently, with a probability that is greater than zero but less than one. Memorized items, however, are always perfectly recalled (i.e., probability equals one). Memorization can then be described as a two-stage process with the first stage involving storage and the second stage focusing upon retrieval. The model defines the events that can occur during each of these two steps and the conditional probability of their occurrence (Greeno, 1968; Howe, 1990). Appendix A contains a mathematical representation of the two-stage model that has been developed for use with certain fixed-trial learning tasks that will be described below (Brainerd, 1985a; Howe, 1990).

The two stages described by the model have been described as the acquisition of an item into memory, followed by learning a specific function that ensures accurate retrieval (Brainerd, 1985b; Greeno, 1968; Halff, 1977; Howe, 1988; 1990). During acquisition, a permanent memory trace is formed that corresponds to the material being memorized (Howe, 1990). Retrieval of the acquired item is governed by general and specific methods (Halff, 1977). The general method functions independent of what is to be remembered. This process is always available to the rememberer, and is characterized by its inconsistent accuracy. Learning a specific retrieval function to assist the recollection of
the particular item that was acquired comprises the second stage of remembering (Brainerd, 1985b; Halff, 1977). A retrieval function is thought to be any set of procedures that ensures the accurate and efficient recollection of a stored item (Brainerd, 1985b). Learning this specific retrieval function requires time, and retrieval is governed by the general method in the interim (Halff, 1977).

This two stage conceptualization of memory is consistent with observations of certain remembering phenomena as well as with current theories of memory function. Bower (1967) observed that people who experience the "tip-of-the-tongue" phenomena (Brown & McNeill, 1966) are able to recall certain information related to the word, such as the initial letter, or a suitable synonym. Bower considered this ability to be a demonstration that a representation of the word has been stored in these cases. That the word had not been forgotten is demonstrated by its correct retrieval at a later time. Bower described the imperfect recall that characterizes the "tip-of-the-tongue" event as the outcome of having not available a retrieval function for a word that had been stored in memory. In contrast, a ready example of an item that is likely to be associated with a retrieval function is one's birthdate. Such an item is accurately and consistently recalled under all but the most extraordinary circumstances.
Tulving (Tulving, 1985) has theorized that efficient recollection involves the interaction between the manner in which a trace was formed and the information that is available at the time of retrieval. He suggested that a necessary condition for retrieval is the presence of a cue that initiates the retrieval process and partly determines the accuracy of the recollection (Tulving, 1985). Even though Tulving's conceptualization of retrieval influences is more complicated than the single event put forth by the two-stage model, both descriptions speculate that efficient recollection involves the interaction of independent, but related, storage and retrieval processes.

Eleven parameters, that bear a meaningful relationship to acquisition and retrieval, are included within the two-stage model. A theoretical interpretation of each of the 11 parameters is provided in Appendix B, and a brief description is given below. Two parameters estimate acquisition learning: $a'$, the probability of acquiring an item on the first trial; and $a$, the probability of acquisition on later trials. One parameter measure, $1-f$, represents the probability of retaining an item between trials (i.e., short-term retention). Eight additional parameters estimate either algorithmic or heuristic retrieval performance. Algorithmic retrieval is a descriptive term used to denote the specific retrieval
function that produces errorless retrieval. Parameters $b'$ and $b$ measure the likelihood that a retrieval function is available for those traces acquired on the first and later trials, respectively. Parameters $c$ and $d$ provide a comparison of whether learning a retrieval function is more likely to occur following a successful or incorrect recall attempt, respectively. As mentioned earlier, the final memorized state ($M$) is characterized by algorithmic, or errorless, retrieval (Howe, 1988). In the intermediate memory state, remembering is governed by heuristic retrieval (i.e., the general retrieval method) and recall performance is inconsistent (Howe, 1988). The parameters $1-r$, $1-e$, $g$, and $h$ measure the difficulty of retrieval before a reliable retrieval function has been acquired. Two of these parameters measure the ease of retrieval performance for traces that are acquired on the first ($1-r$) and later ($1-e$) trials. Whether performance benefits when preceded by a correct ($h$) or incorrect ($g$) recall attempt is provided by the remaining two parameters.

Several assumptions are inherent within the model-based procedure, and the two-stage mathematical model upon which it is predicated. First, items are presumed to be unmemorized initially. Second, acquisition of an item and learning a retrieval function are events that are thought to
occur in an all-or-none fashion. This assumption seems reasonable given the failure of past research to support the hypothesis that partial memorization occurs over trials (e.g., Bower, 1961). Third, acquisition and retrieval learning can occur only during learning trials. Recall trials merely provide the examiner with information regarding the current state of memorization of an item (Greene, 1968). Finally, acquisition and retrieval are considered to be independent functions, but which unfold in the sequential order described above.

In order to interpret learning performance using the model-based procedure, episodic memory tests must conform to one of the two paradigms outlined in Brainerd (1985a) and Howe (1990). One paradigm requires that all subjects complete a multiple trial learning task to a criterion of performance (e.g., two consecutive correct trials). The alternative, fixed-trials, paradigm requires that subjects only complete four test trials (Brainerd, 1985a). In the fixed-trials procedure the learning task is designed so that four discrete recall trials (R) follow learning trials (L) in the following manner: \( L_1 R_{1a} R_{1b} L_2 R_2 L_3 R_3 \). Note that after the first recall trial (\( R_{1a} \)) a second recall trial (\( R_{1b} \)) occurs following a short period of distraction.

The inclusion of a second recall trial after the initial learning trial ensures sufficient degrees of freedom to
render the model identifiable. Models may be considered to be identifiable if "there is only one possible value of each [model] parameter that is consistent with the data. In other words, the data of an experiment will deliver a unique estimate of each...[model] parameter" (Brainerd, Howe, & Desrochers, 1982; p. 641). When the number of available model parameters exceeds the degrees of freedom inherent within the data then the exact relationship between the data and the model parameters becomes unclear. This situation is avoided with the fixed-trials procedure; the model provided in Appendix A was proven to be fully identifiable for this design (Brainerd, Howe, & Kingma, 1982).

There are several characteristics of the model-based procedure, when used with the fixed-trials paradigm, that make this assessment technique well-suited for evaluating episodic memory. An important feature of the procedure is that many conventional learning tasks can be readily adapted for use with the model, including paired-associate learning, free-recall, recognition, and selective reminding tasks. Important for quantitative comparison between groups, the model parameters share a common ratio scale of measurement (Brainerd, 1985b). Russell (1986) has advocated for the introduction of neuropsychological tests that are based upon interval or ratio scales of measurement because of their increased accuracy of measurement, and their greater
isomorphism with the nature of cortical functions. Three additional reasons favour the use of the procedure under question. Only four recall trials are needed to be completed in order to estimate the parameters. Other clinical researchers (e.g., Kraemer, Peabody, Tinklenberg, & Yesavage, 1983) have commented on the need to minimize trials when assessing very impaired patients if floor effects are to be avoided, and to limit the amount of testing a sick or elderly patient is subjected to. Also, the confounding effects that may result from the use of multiple tests (e.g., noncomparable levels of reliability and task difficulty, differences in test stimuli, normative studies conducted on different samples) are avoided. Finally, goodness-of-fit tests exist that examine the model's adequacy for describing the data.

The model-based procedure has been employed in only one clinical study (Howe, 1990). Nevertheless, this technique has been utilized in several developmental studies of memory in normal and learning-disabled children (Brainerd, Kingma, & Howe, 1986; Howe, O'Sullivan, Brainerd, & Kingma, 1989); younger and older children (Brainerd, Howe, Kingma, & Brainerd, 1984); and younger and older adults (Brainerd, Howe, & Kingma, 1982; Howe & Hunter, 1985; 1986).

Howe (1990) conducted a pilot study to determine whether the fixed-trial procedure could differentiate between
storage and retrieval functioning for normal elderly, depressed elderly, and Alzheimer's-type dementia patients. Each subject completed a free-recall and cued-recall task involving two different 16-item lists\(^2\). Analyses revealed that the normal elderly group was superior to the two clinical samples on acquisition and algorithmic retrieval performance, the differences being less between the normal elderly and depressed groups than the elderly and dementia groups. In addition, the dementia subjects were less able than the depressed subjects to use errors to facilitate their retrieval performance.

The second purpose of the Howe (1990) study was to determine if the fixed-trials model could be useful in describing within-group changes in memory function over time. Normal elderly subjects were administered alternate forms of a 16 word list-learning task, consisting of semantically related and unrelated words, on two occasions, eight to twelve months apart. Storage was found to have declined over time. Algorithmic retrieval was worse at the second assessment only for the semantically unrelated words. Finally, a significant interaction between the semantic relatedness of the words, and the time of testing, was

\(^2\) The study involved manipulation of different test conditions. However, all the data was combined in order to ensure a sufficient number of subjects (N=18) to permit evaluation of the model.
observed (Howe, 1990). The results of the Howe (1990) study suggested that the fixed-trials procedure may be potentially useful in clinical investigations of episodic learning.

Brainerd (1985b) had reviewed two types of construct validity evidence in favour of the two-stage model's parameters. The first line of evidence consisted of demonstrating that the model parameters react independently to experimental manipulation of the conditions under which learning occurs. For example, Humphreys and Greeno (1970), using a paired-associate learning paradigm, examined the effect upon storage and retrieval by varying the number of common elements between pairs, and response difficulty. Similarity between items was found to have an adverse effect on acquisition and retrieval estimates, whereas response difficulty only affected retrieval. Brainerd (1985b) cites an additional study in which a picture-word manipulation was employed on a paired-associate learning task with children. The manipulation affected children's retrieval of the targets, but had little effect upon storage parameters.

The second line of validity evidence consisted of demonstrating that the acquisition and retrieval parameters do respond to manipulations that should affect these processes. Brainerd (1985b) again cited the study by Humphreys and Greeno, mentioned above, as an example. Brainerd (1985b) expressed the expectations that the
similarity between target and cues would have a detrimental effect upon both storage and retrieval, but that varying the response difficulty by manipulating the ease with which responses could be pronounced, would only have an effect upon the retrieval parameters. These were the general finding of Humphreys and Greeno (1970).

**Purpose of study.**

Prior to recommending the model-based procedure paradigm for clinical research purposes, an evaluation of the appropriateness and meaningfulness of the inferences that can be drawn from the model parameters is necessary. One manner of accomplishing this evaluation is to examine the construct validity of the measures by comparing the parameter estimates for groups known to differ on acquisition or retrieval functioning against hypotheses regarding their expected performance (Cronbach & Meehl, 1955). As mentioned above, there has not been adequate investigation of the sensitivity of the model parameters to specific impairments of acquisition or retrieval. This remains true for the Howe (1990) study because, as the author appropriately suggests, Alzheimer's dementia patients frequently present with combined storage and retrieval deficits (Butters, Granholm, et al., 1987; Butters, Salmon, et al., 1989; Cummings & Benson, 1992; Hodges et al., 1990; Moss & Albert, 1988).
A body of literature exists that suggests that unilateral temporal lobe surgery patients, whose resection includes mesial-temporal structures (e.g., hippocampus, amygdala, hippocampal gyrus), are impaired in the formation of new stable traces (Frisk & Milner, 1990a; Milner, 1968; 1972; 1975; Weingartner, 1968; Winocur, 1984).

Although impaired acquisition is commonly referenced in the memory difficulties of temporal-lobe epilepsy patients, additional research findings suggest that retrieval difficulties may also exist (Halgren, Wilson, & Stapleton, 1985; Hermann, Wyler, Richey, & Rea, 1987; Martin, Loring, Meador, Lee, Thrash, & Arena, 1991; Mungas, Ehlers, Walton, & McCutchen, 1985). In each of these studies significant impairment of delayed recall was noted for patients with epilepsy lateralized to the dominant hemisphere. More interesting, however, was the absence of impairment in delayed recognition memory (Hermann et al., 1987; Martin et al., 1991) and delayed recall with semantic cueing (Mungas et al., 1985). These findings suggest that the learned verbal material was retained in memory, if not readily retrievable. It should also be noted that these findings in no way disconfirm the suggestion that acquisition of traces may be impaired. As suggested earlier, cuing may merely facilitate the access of poorly acquired traces (Hermann et al., 1987; Moscovitch, 1982; Squire, 1980).
The use of unilateral anterior temporal lobectomy patients serves an additional function by permitting a comparison to be made between the side of operation and the type of material affected by the memory disorder. Patients who have received a dominant unilateral temporal lobectomy demonstrate impaired memory for verbal information, including paired-word associates (Milner, 1972; 1975), semantically related (Weingartner, 1968) and unrelated words (Ribbler & Rausch, 1990; Weingartner, 1968), and short paragraphs (Frisk & Milner, 1990a; Milner, 1972; 1975; Ojemann & Dodrill, 1985). There is little consequence of dominant temporal lobe resection upon remembering nonverbal material (Milner, 1972; 1975). In contrast, patients who have received a nondominant unilateral temporal lobectomy are impaired in learning nonverbal information, including complex drawings and visuospatial block arrays, with a general sparing of verbal memory ability (Kimura, 1963; Milner, 1972; 1975). Although a double dissociation between verbal and nonverbal memory deficits and side of temporal lesion has generally been found, several authors (e.g., Chelune, 1991; Lee et al., 1989) have observed that the literature is less consistent in supporting a nonverbal memory deficit in cases of nondominant temporal lobe lesions. The lesser consistency in the research has been attributed to the lesser sensitivity and specificity of
nonverbal memory tests to nondominant temporal lobe
dysfunction (Lee et al., 1989; Loring, Lee, Martin, &

The present study is designed to evaluate the construct
validity of the acquisition parameters provided by the
model-based procedure by administering the fixed-trials
version to patients who have undergone a unilateral anterior
temporal lobectomy for the treatment of intractible
epilepsy, and non-clinical control subjects. As reviewed
above, previous research has suggested that a double
dissociation exists between the side of lesion and the
material-specific nature of patients' memory difficulties
(Frisk & Milner, 1990a; Hermann et al., 1987; Ivnik,
Sharbrough, & Laws, 1988; Kimura, 1963; Milner, 1972; 1975;
Novelly, Augustine, Mattson, Glaser, Williamson, Spencer et
al., 1984; Ojemann & Dodrill, 1985). Dominant temporal lobe
lesions result in impaired verbal learning and memory.
Epileptogenic lesions in the nondominant temporal lobe
impair memory for visual material. These hemisphere-
specific impairments are exacerbated following unilateral
temporal lobectomy.

Based on these findings, and through the employment of
verbal and nonverbal memory tests that conform to the
requirments of the fixed-trials procedure, some a priori
major and minor hypotheses can be stated:
(A) Major hypotheses:

1. On the verbal test, left temporal lobectomy patients are expected to yield significantly lower estimates of acquisition \((a', a)\) than either right temporal lobectomy or control subjects.

2. Right temporal lobectomy patients' acquisition of nonverbal material \((a', a)\) should be less than the same estimates for left temporal lobectomy or control subjects.

3. Both temporal lobectomy groups should yield comparable estimates for short-term retention \((1-f)\), retrieval learning \((b', b, c, d)\), and retrieval performance \((1-r, 1-e, g, h)\), but these estimates are expected to be less than those for the control subjects.

(B) Minor hypotheses:

4. The verbal acquisition estimates for the left temporal lobectomy patients should be less than their retrieval learning estimates.

5. The right temporal lobectomy patients' acquisition estimates for nonverbal material should be lower than their retrieval learning estimates.

Comparing the temporal lobectomy and control groups' actual patterns of performance against the above hypotheses will provide an initial evaluation of the construct validity of the acquisition parameters associated with this assessment approach.

A shortcoming in utilizing epilepsy patients in memory research is the limitation that is placed upon the generalizability of the results. By definition, the presence of an epileptogenic lesion distinguishes these patients' central nervous systems from those in the normal
population (Kolb & Wishaw, 1985). A history of epilepsy, particularly if it began in early childhood, may have resulted in some alteration in the representation or organization of cortical activity (Mendius & Engel, 1985; Rausch & Walsh, 1984). Furthermore, the presence of neuropsychological deficits in addition to impaired memory can exist for patients with epilepsy (Rausch, 1985; Trimble, 1987; Trimble & Thompson, 1986). The use of epilepsy patients also introduces an additional source of variance in the form of possible medication effects. Anti-convulsant medication is known to have a detrimental effect upon attention, concentration and memory (Bennett, 1992; Dodrill, 1988; Trimble, 1987). Reduced cognitive efficiency, due to the effects of anti-convulsant medication, can reasonably be expected to distinguish epilepsy patients who are receiving medication from other clinical samples and the nonclinical population.
CHAPTER II

METHOD

Subjects

Study participants were 60 unpaid volunteers whose native language is English. Forty subjects were patients who had received a unilateral temporal lobectomy for the treatment of intractible epilepsy. These subjects were assigned to either a left (LT; n = 20) or right (RT; n = 20) temporal lobectomy group, depending on the site of their surgery. Twenty additional, non-clinical, participants served as the control group (NC).

The epilepsy subjects were chosen from among those patients who attended outpatient neurology or neuropsychology clinics for routine post-operative follow-up. The clinics were located at University Hospital (London, Ontario) which is a regional tertiary care hospital that includes a specialized epilepsy investigation and treatment center.

Temporal lobectomy patients were included in the study if they were free of additional neurological history (e.g., head trauma); exhibited no evidence of clinical depression; were left cerebral hemisphere dominant for speech, and
demonstrated adequate intellectual and language ability. Specific operational definitions of these criteria are presented in Table 1. Appendix C provides, for each temporal lobectomy subject, the extent of the surgical resection that was performed and what anticonvulsant medications the patient was receiving at the time of testing.

The NC subjects were solicited from among the relatives of the patients, other visitors to the hospital, and university undergraduate students. Subjects were included within the NC group if they did not have a history of a neurological or psychiatric disorder, did not exhibit signs of clinical depression, and demonstrated adequate levels of psychometric intelligence and language ability. Table 2 provides the operational definitions of the criteria used to select the NC subjects.

Selection of NC subjects was also limited to right-handed individuals in order to reduce the likelihood of including persons with atypical lateralization of speech representation. Rasmussen and Milner (1977) had studied the relationship between hand-preference and language lateralization in 262 epilepsy patients who had received bilateral sodium amobarbital tests. None of the patients evidenced early damage to the left-hemisphere. The authors
<table>
<thead>
<tr>
<th>Criteria</th>
<th>Operational Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absence of additional neurological history</td>
<td>No report of additional neurological disorders in the patient's medical chart, and negative evidence of additional pathology on pre-surgical diagnostic imaging (MRI, CT), EEG examination, or neurologic testing.</td>
</tr>
<tr>
<td>Absence of clinical depression or other psychiatric disorder</td>
<td>No current reports of clinical depression or other psychiatric disorder in the patient's medical chart. In addition, the patient's score on the Beck Depression Inventory is 15 or less.</td>
</tr>
<tr>
<td>Left cerebral hemisphere dominance for language</td>
<td>Pre-operative findings of: a right visual field advantage for letters presented tachistoscopically and a right ear advantage on dichotic listening; or dysphasia following left, but not right, intracarotid injection of sodium amobarbital (Wada procedure).</td>
</tr>
<tr>
<td>Adequate intellectual and language ability</td>
<td>WAIS-R Verbal and Performance IQ scores equal to, or greater than, 80.</td>
</tr>
</tbody>
</table>
Table 2
Inclusion Criteria for Control Subjects

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Operational Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absence of either a neurological or psychiatric history</td>
<td>As indicated by the patient's negative reported history,</td>
</tr>
<tr>
<td>Absence of clinical depression</td>
<td>The subject does not report depressive symptomatology when interviewed. In addition, the subject's score on the Beck Depression Inventory is 15 or less,</td>
</tr>
<tr>
<td>Adequate intellectual and language ability</td>
<td>WAIS-R Verbal and Performance IQ scores greater than, or equal to, 80.</td>
</tr>
</tbody>
</table>

reported that the left cerebral hemisphere was dominant for speech representation in 96 percent of the right-handed sample, as inferred from aphasia following left—but not right—intracarotid injection of sodium amobarbital. The low frequency of right-handers that exhibited atypical speech lateralization (4 percent) was considered to be an over-estimate of the actual prevalence in the non-clinical population (Kolb & Wishaw, 1985; Rasmussen & Milner, 1977) and suggests that this was an unlikely event in the NC group.
To avoid confounding effects due to group differences in age, education level, or gender (Albert, 1988; Ruff, Light, & Quayhagen, 1989; Smith, 1980) the RLT, LTL, and NC groups were matched on these variables.

**Test Materials**

As part of the selection procedure, each subject completed the Beck Depression Inventory (BDI), a 21-item instrument designed to assess the severity of depression in adults (Beck & Steer, 1987). Each item on the BDI consists of four descriptions of symptoms and attitudes: a non-symptomatic statement (e.g., "I do not feel sad"), and three symptomatic statements ordered in terms of severity (e.g. "I feel sad", "I am sad all the time and I can't snap out of it", and "I am so sad or unhappy that I can't stand it"). The subject is required to select one statement from within each group that best describes their general mood over the past week. The test authors (Beck & Steer, 1987) have suggested that a BDI score of 15 or less is a suitable cut-off for selecting non-depressed individuals from a general non-psychiatric sample.

The Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981) was employed to evaluate subjects' current level of psychometric intellectual ability. The control subjects were administered the WAIS-R as one of the pre-selection measures. All of the epilepsy patients
received WAIS-R evaluations as part of their pre-surgical neuropsychological assessment, and most had been re-assessed post-surgically. When available, post-surgical WAIS-R results were used in the patient selection process as these were considered to be a more accurate estimate of the patients' current level of cognitive ability. For patients who had not yet been re-assessed, their pre-operative scores were utilized. Previous research suggests that pre-operative intellectual scores would serve as a more conservative measure of an epilepsy patient's post-surgical intellectual level (Blakemore & Falconer, 1967; Chelune, 1991; Ivnik et al., 1988; Lieb, Rausch, Engel, Brown, & Crandall, 1982; Milner, 1975; Novelly et al., 1984).

Pre-operative WAIS-R scores were used for 15 patients: nine from the RTL group and six from the LTL group.

Two memory tests were employed to test the study hypotheses. The selection of the two study tests was based largely upon whether they could be adapted for use with the model-based assessment procedure. This was easily accomplished for the verbal test because similar list-learning tasks had already been successfully used with this procedure. Unfortunately, few tests of nonverbal memory exist that are adaptable to the new procedure. An existing children's nonverbal memory test, that required the learning of dot sequences, was selected and modified for use in the
present study. Each test is described below.

The assessment of verbal episodic memory performance was conducted using a list-learning test developed by Shore (1979). The sensitivity of verbal list-learning tasks in detecting verbal memory deficits in epilepsy patients with unilateral dominant hemisphere lesions has been demonstrated in previous studies (Hermann et al., 1987; Jónsdóttir & Rettig, 1990; Lee et al. 1989; Loring et al., 1991; Ribbler & Rausch, 1990).

The verbal memory test consisted of 12 unrelated, high frequency words (AA; Thorndike & Lorge, 1944) that differed in terms of concreteness and imagery. The six more concrete and imageable words had the following ratings on a scale where 10 equals highly possessing of this trait and 0 equals none of this trait (means, standard deviations): imagery (6.53, ± 0.25), concreteness (6.84, ± 0.18), and meaningfulness (6.64, ± 1.30; Pavio, Yuille, & Madigan, 1968). The ratings of the six less concrete and imaginable words were: imagery (2.96, ± 0.35), concreteness (2.48, ± 0.65), and meaningfulness (5.89, ± 0.61; Pavio et al., 1968). A modification was made to the test prior to utilizing it as part of this study. In the original version (Shore, 1979), the words with higher ratings for

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3 The imagery and concreteness of the stimulus words were not experimental variables in the present study.
concreteness and imagery were presented first, followed by the six less concrete and imaginable words. For the present study, all 12 words were ordered in an alternating fashion for presentation. Appendix D contains a copy of the verbal test.

Assessment methods that utilize complex, difficult to verbalize stimuli (e.g., complex geometric designs, unfamiliar faces, nonsense figures) have proven the most successful for detecting nonverbal memory deficits in patients with nondominant hemisphere lesions (Kimura, 1963; Milner, 1968; 1972; Milner & Teuber, 1968). The nonverbal memory test stimuli, which consisted of random patterns of dots, were adapted from a children's visual selective reminding test developed by Fletcher (1985). These particular stimuli satisfied two important conditions: they could be used in a list-learning type of task, and verbal identification of the dot locations was judged to be difficult. The layout of the nonverbal stimuli consisted of a 14 inch (long) by 11 inch (wide) board upon which eight 2-3/4 inch squares were arranged in two columns of four. Within each square, five 1/2 inch black dots were arranged in a random pattern against a contrasting white background. Figure 1 contains an illustration of the nonverbal stimuli.

Two alterations distinguish the present stimuli from that used by Fletcher (1985). First, the board was presented to
Figure 1. Illustration of the Nonverbal Memory Test Stimuli.
subjects in a vertical position, as opposed to the horizontal position favoured by Fletcher. Second, the dots selected for presentation were chosen by the present author (quite independently of Fletcher's choices) to minimize their potential for verbal identification. To confirm that the dot locations could not be easily verbalized three neuropsychologists and three neuropsychometrists were asked to evaluate the stimuli for ease of verbal labelling. All reported that the use of verbal descriptors to identify the dots would be difficult to implement and would require considerable effort to remember.

Assessment Procedure

The verbal and nonverbal memory tests were administered in a counter-balanced manner to all subjects. For both tests, the general order of events was as follows. The stimulus items were presented to the subject who then attempted to recall the items. This was then followed by a brief period of distraction after which the subject again attempted to recall the list items. For the remaining two trials, the subject was selectively reminded of only those items not correctly recalled on the preceding recall attempt. Specific administration procedures are provided next for the verbal and nonverbal tests.
Administration of the verbal memory test.

At the beginning of the verbal test, each subject received the following instructions, "I have some words that I want you to try to remember. I am going to say the words, one at a time, and I want you to repeat each word, out loud, after I say it". The list of words was then presented, at the rate of one word every two seconds. The subject's repetition of the list was monitored to ensure that the correct words had been heard. Next, the subject was instructed, "Now tell me all of the words that you can remember, in any order."

During the free recall that ensued, any extra-list intrusions were documented and the subject was informed that the word was not part of the original list. On each recall trial, the examiner encouraged free recall to continue as long as the subject was providing words. The trial was discontinued if a 30 second period had elapsed without the subject responding and the subject had indicated that they could not recall additional words.

At the end of this first verbal recall trial, the subject was instructed, "Begin with the number 100 and count backwards by threes, out loud, like this: 100, 97, 94 and so on." This period of distraction continued for 24 seconds, after which the subject was again instructed to recall as many words as they could remember from the original list.
Beginning with the third presentation trial, the subject was told, "Here are the words that you did not recall on the last attempt." Those words were read to the subject, at the same rate as on the first trial, and the subject was then instructed, "Now recall all the words that you can remember in any order, including the words you had correctly recalled last time." These instructions were repeated for the final presentation and recall trial.

**Administration of the nonverbal memory test.**

Prior to beginning the nonverbal test, the board was positioned within the epilepsy patients' visual field ipsilateral to their side of operation\(^4\). The board was placed centrally for the control subjects. The procedures for administering the nonverbal test were similar to those used with the verbal test. Each subject received the following instructions, "On this board are eight squares. Each square has five dots in it. I am going to touch one dot in each square, one at a time. I want you to touch each dot after me. Remember the dots that I show you."

The stimulus dots were then presented at the rate of one every two seconds. Having the subject touch the dots ensured that he or she had correctly identified the stimulus dots.

\(^4\) Due to severing fibres in the lower portion of the optical radiation during surgery, it is a common consequence of temporal lobe resection that the patient experiences an homonymous upper quadrantopsia contralateral to the side of the operation.
item. If the subject touched an incorrect dot the correct dot was presented again for the subject to touch. Once all of the stimulus dots had been presented, the subject was told, "Now touch all the dots that you remember, in any order. After you touch each dot I will say 'NEXT' before you touch the next dot". The addition of a two second pause between the subject's responses reduced the likelihood that remembering from short-term store was involved.

If the subject requested, he or she was permitted to change a particular response choice. In a small number of cases, different dots were chosen in the same square during the same recall trial because the subject had forgotten that they had already made a selection. In this situation, the subject was informed that they had already made a choice in that square, and their new selection was disregarded.

Following the initial recall attempt, the subject was instructed, "Begin with the number 98 and count backwards by threes, out loud, like this: 98, 95, 92 and so on." This distractor task was continued for 24 seconds, and then the subject was told, "Now, again touch all the dots that you were shown, in any order. Just like before, after you touch each dot I will say 'NEXT' before you touch the next dot". Upon completion of the second recall attempt, the subject was instructed, "Here are the dots that you did not recall on the last attempt", and the correct dots were again
presented to the subject.

On the subsequent test trial, the subject was instructed to identify the original list of dots, in any order. Recall was followed by the examiner showing the subject the correct choices for those dots that were incorrectly recalled. The instructions used were the same as for the second recall trial. This procedure was repeated one more time on the final test trial.
CHAPTER III

RESULTS

Pre-test Group Differences

Table 3 lists the group means and standard deviations for age, education, and Verbal and Performance IQs. These dependent variables were submitted to separate univariate analysis of variance (ANOVA) with group membership serving as the independent variable. The results of these ANOVAs are presented in the bottom row of Table 3. No significant differences between groups were found for the age, education, and Performance IQ variables. A significant difference was found for the Verbal IQ variable $[F (2,57) = 7.081; p < .01]$. Pair-wise comparison of means, using the Scheffe test, revealed that the NC group had significantly greater Verbal IQ scores than either the LT group ($p < .01$) or the RT group ($p < .05$), but that the two temporal lobectomy groups did not differ significantly ($p > .05$).

Group distributions for gender and hand preference are presented in Table 4. Each group was compared for differences in the frequency of occurrence of males and females. The absence of significant chi-square comparison
Table 3

Group Demographics for Age, Education, and Intellectual Level

<table>
<thead>
<tr>
<th>Group</th>
<th>Age</th>
<th>Education</th>
<th>PIQ</th>
<th>VIQ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
</tr>
<tr>
<td>Right Temporal</td>
<td>33.9 (7.7)</td>
<td>13.2 (2.0)</td>
<td>95.4 (7.8)</td>
<td>96.2 (8.7)</td>
</tr>
<tr>
<td>Left Temporal</td>
<td>33.0 (10.2)</td>
<td>12.1 (2.8)</td>
<td>102.8 (14.7)</td>
<td>92.2 (11.7)</td>
</tr>
<tr>
<td>Normal Control</td>
<td>32.2 (11.1)</td>
<td>13.0 (1.2)</td>
<td>99.3 (18.6)</td>
<td>107.6 (18.0)</td>
</tr>
</tbody>
</table>

\[ F (2, 57) = 0.146^{\dagger} \quad 1.680^{\dagger} \quad 1.321^{\dagger} \quad 7.081^{*} \]

Note. VIQ = Wechsler Adult Intelligence Scale-Revised Verbal IQ; PIQ = Wechsler Adult Intelligence Scale-Revised Performance IQ.

\( a_n = 20 \) for each group.

\( \dagger P > .05; \quad * P < .01. \)
Table 4
Groups Characteristics for Gender and Handedness

<table>
<thead>
<tr>
<th>Group</th>
<th>Gender</th>
<th></th>
<th>Handedness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Right</td>
</tr>
<tr>
<td>Right Temporal</td>
<td>11</td>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>Left Temporal</td>
<td>11</td>
<td>9</td>
<td>17</td>
</tr>
<tr>
<td>Normal Control</td>
<td>8</td>
<td>12</td>
<td>20</td>
</tr>
</tbody>
</table>

\( n = 20 \) for each group.

results indicated equivalent gender membership within the LT, RT, and NC groups. The two temporal lobectomy groups differed in the extent of the neocortical excision performed at the time of operation. Table 5 provides these data for the RT and LT groups.

Scoring Procedures for Memory Tests

For each test item (either a word or a particular dot) there were 16 possible correct (C) or error (E) response patterns that a subject could make over the four trials. These "four-tuple" patterns are presented in Appendix E. For example, a subject could correctly recall the item on
### Table 5

**Extent of Neocortical Resection for the Temporal Lobectomy Groups**

<table>
<thead>
<tr>
<th>Group</th>
<th>Extent of Neocortical Resection (mm)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sylvian Fissure</td>
<td>Temporal lobe base</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>Range</td>
<td>Mean</td>
</tr>
<tr>
<td>Right Temporals</td>
<td>55</td>
<td>30 - 72</td>
<td>69</td>
</tr>
<tr>
<td>Left Temporals</td>
<td>48</td>
<td>35 - 70</td>
<td>62</td>
</tr>
</tbody>
</table>

all four test trials (C,C,C,C), or on only the first three trials (C,C,C,E). The frequency of occurrence for each of the possible 16 four-tuples was tabulated for each subject and summed within each group. Therefore, for the verbal test, each subject would generate 12 four-tuple sequences, one for every test item, and each group would yield 240 such patterns (i.e., 12 test items × 20 subjects). Because fewer items are used on the nonverbal test (eight), each group provided 160 four-tuple sequences. The frequency counts for each of the 16 possible four-tuple patterns comprised the data that were submitted for analysis.
Verbal Memory Test Findings

The average proportion correct on the verbal learning trials is illustrated in Figure 2. The mean number of words recalled across groups, and across trials, are presented in Table 6. The number of words recalled on those trials that followed presentation trials (i.e., trials 1a, 2, and 3) were analyzed in a mixed-design, 3 (Group) by 3 (Trials) ANOVA. There was a significant Group effect, $F(2, 57) = 15.74, p < .001$, and a significant Trials effect, $F(2, 114) = 104.94, p < .001$, but no significant Group by Trials interaction, $F(4, 114) = 2.06, p > .05$.

Planned comparisons were used to partially test the minor hypothesis. The first comparison determined whether the RT and NC groups differed in their verbal test performance, and a significant result was found, $F(1, 177) = 6.07, p < .05$. The second comparison tested the difference between the LT group and the RT and NC groups. Again, a significant result was yielded, $F(1, 177) = 38.75, p < .01$.

Despite the inter-group differences in level of performance, all three groups provided strikingly similar patterns of performance. Trend analyses revealed that recall improved in a constant manner across trials 1a, 2, and 3 for the NC ($F(1, 57) = 66.39, p < .01$), RT ($F(1, 57) = 27.51, p < .01$), and LT ($F(1, 57) = 12.19, p < .01$) groups. The reduction in correct recall attempts from trial 1a to
Figure 2. Average proportion correct recall across verbal learning trials for left temporal lobectomy, right temporal lobectomy, and normal control subjects.
Table 6
Group and Trial Means and Standard Deviations on the Verbal Test

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>(SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Temporals</td>
<td>7.30</td>
<td>(2.09)</td>
</tr>
<tr>
<td>Left Temporals</td>
<td>5.58</td>
<td>(2.43)</td>
</tr>
<tr>
<td>Normal Controls</td>
<td>8.32</td>
<td>(2.24)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial</th>
<th>Mean</th>
<th>(SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>5.27</td>
<td>(1.83)</td>
</tr>
<tr>
<td>2</td>
<td>7.58</td>
<td>(2.21)</td>
</tr>
<tr>
<td>3</td>
<td>8.35</td>
<td>(2.39)</td>
</tr>
</tbody>
</table>
trial 1b is to be expected. A period of distraction follows trial 1a, and the words are not provided to the subjects before their recall attempt on trial 1b. Following a description of the analytic procedures involved, the results of the goodness-of-fit tests will be provided, along with the analyses of group performance.

Analytic Procedures

Brainerd (1985a) and Howe (1990) have outlined the calculations required to analyze these data in terms of the two-stage model and the statistics necessary to evaluate the results. Data analysis involved comparing numerical estimations of the model parameters. Details concerning the derivation of the equations needed to generate these estimates, and to perform the comparisons, can be found in several sources (Brainerd, 1985a; Brainerd, Howe, & Desrochers, 1982; Brainerd, Howe, & Kingma, 1982; Howe, 1990).

The numerical estimations were arrived at by generating maximum likelihood functions of the parameters through the use of an optimization algorithm developed by Siddall and Bonham (1974). The likelihood functions are typically of very small magnitude, therefore the estimates were transformed, by taking twice the negative log of the likelihood function, to produce usable values (Brainerd, 1985a). Howe (1990) has developed a computer algorithm that
performed this step. The distribution of the transformed statistic conforms to that for chi-square, therefore this nonparametric test was used to compare the likelihood functions (Brainerd, 1985a; Howe, 1990).

**Goodness-of-fit tests.**

Two goodness-of-fit tests—a necessity test and a sufficiency test—were performed on both sets of memory test data. The goodness-of-fit tests examined whether the two-stage model provided a statistically tolerable account of the data prior to hypothesis testing (Brainerd, 1985a; Howe, 1990). The calculations required to perform these goodness-of-fit tests, including determining the necessary degrees of freedom, have been developed and tested by Brainerd and colleagues; the derivation of the equations can be found in Brainerd (1985a), Brainerd, Howe, and Desrochers (1982), and Brainerd, Howe, and Kingma (1982), and the final equations are also presented in Appendix F.

Necessity is established through the rejection of the null hypothesis that the 11 parameter two-stage model, and a simpler 6 parameter version, provide equally satisfactory accounts of the test data for each group (Brainerd, 1985a). Utilizing the data from each of the memory tests in turn, numerical estimates (maximum likelihood functions) for the 11 parameter and 6 parameter models were generated through the use of the Siddall and Bonham (1974), and Howe (1990)
computer algorithms. The 6 parameter version is actually a
submodel of the 11 parameter model, and the resulting
statistic is asymptotically distributed as a chi-square with
five degrees of freedom (Brainerd, 1985a). The
establishment of the two-stage model's necessity permits the
examination of its sufficiency.

The sufficiency of the model is established through the
acceptance of the null hypothesis that the two-stage model
provides as good an account of the test data as a more
complex 15 parameter model (Howe, 1990). Comparisons were
performed separately for the verbal and nonverbal data sets.
As was the case for the necessity test, the maximum
likelihood functions for each model were generated by the
Howe (1990) and Siddall and Bonham (1974) computer programs.
The statistical test was a chi-square with four degrees of
freedom (Brainerd, 1985a; Howe, 1990).

Table 7 provides these maximum likelihood values for the
verbal data, and includes the results of the necessity and
sufficiency tests conducted for each group. In order for
the goodness-of-fit of the two-stage model to the verbal
data to fall within statistically acceptable ranges, the
result of the necessity test must exceed the critical value,
$\chi^2(5) > 11.07$, and the sufficiency statistic must not
be equal or better the critical value of $\chi^2(4) = 9.49$. As presented
in Table 7, these conditions were met for each group.
Table 7

Goodness-of-fit Tests for the Verbal Data

<table>
<thead>
<tr>
<th>Group</th>
<th>(-2\ln L_6)</th>
<th>(-2\ln L_{11})</th>
<th>(-2\ln L_{15})</th>
<th>Necessity(^a) test</th>
<th>Sufficiency(^b) test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Temporal</td>
<td>1358.64</td>
<td>1091.43</td>
<td>1083.25</td>
<td>267.21</td>
<td>8.18</td>
</tr>
<tr>
<td>Left Temporal</td>
<td>1266.48</td>
<td>1074.46</td>
<td>1068.13</td>
<td>192.02</td>
<td>6.33</td>
</tr>
<tr>
<td>Normal Control</td>
<td>1154.74</td>
<td>928.17</td>
<td>922.75</td>
<td>226.57</td>
<td>5.41</td>
</tr>
</tbody>
</table>

Note. \(-2\ln L_6\) = the maximum likelihood value for the 6 parameter model; \(-2\ln L_{11}\) = the maximum likelihood value for the 11 parameter two-stage model; \(-2\ln L_{15}\) = the maximum likelihood value for the 15 parameter model.

\(^a\)The critical value that the test statistic must exceed to pass the necessity test is \(\chi^2(5) > 11.07, \ p < .05.\)

\(^b\)The criterion value that the test statistic must not exceed to pass the sufficiency test is \(\chi^2(4) < 9.49, \ p = .05.\)
Experimentwise, conditionwise, and parameterwise tests.

In order to guard against inflated Type-I error due to multiple comparisons, the conservative approach to data analysis suggested by Brainerd (Brainerd, 1985a; Brainerd, Howe, & Kingma, 1982) was adopted. A hierarchical sequence of analyses, that examined increasingly specific aspects of the data, were conducted with the proviso that the performance of a more specific comparison depended upon a significant result having been found for the preceding, more general, comparison.

The first analysis was an experimentwise test (analogous to an omnibus F-statistic) that sought to determine if inter-group differences in parameter values existed at a global level. The equations for this and the remainder of the analyses are included in Appendix F. The experimentwise test statistic was a chi-square, and the necessary degrees of freedom were found by the calculation \([ (k \times 11) - 11] \), where \( k \) equals the number of conditions in the study (Howe, 1990). The GROUP (3) by TEST (2) design of the present study yielded 55 degrees of freedom for the experiment-wise test. The result of this test was significant \( \chi^2(22) = 107.84; \ p < .001 \), and provided an opportunity for the next level of analysis to be performed.

A series of conditionwise tests (analogous to t-tests) were conducted to determine which pairs of groups differed
on the model parameters. The statistic for these condition-wise tests was a chi-square with 11 degrees of freedom (Howe, 1990). Comparison of the LT and RT groups [$\chi^2(11) = 48.63; p < .001$], the LT and NC groups [$\chi^2(11) = 87.70; p < .001$], and the RT and NC groups [$\chi^2(11) = 21.10; p < .05$] were all significant. Following the completion of the conditionwise tests, a series of parameterwise tests, that compare pairs of groups on each model parameter, were performed. The statistic for these tests was a chi-square with one degree of freedom.

Estimates of the two-stage model parameters are provided for each group in Table 8. Parameterwise tests were conducted for each model parameter, for each of three possible group pairs, resulting in a total of 33 comparisons. The results of these parameterwise tests are provided in Table 9.

The acquisition of words during earlier ($a'$) and later ($a$) test trials was clearly more difficult for the LT group than either the RT or NC groups. The latter two groups differed only on the $a$ measure. The retention of words between learning trials ($1-f$) was more difficult for the LT group than the NC group. No significant differences were apparent between the RT and NC groups, nor between the two temporal lobectomy groups.
Table 8

Parameter Estimates for Verbal Test

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Right Temporal</th>
<th>Left Temporal</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acquisition Learning</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$a'$</td>
<td>.51</td>
<td>.37</td>
<td>.53</td>
</tr>
<tr>
<td>$1-f$</td>
<td>.94</td>
<td>.80</td>
<td>1.00</td>
</tr>
<tr>
<td>$a$</td>
<td>.72</td>
<td>.49</td>
<td>.81</td>
</tr>
<tr>
<td><strong>Retrieval Learning</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$b'$</td>
<td>.26</td>
<td>.32</td>
<td>.57</td>
</tr>
<tr>
<td>$b$</td>
<td>$15 \times 10^{-5}$</td>
<td>.08</td>
<td>.36</td>
</tr>
<tr>
<td>$c$</td>
<td>$50 \times 10^{-5}$</td>
<td>.04</td>
<td>.06</td>
</tr>
<tr>
<td>$d$</td>
<td>$37 \times 10^{-5}$</td>
<td>$64 \times 10^{-5}$</td>
<td>$57 \times 10^{-5}$</td>
</tr>
<tr>
<td><strong>Retrieval Performance</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$1-r$</td>
<td>.88</td>
<td>.88</td>
<td>.92</td>
</tr>
<tr>
<td>$1-c$</td>
<td>.75</td>
<td>.87</td>
<td>.70</td>
</tr>
<tr>
<td>$g$</td>
<td>.93</td>
<td>.70</td>
<td>.93</td>
</tr>
<tr>
<td>$h$</td>
<td>.64</td>
<td>.36</td>
<td>.54</td>
</tr>
</tbody>
</table>
Table 9

Inter-group Parameterwise Comparison Results $[\chi^2(1)]$ for Verbal Test

<table>
<thead>
<tr>
<th>Process and Parameter</th>
<th>Acquisition</th>
<th>Retrieval Learning</th>
<th>Retrieval Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$a'$ 1-f $a$</td>
<td>$b'$ $b$ $c$ $d$</td>
<td>$1-r$ $1-c$ $g$ $h$</td>
</tr>
<tr>
<td>Comparison</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LT vs RT</td>
<td>17.3*** 1.7 38.6*** 1.2 0.8 0.3 0.0</td>
<td>0.0 2.3 11.0*** 34.7***</td>
<td></td>
</tr>
<tr>
<td>LT vs NC</td>
<td>22.6*** 5.5 75.6*** 20.5*** 9.7** 0.1 0.0</td>
<td>0.9 4.5 11.0*** 14.0***</td>
<td></td>
</tr>
<tr>
<td>RT vs NC</td>
<td>0.4 0.7 4.5 28.7*** 16.0*** 2.8 0.0</td>
<td>0.9 0.5 0.0 7.8**</td>
<td></td>
</tr>
</tbody>
</table>

Note. LT = left temporal group; RT = right temporal group; NC = normal control group.

*p < .05.  **p < .01.  ***p < .001.
Turning to the measures of retrieval learning, the parameter estimates were generally of small magnitude. Only the parameter $b'$ for the temporal lobectomy groups, and only $b'$ and $b$ for the NC group, were associated with estimates greater than .10.

None of the differences between the two temporal lobectomy groups on the four parameters ($b'$, $b$, $c$, $d$) that measure retrieval learning reached statistical significance. However, the NC group demonstrated greater efficiency than the LT or RT groups in forming a retrieval rule at the same time that a word is acquired ($b'$, $b$). Retrieval learning following successful and incorrect recall attempts ($c$, $d$, respectively) was similar for the three groups.

The two-stage model includes four measures of retrieval performance ($1-r$, $1-e$, $g$, $h$). Groups did not differ in their retrieval of words entering memory (i.e., State $P$) on the initial test trial ($1-r$). An unexpected result was that the LT group's estimate of retrieval performance for words entering memory on later trials ($1-e$) was greater than that for the NC group. However, the LT group's performance in recalling more difficult words ($g$, $h$) was significantly less than those for the RT and NC groups. The RT and NC groups were statistically distinguished on only one retrieval
performance measure, \( h \), the likelihood of correctly recalling a word having correctly remembered the word on the previous trial.

In addition to examining inter-group differences on each parameter, it is often informative to conduct within-group comparisons of parameters. The study's minor hypothesis, that acquisition estimates will be lower than retrieval learning estimates (i.e., \( \{a', a < b', b\} \)), necessitated one comparison. Similarly, qualitative invariances across groups suggested meaningful patterns in the data that warranted investigation. What are meant by qualitative invariances are relationships between individual parameters, or sets of parameters, that are consistent between groups (Howe, 1988).

Considering the minor hypothesis first, inspection of Table 8 clearly reveals that acquisition (\( a', a \)) is superior to retrieval learning (\( b', b \)) for the three groups. In only one instance, the comparison of \( a' \) with \( b' \) for the NC group, was the relationship in the direction of the minor hypothesis. A test of that comparison, however, was nonsignificant \( [\chi^2(1) = 1.84; p > .05] \).

Several within-group comparisons of parameters were conducted and the results were tested using a chi-square statistic with a single degree of freedom. A difficulty
with the within-group comparisons is how to control for inflated Type-I error resulting from numerous comparisons. The error rate per comparison can be controlled by establishing a particular alpha level. However, when more than one comparison is performed the Type-I error rate across comparisons becomes inflated. With 11 parameters there are 55 possible comparisons that could be performed within each group. The extent to which Type-I error becomes inflated can be calculated using the formula

\[ E = 1 - (1 - \alpha)^C, \]

where \( E \) is the Type-I error rate across comparisons, \( \alpha \) is the Type-I error rate per comparison, and \( C \) is the number of comparisons (Hummel & Sligo, 1971). With 55 comparisons, and a per comparison Type-I error rate of .05, the value of \( E \) becomes .94, clearly an unreasonable level. Control of Type-I error was accomplished through two means. First, the number of comparisons performed was limited to those necessary to test the study hypotheses and to investigate cases of qualitative invariance (i.e., consistent patterns of relationships among parameters) which were of theoretical interest (Klockars & Sax, 1986). Second, the comparison alpha level was set at a more stringent level to ensure that the accumulated Type-I error rate remained at a reasonable level (e.g., \( p < .05 \)).

Five qualitative invariances were discerned from the verbal data: (1) \( \{a' < a\} \); (2) \( \{1-f > a', a\} \); (3) \( \{b < b'\} \);
(4) \( h < g \); and (5) \( r < e \). Within each group, these patterns were tested for significance using a corrected per comparison Type-I error level. It was determined that in order to ensure an across comparison Type-I error level of \(.05\), the per comparison error must be set at \(.01\) or less.

The results of the within group comparisons are provided in Table 10. Pattern 1 was supported for all three groups, and indicated that acquiring a word was less difficult on later trials than on the initial trial. In other words, a carry-over effect in acquisition was observed from the first to later learning trials. Pattern 2 was found to be significant for only the RT and NC groups. Retention of a trace between trials was easier than the process of acquiring the trace. Pattern 3 was found to only be significant for the RT and LT groups. Words acquired on the first learning trial were more likely to also have a specific retrieval function learned on that same trial. All three groups provided significant results for pattern 4. Correct recall was more likely to be preceded by an incorrect response than a correct response on the previous recall attempt. It appears that when retrieval is governed by general processes unsuccessful attempts are an important factor in guiding retrieval. Finally, only the RT and NC groups were found to have significant differences on pattern 5. For these subjects, retrieval performance was better for
<table>
<thead>
<tr>
<th>Group</th>
<th>{a' &lt; a}</th>
<th>{1-f &gt; a'}</th>
<th>{1-f &gt; a}</th>
<th>{b &lt; b'}</th>
<th>{h &lt; g}</th>
<th>{r &lt; e}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Temporal</td>
<td>45.7**</td>
<td>45.2**</td>
<td>96.2**</td>
<td>9.4*</td>
<td>159.9**</td>
<td>9.1*</td>
</tr>
<tr>
<td>Left Temporal</td>
<td>12.7**</td>
<td>1.9</td>
<td>5.7</td>
<td>7.2*</td>
<td>53.4**</td>
<td>0.1</td>
</tr>
<tr>
<td>Normal Control</td>
<td>97.9**</td>
<td>29.5**</td>
<td>75.9**</td>
<td>6.1</td>
<td>141.1**</td>
<td>14.7**</td>
</tr>
</tbody>
</table>

*p < .01.  **p < .001.
words acquired after the initial trial than on the initial trial.

Nonverbal Test Findings

Figure 3 presents the mean group proportions of correct recall across learning trials. Table 11 provides means and standard deviations for the number of dot locations correctly identified across groups and trials. As was done for the verbal test, scores on recall trials 1a, 2, and 3 were analyzed in a mixed design, 3 (Group) by 3 (Trials) ANOVA. There was a significant effect for Group, $F(2,57) = 9.73, p < .001$, and a significant effect for Trials, $F(2,114) = 10.53, p < .001$, but no significant interaction, $F(4,114) = 0.68, p > .05$.

Planned comparisons revealed that the LT group recalled significantly fewer items than the NC group, $F(1.177) = 29.75, p < .05$. Similarly, the RT group was significantly inferior to the NC group, $F(1.177) = 118.14, p < .01$. Separate trend analyses were conducted for each group's recall data. Linear trends for the NC ($F(1,57) = 5.06, p < .05$) and LT ($F(1,57) = 7.42, p < .01$) groups suggested that their recall improved over trials. The RT group, however, failed to demonstrate a similar trend ($F(1,57) = 1.45, p > .05$).

A striking feature of Figure 3, was that unlike the RT or NC groups, the proportion of items recalled by the LT group
Figure 3. Average proportion correct recall across nonverbal learning trials for left temporal lobectomy, right temporal lobectomy, and normal control subjects.
Table 11

Group and Trial Means and Standard Deviations on the Nonverbal Test

<table>
<thead>
<tr>
<th>Dot Locations Recalled Across Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
</tr>
<tr>
<td>-------------------------------------</td>
</tr>
<tr>
<td>Right Temporals</td>
</tr>
<tr>
<td>Left Temporals</td>
</tr>
<tr>
<td>Normal Controls</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dot Locations Recalled Across Trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial</td>
</tr>
<tr>
<td>--------------------------------------</td>
</tr>
<tr>
<td>1a</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
</tbody>
</table>
on trial 1b appeared to increase relative to their recall on trial 1a. As reported above in the presentation of the verbal test findings, a performance decrease is expected on trial 1b due to the presence of interference between recall trial 1a and 1b, and the absence of a study trial prior to trial 1b. Furthermore, the LT group's greater recall on trial 1b cannot be attributable to extreme increments in recall for a few subjects. As provided in Table 12, the majority of LT subjects (55 percent) correctly recalled more nonverbal items on trial 1b than on trial 1a. Note also, that while each group included one or more subjects who displayed a similar improvement on either memory test, the proportion of LT subjects' whose recall increased on the second trial of the nonverbal test was quite remarkable. A test of whether the proportion of LT subjects (55 percent) that had improved scores on trial 1b differed significantly from the proportions observed within the RT and NC groups (15 percent) was significant ($\chi^2(1) = 10.51, p < .01$). The data for the RT and NC groups were combined because of the similarity in the proportion of subjects who had, or had not, improved.

**Goodness-of-fit tests.**

Tests of the two-stage model's goodness-of-fit to the nonverbal memory data were conducted in the same manner as was reported for the verbal test. The reader is referred to
Table 12
Patterns of Recall Change from Trial 1a to 1b on the Memory Tests.

<table>
<thead>
<tr>
<th>Group</th>
<th>Increase (%)</th>
<th>Decrease or No Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nonverbal Test</td>
<td></td>
</tr>
<tr>
<td>Left Temporal</td>
<td>11 (55)</td>
<td>9 (45)</td>
</tr>
<tr>
<td>Right Temporal</td>
<td>2 (10)</td>
<td>18 (90)</td>
</tr>
<tr>
<td>Normal Control</td>
<td>4 (20)</td>
<td>16 (80)</td>
</tr>
<tr>
<td></td>
<td>Verbal Test</td>
<td></td>
</tr>
<tr>
<td>Left Temporal</td>
<td>1 (5)</td>
<td>19 (95)</td>
</tr>
<tr>
<td>Right Temporal</td>
<td>2 (10)</td>
<td>18 (90)</td>
</tr>
<tr>
<td>Normal Control</td>
<td>1 (5)</td>
<td>19 (95)</td>
</tr>
</tbody>
</table>

\(^a_n = 20\) for each group.
the earlier presentation of the verbal test data for an overview of these procedures. The results of the sufficiency and necessity tests are provided in Table 13, and indicated that the model provided an adequate account of the data.

**Experimentwise, conditionwise, and parameterwise tests.**

Summaries of the rationale and procedures involved in the conduction of these analyses are provided in the earlier presentation of the verbal test results. The experimentwise test was significant \( \chi^2(22) = 51.54; p < .001 \), and revealed parameter differences at a global level. Three conditionwise tests were conducted. Two of these comparisons, LT and NC groups \( \chi^2(11) = 32.24; p < .001 \), and RT and NC groups \( \chi^2(11) = 31.84; p < .001 \), proved significant. A comparison of the LT and RT groups revealed a high degree of inter-group similarity \( \chi^2(11) = 11.56; p > .05 \). This result was understandable given both, the relatedness of the groups' performance patterns in Figure 3 and the close correspondence of their parameter estimates in Table 14. Nonetheless, the conduction of parameterwise tests between the LT and RT groups was precluded by the insignificant conditionwise test. Table 15 provides the results of parameterwise tests between each of the temporal lobectomy groups and the NC group. Relative to
Table 13

Goodness-of-fit Tests for the Nonverbal Data

<table>
<thead>
<tr>
<th>Group</th>
<th>-2lnL₆</th>
<th>-2lnL₁₁</th>
<th>-2lnL₁₅</th>
<th>Necessity test</th>
<th>Sufficiency test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Temporal</td>
<td>890.92</td>
<td>811.09</td>
<td>805.74</td>
<td>79.83</td>
<td>5.35</td>
</tr>
<tr>
<td>Left Temporal</td>
<td>875.61</td>
<td>827.23</td>
<td>818.72</td>
<td>48.38</td>
<td>8.15</td>
</tr>
<tr>
<td>Normal Control</td>
<td>810.23</td>
<td>720.07</td>
<td>712.18</td>
<td>90.16</td>
<td>7.89</td>
</tr>
</tbody>
</table>

Note. -2lnL₆ = the maximum likelihood value for the 6 parameter model; -2lnL₁₁ = the maximum likelihood value for the 11 parameter two-stage model; -2lnL₁₅ = the maximum likelihood value for the 15 parameter model.

The critical value that the test statistic must exceed to pass the necessity test is $\chi^2(5) > 11.07$, $p < .05$.

The criterion value that the test statistic must not exceed to pass the sufficiency test is $\chi^2(4) < 9.49$, $p = .05$.  

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Right Temporal</th>
<th>Left Temporal</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition Learning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$a'$</td>
<td>.62</td>
<td>.65</td>
<td>.72</td>
</tr>
<tr>
<td>$1-f$</td>
<td>.90</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>$a$</td>
<td>.34</td>
<td>.49</td>
<td>.86</td>
</tr>
<tr>
<td>Retrieval Learning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$b'$</td>
<td>.16</td>
<td>.18</td>
<td>.40</td>
</tr>
<tr>
<td>$b$</td>
<td>$3.4 \times 10^{-6}$</td>
<td>.01</td>
<td>$3.5 \times 10^{-5}$</td>
</tr>
<tr>
<td>$c$</td>
<td>$4.3 \times 10^{-5}$</td>
<td>$3.2 \times 10^{-6}$</td>
<td>$1.1 \times 10^{-5}$</td>
</tr>
<tr>
<td>$d$</td>
<td>.28</td>
<td>.01</td>
<td>$5.7 \times 10^{-5}$</td>
</tr>
<tr>
<td>Retrieval Performance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$1-r$</td>
<td>.69</td>
<td>.51</td>
<td>.76</td>
</tr>
<tr>
<td>$1-c$</td>
<td>.92</td>
<td>.91</td>
<td>.60</td>
</tr>
<tr>
<td>$g$</td>
<td>.61</td>
<td>.63</td>
<td>.67</td>
</tr>
<tr>
<td>$h$</td>
<td>.51</td>
<td>.45</td>
<td>.62</td>
</tr>
</tbody>
</table>
Table 15

Inter-group Parameterwise Comparison Results [$\chi^2(1)$] for Nonverbal Test

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Acquisition</th>
<th>Retrieval Learning</th>
<th>Retrieval Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$a'$</td>
<td>1-$f$</td>
<td>$a$</td>
</tr>
<tr>
<td>Comparison</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LT vs NC</td>
<td>2.7</td>
<td>0.0</td>
<td>30.5***</td>
</tr>
<tr>
<td>RT vs NC</td>
<td>4.9*</td>
<td>2.6</td>
<td>92.4***</td>
</tr>
</tbody>
</table>

Note. LT = left temporal group; RT = right temporal group; NC = normal control group.

*p < .05. **p < .01. ***p < .001.
the NC group, both temporal groups demonstrated difficulty in acquiring the dot locations. However, while the RT group experienced this difficulty on initial trials \( (a') \), as well as later trials \( (a) \), the LT group performed significantly worse on only the later recall attempts \( (a) \). No differences were found in groups' retention of the dot locations between trials \( (1-f) \). Considering retrieval learning, the RT and LT groups were less likely than the NC group to learn a retrieval function for traces acquired on the initial test trial \( (b') \). Reliably accessing traces on later test trials \( (b) \), or learning a retrieval function after successful \( (c) \) and unsuccessful recall \( (d) \) was not different across groups.

The results of comparisons between measures of retrieval performance \( (1-e, 1-r, g, h) \) evidenced additional distinction between the temporal lobectomy and NC groups. The LT group was less likely than the NC group to correctly recall dot locations acquired on the initial test trial \( (1-r) \). Unexpectedly, both temporal lobectomy groups proved more able to retrieve traces that had been acquired on later test trials \( (1-e) \). Finally, while the three groups were similar in retrieving traces that were previously incorrectly recalled \( (g) \), the retrieval performance of the LT group was less likely to be successful when it followed a correct
recall attempt \((h)\).

On tests of within group differences, five patterns of qualitative invariance between parameters were observed:

1. \(b', b < a', a\); 2. \(1-f > a', a\); 3. \(b < b'\);
4. \(h < g\); and, 5. \(c < d\). Observe that pattern 1 is the opposite of the minor hypothesis for the nonverbal test. That is, while it was predicted that the RT group's acquisition would be worse than retrieval learning this relationship was not observed for the RT group or the other groups.

The results of the within group tests are provided in Table 16. The level of per comparison Type-I error was adjusted to maintain the accumulated false positive error rate to an acceptable level (i.e., \(\alpha = .05\)). The test of \(b' < a'\) was significant for each group. Comparison of \(b < a\) was significant for only the NC group. At least for the first learning trial, trace acquisition was more likely to occur for subjects than learning a specific retrieval function for the traces. Pattern 2 was significant for all groups, and suggested that acquisition was a more difficult process than the short-term retention of traces between trials. Pattern 3 was supported for only the NC group. The likelihood that a function to facilitate retrieval is available at the time that a trace is acquired is greater on
Table 16

**Within-group Comparison Results \( \chi^2(1) \) for Nonverbal Data**

<table>
<thead>
<tr>
<th>Group</th>
<th>( {b' &lt; a'} )</th>
<th>( {b &lt; a} )</th>
<th>( {1-f &gt; a'} )</th>
<th>( {1-f &gt; a} )</th>
<th>( b &lt; b' )</th>
<th>( h &lt; g )</th>
<th>( c &lt; d )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Temporal</td>
<td>69.3**</td>
<td>6.9</td>
<td>39.9**</td>
<td>8.9*</td>
<td>2.7</td>
<td>4.2</td>
<td>15.0**</td>
</tr>
<tr>
<td>Left Temporal</td>
<td>78.5**</td>
<td>6.0</td>
<td>60.7**</td>
<td>33.3**</td>
<td>0.8</td>
<td>16.7**</td>
<td>0.2</td>
</tr>
<tr>
<td>Normal Control</td>
<td>35.6**</td>
<td>54.4**</td>
<td>63.7**</td>
<td>108.9**</td>
<td>12.9**</td>
<td>1.2</td>
<td>0.0</td>
</tr>
</tbody>
</table>

*\( p < .005 \).  **\( p < .001 \).
the initial trial than on later trials. Only the LT group provided a significant finding for pattern 4. For these subjects, retrieval performance benefitted more from the occasion of a previous incorrect recall attempt than it did from an earlier success. Finally, pattern 5 was significant for only the RT group. This result revealed that a preceding error was most likely to be followed by retrieval learning. The results of the nonverbal test, along with those for the verbal test, will be discussed in Chapter IV.
CHAPTER IV
DISCUSSION

Brainerd and Howe (e.g., Brainerd, 1985b; Brainerd, Howe, & Desrochers, 1982; Brainerd, Howe, & Kingma, 1982; Howe, 1990) have introduced, within the cognitive developmental research area, a new memory assessment procedure that is based upon a two-stage learning model. The two-stage memory model includes separate estimates for acquisition and retrieval, measured along a common ratio scale of measurement. A fixed-trials variant of this procedure, which requires only four test trials to estimate acquisition and retrieval, offers several important advantages to researchers investigating memory deficits in clinical populations. This model-based procedure is easily adapted to repeated-trial learning tasks. Acquisition and retrieval are measured on a common task, and the use of ratio scaling permits direct comparison between numerical estimates of these two processes. Moreover, the need for only four test trials makes the procedure ideally suited for use with patients with severe memory disorders or neurological deficits, who might otherwise be ill-suited for the more
commonly used memory tests.

To date, however, the construct validity of the acquisition and retrieval parameters contained within the two-stage model has not been adequately established. The present study was designed to partially redress this situation by evaluating the validity of the two acquisition parameters (i.e., $a'$ and $a$). Verbal and nonverbal tests, designed for use with the fixed-trials variant of the model-based procedure, were administered to patients who had undergone unilateral temporal lobectomy for the treatment of intractible epilepsy.

Damage to mesial-temporal structures (e.g., hippocampus, amygdala, hippocampal gyrus) is known to cause deficits in acquisition; that is, the formation of stable memory traces becomes impaired (Fedio et al., 1984; Frisk & Milner, 1990a; Milner, 1968; 1972; 1975; L'Hermitte & Signoret, 1976; Weingartner, 1968). Also, the type of material that acquisition is impaired for is dependent upon the hemispheric side of the lesion. Dominant temporal lobe lesions generally disrupt memory for verbal types of material while nondominant temporal lobe dysfunction affects memory for nonverbal material (Chelune, 1991; Frisk & Milner, 1990a; Hermann et al., 1987; Kimura, 1963; Loring et al., 1991; Milner, 1968; 1972; 1978; Ojemann & Dodrill, 1985; Ribbeler & Rausch, 1990; Weingartner, 1968).
The parameters $a'$ and $a$ represent the likelihood of acquiring items presented on the first learning trial and later learning trials, respectively. If $a'$ and $a$ are valid indices of acquisition efficiency then it is reasonable to expect that both parameters would be sensitive measures of the memory difficulties displayed by patients who had undergone anterior temporal lobectomy. In accordance with the material nature of memory deficits, low estimates of $a'$ and $a$ are expected on a verbal test for patients whose resection involved the dominant temporal lobe. Patients who have surgery on the nondominant temporal lobe should provide low $a'$ and $a$ values on a nonverbal test.

The present study's results largely supported these expectations. Relative to the NC group, the LT group was impaired in their acquisition of words presented on the first learning trial (based on $a'$) as well as on later trials (as inferred from $a$). Furthermore, the estimates for the LT group were significantly lower than those for the RT subjects, whose resections were constrained to the nondominant hemisphere. These findings are consistent with the neuropsychological literature in demonstrating that the memory impairment associated with dominant temporal lobectomy principally affects verbal material (Chelune, 1991; Frisk & Milner, 1990a; Hermann et al., 1987; Loring et
al., 1991; Milner, 1972; 1978; Ojemann & Dodrill, 1985; Ribbler & Rausch, 1990; Weingartner, 1968). Somewhat surprisingly, however, impaired acquisition on the verbal test was not limited to the LT group. As will be discussed separately below, the RT group also evidenced difficulty in acquiring words presented on later learning trials, though not to the extent seen for the LT subjects.

In a similar manner, the nonverbal test proved to be sensitive to the memory deficits of the RT group, though specificity of the acquisition parameters to the RT patients was not demonstrated. While the RT subjects evidenced difficulty with acquiring the dot locations on all test trials (based on the $a'$ and $a$ parameters), the performance of these patients could not be distinguished from that of the LT group. There was, however, a pattern of lesser $a'$ and $a$ values for the RT group than for the LT group. As was the case on the verbal test, an unexpected finding was deficient acquisition of the nonverbal stimuli after the initial learning trial for the LT subjects. Again, this latter result will be discussed separately below as a corollary finding.

The sensitivity of the estimates of $a'$ and $a$ in differentiating patients with impaired acquisition apart from non-clinical control subjects supports the construct
validity of the acquisition parameters included within the
two-stage model. The present study extends the evidence in
support of the validity of two-stage model's parameters
reviewed in Brainerd (1985b), and outlined in Chapter I.
The acquisition and retrieval parameters have been shown to
react independently to experimental manipulations. In
addition, the parameters respond appropriately to procedures
that ought to affect these processes.

The present findings also extend the results of Howe
(1990) in demonstrating that the model-based procedure has
practical usefulness as a clinical method for evaluating
impaired acquisition. Unfortunately, an important
limitation has emerged from the present study that questions
the clinical usefulness of the fixed-trials version as a
memory assessment procedure. Before discussing this
limitation, however, the remainder of the study findings will
be presented. First, the expected differences between the
LT and RT groups on the nonverbal test failed to
materialize, and possible reasons for this finding will be
addressed. Second, an important corollary finding was the
unexpected observation that the LT and RT groups evidenced
impaired acquisition on tests that they were expected to do
well on. Third, keeping in mind that the construct validity
of the short-term retention and retrieval parameters has not
yet been established, an overview of how the study groups
compared on these measures will be provided. Following
discussion of these topics, the clinical usefulness of the
fixed-trials procedure will be discussed.

Absence of Patient Differences on the Nonverbal Test

The LT and RT groups yielded uniformly poor estimates of
acquisition on the nonverbal test. The absence of
differences between the two patient groups does not stem
from a general insensitivity of the nonverbal test to
impaired acquisition of the dot stimuli, and cannot be
attributable to a "good" performance on the part of the RT
subjects. The RT subjects were clearly impaired on this
test; their estimates of $a'$ and $a$ were significantly worse
than those for the NC group. Furthermore, the RT group
failed to yield a significant learning trend on the
nonverbal test. These results are consistent with previous
reports of the detrimental effect of nondominant temporal
lobectomy upon nonverbal memory function (e.g., Chelune,
is more likely that the absence of patient differences stems
from the LT group's difficulty in memorizing the nonverbal
test stimuli.

Given the prominence of language functioning in assisting
mankind's adaptation to his environment, it seems a
reasonable assumption that humans will employ language and
verbal mediation whenever it facilitates completion of a
task, including remembering nonverbal material. Indeed, it has long been recognized that in order to prevent verbal mediation from influencing test performance when nonverbal material was to be memorized, the tests needed to be comprised of complex and novel stimuli (Heilbrunner, 1992; Kimura, 1963; Lee et al., 1989; Loring & Papanicolaou, 1987; Milner, 1968; 1978; Milner & Teuber, 1968).

The neuropsychological literature contains a possible explanation as to why dominant temporal lobectomy may impair learning of nonverbal material. Jaccarino (cited in Milner, 1978) found that learning and recalling simple drawings of representational objects was impaired irrespective of the laterality of temporal lobe resection. The author hypothesized that, unlike stimuli that are complex or novel, familiar and easily named visual stimuli invoke a "dual-code" whereby a verbal trace is formed in addition to the visual trace. Efficient remembering of such stimuli is dependent upon the establishment of both forms of memory trace. Consequently, patients with dominant-sided temporal lesions may be expected to have difficulty remembering such representational stimuli if their memory impairment prevents them from forming an adequate verbal trace to supplement the visual trace (Kimura, 1963; Milner, 1978).

The dot locations used as the nonverbal stimuli in the present study were chosen to minimize the beneficial effects
that verbal labelling may have provided subjects. Nonetheless, it was impossible to ensure that subjects would not engage in attempts at verbal mediation during this test. Given the study results of Jaccarino, it is possible that the LT subjects performed poorly on the nonverbal test because they attempted to rely upon verbal strategies to facilitate memorization of the nonverbal stimuli. If such attempts did occur, then their failure to perform at a level comparable to that of the NC subjects may have resulted from a difficulty in remembering the verbal labels, rather than an impairment in learning and remembering the spatial locations of the dots.

An second explanation for why patients with well-documented left cerebral hemisphere lesions may have difficulty learning and remembering nonverbal stimuli has less to do with the material nature of the stimuli than its degree of familiarity. Goldberg and Costa (1981) distinguished between "familiar" stimuli, for which the subject already possesses a descriptive system within their cognitive repertoire, and "novel", stimuli for which descriptive systems do not exist. The authors hypothesized that the left cerebral hemisphere is specialized for

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5 Goldberg and Costa (1981) define a descriptive system as any "set of discrete units of encoding or rules of transformation which can be successfully applied to the processing of a certain class of stimuli" (p. 151).
processing familiar stimuli. The right cerebral hemisphere, in turn, has an advantage for processing stimuli that are novel. Moreover, these specializations are thought to be in addition to the relative advantage that either hemisphere has for processing particular forms of material (i.e., verbal processing for the left hemisphere and spatial and other nonverbal types of processing for the right hemisphere).

Goldberg and Costa (1981) based their hypotheses upon several important cytoarchitectural differences that are known to exist between the two cerebral hemispheres. Auditory, visual, and somatosensory association areas, as well as primary sensory and motor representation areas, are more prominent within the left hemisphere that the right. The ratio of grey matter (e.g., neuronal operculum and short nonmyelinated fibers) to white matter (e.g., long myelinated fibers) is greater within the left hemisphere. Also, the left hemisphere appears to be organized with a greater emphasis upon intra-regional integration, while the right hemisphere is designed to facilitate inter-regional integration. Areas of association cortex, including inter-modal association areas (Luria's tertiary association areas) are larger within the right hemisphere.

Within the framework outlined by Goldberg and Costa (1981), the nonverbal test stimuli used in the present study
may have been associated with a pre-existing descriptive system, and therefore, may have placed demands upon the left cerebral hemisphere for processing. For the LT subjects, their poor performance could be explained on the basis that their temporal lobectomies gave rise to a "processing deficit", in the sense that they were hampered in their ability to process these familiar codes. In other words, their difficulty was not due to a primary impairment in memory. The RT group, on the other hand, performed poorly because their longstanding right cerebral damage impaired their formation of a descriptive system, and subsequent "shift" of the system to the left cerebral hemisphere for implementation and elaboration.

It should be readily apparent that both explanations share a close relationship to each other. If the LT subjects attempted to form and remember verbal traces of the dot locations then, because verbal language is considered to be a familiar descriptive system (Goldberg & Costa, 1981), the left cerebral hemisphere would be expected to play a major role, in accordance with Goldberg and Costa's suggestion. The difference between the two positions concerns where in the processing sequence the difficulty is presumed to occur; prior to memory formation, as suggested by Goldberg and Costa, or at the time of trace storage, indicative of an acquisition deficit?
There is also a third possible explanation for why the nonverbal test failed to discriminate between the two clinical groups. It is possible that the memory deficit for each group had a general component, in addition to a material-specific component. If this is true, then a similarity in the degree of specific impairment for the RT group and general impairment for the LT group may have masked group differences on the nonverbal test. The possibility of experiencing both specific and general memory difficulties following temporal lobectomy will be examined next.

**Generalized and Specific Deficits**

A corollary finding that emerged from the present study suggests that a general memory inefficiency may accompany a more severe material-specific memory impairment. In addition to their expected material-specific impairment in learning, both the RT and LT groups were found to be impaired on tests that each was expected to do well on (i.e., the verbal test for the RT group and the nonverbal test for the LT group). The parameterwise tests revealed that, relative to the NC group, the patient groups provided significantly lower estimates of the $a$ parameter which estimates acquisition on trials after the first learning opportunity. The relatively large estimate of $a$ for the RT group on the verbal test (.72) suggests that these
"unexpected" deficits are not merely due to an artifact arising because of an insufficient number of learning trials.

The most plausible alternative explanation for the presence of additional deficits is that the temporal lobectomy groups are demonstrating a general inefficiency of memory, with an accentuation or specific deficit for learning a particular form of material. This pattern of deficit can also be described as a greater acquisition deficit on hemispheric "concordant" memory tasks (i.e., significantly lower estimates for \( a' \) and \( a \) on the verbal test for the LT group and on the nonverbal test for the RT group) combined with an inefficiency affecting performance on memory tasks that are hemisphere "discordant" (i.e., lower values for \( a \) on the nonverbal test for the LT group and on the verbal test for the RT group).

Such hemisphere discordant memory inefficiency is not commonly described in the temporal lobectomy literature. Patients who have lesions in the mesial structures of the left temporal lobe, or who have received dominant temporal lobectomy, are not typically distinguishable from control subjects, on tests of nonverbal learning. Similarly, the verbal memory performance of patients with nondominant temporal lobe lesions is generally found to be comparable to that of controls (Chelune, 1991; Kimura, 1963; Milner, 1968;
1972; 1975). Nonetheless, a review of the temporal lobectomy literature revealed studies (e.g., Fedio et al., 1984; Frisk & Milner, 1990a; 1990b; Hermann et al., 1987; Jones-Gotman & Milner, 1978; Milner, 1978; 1968; Mungas et al., 1985; Novelty et al., 1984; Ribbler & Rausch, 1990; Saykin, Gur, Sussman, O'Connor, & Gur, 1989; Tucker, Novelty, Isaac, & Spencer, 1986) in which a trend towards hemisphere discordant memory deficits was apparent, even if comparisons with control groups failed to reach statistical significance.

Additionally, at least two studies have found samples of left temporal lobectomy patients that were impaired in learning visual material. The findings of Jaccarino (cited in Milner, 1978) have already been presented above and will not be repeated here. An additional study by Tucker et al. (1986) examined the effect of presentation method (simultaneous versus sequential) upon temporal lobectomy patients' recall of a visuospatial array. In addition to the impaired recall of the right temporal lobectomy group under both test conditions, patients who had undergone left temporal removals were also impaired in recalling the visual stimuli, but only in simultaneous condition.

Isolated reports of discordant memory deficits are not limited to samples of dominant temporal lobectomy patients. In separate studies, Jones-Gotman and Milner (1978), and
Fedio et al. (1984) reported impaired verbal learning for patients with nondominant temporal lobectomy lesions. In both studies, the verbal material had the additional quality of being easily visualizable, which led the authors to suggest that a visual code of the stimuli was being formed in addition to whatever verbal code was acquired. The memory deficit seen on these verbal tasks for the nondominant temporal lesion samples was hypothesized to be secondary to their difficulty in visual trace formation (Jones-Gotman & Milner, 1978).

Ribbler & Rausch (1990) utilized separate lists of semantically-related (four-legged animals) and unrelated words to evaluate storage and retention in epilepsy patients with unilateral left or right temporal resections and normal control subjects. Consistent with the majority of the neuropsychological literature, the left temporal resection group demonstrated the greatest impairment in remembering the different word lists. Relevant to the present hypothesis, however, the right temporal lobectomy group was impaired in storing and retaining the semantically-related words. The authors interpreted this finding as a failure on the part of right temporal lobe patients to employ semantic processing; however, animal names would be expected to encourage visualization. If this is true, then the right temporal lobe patients, like those in the Jones-Gotman and
Milner, and Fedio et al. studies, may have had difficulty in forming visual traces to associate with the words. In the present study, equal numbers of words that can be easily visualizable and others that are abstract were employed on the verbal test. Although the study was not designed with this in mind, the performance of the RT group was re-examined to see if the easily visualized words were more difficult for these subjects to recall. On each recall trial a greater number of easily visualizable than abstract words were recalled by the RT patients, as well as the LT and NC groups. Consequently, dual-coding is not thought to have played a factor in the RT group's verbal test deficit. Instead, a general inefficiency of memory, affecting learning of both verbal and nonverbal material, is postulated.

There are several mechanisms by which a general cognitive inefficiency may arise in some temporal lobectomy patients. First consideration must be afforded to the spread of epileptogenic discharges. Clinical, or even subclinical, spread of abnormal electrical discharges have been demonstrated to affect neuroanatomical systems distant from the temporal seizure focus (Cromwell, 1970), particularly from seizure origins located within the hippocampus (McIntosh, 1992), a structure frequently implicated in cases of temporal lobe epilepsy. If these discharges effect
subtle changes in other neuroanatomical regions, the consequence may be subtle dysfunction of other cognitive systems, manifested as an overall lowering of cognitive efficiency. In addition, long-term pharmacological therapy with anticonvulsant medications may also have a significant effect upon cognitive ability by interfering with the attentional capacities of patients (Bennett, 1992; Dodrill, 1988; Trimble, 1987).

Disturbances of attention and/or concentration may manifest as general impairments in memory or other cognitive processes. In cases where the onset of seizures is early in development, and when the frequency of seizure activity is high, the detrimental effect of the above-mentioned influences can be exacerbated (Bennett, 1992; Trimble & Thompson, 1986).

A final consideration could be afforded to the effects of large cortical removals on the overall efficiency of cognition. However, there is an absence of research demonstrating that the removal of the anterior segment of a single temporal lobe has a detrimental impact upon the overall function of the remaining brain, by virtue of a reduction in the amount of cortical tissue available. While one may conjecture such a mass action hypothesis, one cannot discount that whatever detrimental effects may occur as a result of tissue removal, are off-set by the reduction in
seizure activity and medications. Also, speculating that the resected tissue was normally functioning prior to removal may be false. This is especially true in cases where epileptogenic activity has been recorded in the resected regions.

The results of the present study suggest that a general inefficiency of memory may be revealed in temporal lobectomy patients through the use of the model-based assessment procedure. This general inefficiency accompanies the better known material-specific memory deficits associated with temporal lobe lesions. Furthermore, these conclusions are consistent with the pattern of memory test performance reported in numerous studies (e.g., Fedio et al., 1984; Frisk & Milner, 1990a; 1990b; Hermann et al., 1987; Jones-Gotman & Milner, 1978; Milner, 1978; 1968; Mungas et al., 1985; Novelly et al., 1984; Ribbler & Rausch, 1990; Saykin et al., 1989; Tucker et al., 1986).

Short-term Retention

No specific differences were predicted between the temporal lobectomy and NC groups on the 1/f parameter. Recall that this measure estimates the ease with which acquired items are subsequently lost from memory (Brainerd, 1985a; Howe, 1988; 1990). Short-term retention deficits have been reported in cases of parietal lobe dysfunction (Kolb & Wishaw, 1985; Shallice & Warrington, 1970;
Warrington & Shallice, 1969; Warrington et al., 1971), as well as with cases of bilateral hippocampal resection (e.g., Huppert & Piercy, 1982; Squire, 1981). Similar deficits have been cited for pre-operative (Delaney, Prevey, & Mattson, 1982) and post-operative patients with temporal lobe epilepsy (Milner, 1972; 1975; Samuels, Butters, & Fedio, 1972).

The literature concerning whether the laterality of the lesion determines the type of material affected by the retention deficit is inconclusive. A material-specific relationship to the side of operation was reported by Milner (1972; 1975), while Delaney et al. (1982) and Samuels et al. (1972) found that only verbal material was affected, and that the deficit was equivalent regardless of lesion laterality.

The pattern of $l-f$ estimates for the LT and RT groups is most congruent to a material-specific effect of lesion laterality upon short-term retention (e.g., Milner, 1972; 1975). On the verbal test, the LT group demonstrated the most difficulty with short-term retention. The RT group's estimate for $l-f$ was only slightly lower than the NC group's. Moreover, within-group comparisons revealed that the RT and NC group, but not the LT group, found short-term retention of acquired traces to be easier than acquisition. Group differences on the nonverbal test were not apparent.
for this parameter, and all groups found short-term retention easier than acquisition. Nonetheless, the RT group produced the lowest estimate, while values of \( 1-f \) for the LT and NC group were the same and approximated unity. The interpretation of a material-specific relationship between side of temporal lobectomy and deficits on \( 1-f \) is only tentative because of the absence of meaningful group differences on the nonverbal test. Further studies are necessary to evaluate the validity of this variable, and to explore the pattern of performance as it relates to lesion laterality.

**Retrieval Performance**

The retrieval performance parameters provide a "snap-shot" of retrieval efficiency during the only stage in which performance can vary; that is, after acquisition has occurred but before a retrieval function is formed. As described in Chapter I, the examination of these measures provides a means of assessing retrieval accuracy at different periods within the intermediate memory state (Brainerd, 1985b).

Specific hypotheses regarding the retrieval performance of each temporal lobectomy group were not made. Instead, it was expected that because of a primary deficit in acquiring material both temporal lobectomy groups would evidence more difficulty than the nonclinical group in recalling material
that had not yet been associated with a retrieval function.

Patients with temporal lobectomies, in particular those who had received dominant resections, could not be distinguished from the non-clinical subjects on the basis of their accuracy in retrieving items that had been acquired on trial 1a of the verbal test. On the nonverbal test, however, the LT subjects were less able to accurately retrieve dot sequences stored on the first learning trial. A reversal of patterns was apparent for the retrieval accuracy of items stored on trials after trial 1a. For these items, the LT and RT groups appeared to be more successful than the NC group in retrieval, based on the greater estimates for 1-\(e\) for the LT group on the verbal test, and for the LT and RT groups on the nonverbal test.

It is difficult to explain the greater accuracy of the LT and RT groups, or conversely, the lesser accuracy of the NC group, in retrieving items that enter the intermediate memory stage after trial 1a. It is possible that this finding is an artifact arising from the inclusion of less difficult items in the estimation of \(e\). Estimation of \(e\) is based upon all items that entered the intermediate memory state. In contrast, the retrieval performance parameters \(g\) and \(h\) are based only upon those items that remained within the intermediate state for at least two consecutive trials.
(i.e., the more difficult items). The LT group was less able than the NC group to retrieve these more difficult words and dot locations, particularly if a successful retrieval had occurred on the previous trial (based on $h$). Similarly, the RT group evidenced difficulty in retrieving items (words and dot locations) on trials after a successful retrieval.

Finally, within-group comparisons revealed that attempting to retrieve a word after a successful recall on the previous trial is associated with a greater level of success than if the previous retrieval attempt was unsuccessful (i.e., $g > h$). In general, it would seem that prior to forming a retrieval rule for items, retrieval accuracy for memory-impaired and normal adults is enhanced by being able to determine which retrieval strategies are effective. That is, an unsuccessful trial conveys to the subject that the strategy used had failed, and they are then able to shift to a new retrieval strategy. Other research using a Markov-based assessment approach has provided similar results for adults (Halff, 1977) and older children (Brainerd et al., 1984).

**Acquisition versus Retrieval Learning.**

The present study was conducted in order to evaluate the construct validity of the acquisition learning parameters included in the two-stage memory model, as assessed using
the model-based procedure. A principal advantage of the procedure is that it yields independent estimates of acquisition and retrieval learning on the same task. The availability of these estimates afford the clinical researcher the opportunity to directly compare these fundamental memory processes.

It was hypothesized that because the locus of the temporal lobectomy patients' memory difficulties was presumed to lie at the stage of acquisition, the temporal lobectomy patients would perform well on the retrieval learning measures. Unfortunately, this hypothesis was not borne out by the data. Within group comparisons revealed that the acquisition estimates were superior to the retrieval learning estimates on both memory tests for all groups. Examination of the retrieval learning estimates, however, revealed them to generally be of unusually small magnitude; the exception being the estimates for $b'$, the likelihood of learning a retrieval function for items acquired on the first trial.

According to the two-stage model, memorizing consists of acquisition of an item followed by learning to retrieve the item in a reliable manner. Halff (1977) has suggested that the early trials of a serial learning task are primarily occupied with the first stage, acquisition. Later trials provide the opportunity for retrieval learning to occur.
Learning a retrieval function ensures perfect recollection of the item (Brainerd, 1985a; Halff, 1977).

The present results suggest that more than the three learning trials included within the fixed-trials version of the model-based procedure are necessary if reasonable estimates of retrieval learning are to be obtained for a clinical sample. It is possible that the interpretive algorithms written by Howe (1990) can be revised to allow estimation of acquisition and retrieval learning to occur over a greater number of trials (M. L. Howe, personal communication, May, 1993). This would be a necessary step if the suitability of the model-based procedure for clinical research is to be pursued.

Conclusions and Future Directions

The principal purpose of the present study was to evaluate the validity of the two acquisition parameters included within the model-based procedure. This evaluation was performed by administering the fixed-trials version of the procedure to patients who are impaired in the acquisition and learning of new material. The secondary purpose of this study was to determine whether the fixed-trials assessment approach was a practical and useful means of evaluating memory processes in clinical populations.

The study findings largely supported the $a'$ and $a$ parameters as measures of acquisition efficiency.
Estimations of these parameters successfully discriminated between the clinical patients and the non-clinical control subjects. Prior to accepting the validity of these parameters as being established additional studies are clearly needed. These studies need to be directed towards accomplishing three aims: (1) replicating the present findings using additional samples of epilepsy patients who had undergone temporal lobe removals; (2) demonstrating a similar degree of sensitivity to other patient populations who are known to have poor acquisitition (such as certain populations of dementia patients); and (3) assessing the construct validity of the short-term retention and retrieval learning parameters by administering the model-based procedure to selected patient samples who are known to be impaired in these abilities. Patients who are in the early stages of dementia stemming from Huntington's chorea may be a suitable group to study the retrieval learning parameters (Butters, Granholm, et al., 1987; Butters, Salmon, et al., 1989; Cummings & Benson, 1992; Hodges et al., 1990).

Other researchers (e.g., Kraemer et al., 1983) have discussed the need to minimize the number of test trials, and the quantity of items included on each trial, to avoid floor effects when assessing memory in clinical patients. In addition, there is always concern on the part of the clinical researcher to limit the duration of testing, while
not restricting the scope and breadth of the assessment. It was hoped, therefore, that the three learning trials included in the fixed-trials version of the model-based procedure would prove to be sufficient to provide meaningful estimates of acquisition and retrieval learning. However, the failure to attain reasonable estimates of retrieval learning for the present subject groups raises a serious concern about the adequacy of the fixed-trials version for assessing memory within clinical populations.

It would be possible to revise the fixed-trials version to include more learning trials. Revision would entail outlining the possible patterns of correct and error responses for the number of trials included, and re-writing the estimation algorithms to accommodate the greater number of test trials. Kraemer et al. (1983) recommended that in order to be suitable for use with impaired patients, an optimal number of test trials would be ten or fewer. Research would be necessary to determine what the optimum number of trials would be to satisfy the clinical requirements of the test, and still provide meaningful estimation of acquisition and retrieval parameters.

The model-based approach used in the present study serves as an example of how cognitive research initiatives can contribute to the development of clinical research tools. Consistent with the predictions of Levin (1986) and Schacter
(1989) the development of new strategies for evaluating memory within a clinical research setting will become increasing dependent upon the theory and techniques spawned through cognitive research. This trend will continue, to the mutual benefit of both disciplines.
Appendix A

Two-stage Model for Fixed-trials Procedure

Starting Vector:

\[
[M(1')M(1), M(1')PE(1), M(1')PC(1), M(1')U(1), PE(1')M(1), PE(1')PE(1), PE(1')PC(1), PE(1')U(1), PC(1')M(1), PC(1')PE(1), PC(1')PC(1), PC(1')U(1), U(1')M(1), U(1')PE(1), U(1')PC(1), U(1')U(1)]
\]

\[
U(1) = [a'b', 0, 0, 0, 0, a'(1-b')r(1-f)(1-g), a'(1-b')r(1-f)g, a' \]

\[
(1-b')(1-r)f, 0, a'(1-b')(1-r)(1-f)(1-h), a'(1-b')(1-r)(1-f)h, a' \]

\[
(1-b')(1-r)f, 0, 0, 0, 1-a']
\]

Transition Matrix:

<table>
<thead>
<tr>
<th></th>
<th>( M(n+1) )</th>
<th>( PE(n+1) )</th>
<th>( PC(n+1) )</th>
<th>( U(n+1) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( M(n) )</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>( PE(n) )</td>
<td>( d ) ( (1-d)(1-g) ) ( (1-d)g ) ( 0 )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( PC(n) )</td>
<td>( c ) ( (1-c)(1-h) ) ( (1-c)h ) ( 0 )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( U(n) )</td>
<td>( ab ) ( a(1-b)e ) ( a(1-b)(1-e) ) ( (1-a) )</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a \text{Adapted from Howe (1990).} \)
Appendix B

Interpretation of the Two-stage Model Parameters

<table>
<thead>
<tr>
<th>Process and Parameter</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition Learning</td>
<td></td>
</tr>
<tr>
<td>$a'$</td>
<td>Probability of storing an item on trial 1</td>
</tr>
<tr>
<td>$a$</td>
<td>Probability of storing an item on any trial after trial 1</td>
</tr>
<tr>
<td>$1-f$</td>
<td>Probability that a stored item remains in storage between the first and second test trials</td>
</tr>
<tr>
<td>Retrieval Learning</td>
<td></td>
</tr>
<tr>
<td>$b'$</td>
<td>For items stored on trial 1, the probability that no further retrieval learning is needed</td>
</tr>
<tr>
<td>$b$</td>
<td>For items stored after trial 1, the probability that no further retrieval learning is needed</td>
</tr>
<tr>
<td>$c$</td>
<td>The probability of learning a retrieval algorithm after a success in State P</td>
</tr>
<tr>
<td>$d$</td>
<td>The probability of learning a retrieval algorithm after an error in State P</td>
</tr>
<tr>
<td>Retrieval Performance</td>
<td></td>
</tr>
<tr>
<td>$1-r$</td>
<td>For items entering State P on trial 1, the probability of a success</td>
</tr>
<tr>
<td>$1-e$</td>
<td>For items entering State P after trial 1, the probability of a success</td>
</tr>
<tr>
<td>$g$</td>
<td>For two consecutive trials in State P, the probability that a success follows an error</td>
</tr>
<tr>
<td>$h$</td>
<td>For two consecutive trials in State P, the probability that a success follows a success</td>
</tr>
</tbody>
</table>

*Adapted from Brainerd (1985b) and Howe (1990).*
Appendix C

Extent of Resection and Anticonvulsant Medications
for Each Subject

<table>
<thead>
<tr>
<th>Group &amp; Subject</th>
<th>Sylv</th>
<th>Base</th>
<th>Medications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Right Temporal</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>101</td>
<td>53</td>
<td>102</td>
<td>carbamazepine</td>
</tr>
<tr>
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<td>65</td>
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</tr>
<tr>
<td>104</td>
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<td>65</td>
<td>none</td>
</tr>
<tr>
<td>105</td>
<td>72</td>
<td>75</td>
<td>phenytoin</td>
</tr>
<tr>
<td>106</td>
<td>60</td>
<td>75</td>
<td>carbamazepine, phenytoin, phenobarbital</td>
</tr>
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<td>65</td>
<td>carbamazepine</td>
</tr>
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<td>carbamazepine</td>
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<td>phenytoin</td>
</tr>
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<td>112</td>
<td>70</td>
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<td>113</td>
<td>50</td>
<td>55</td>
<td>none</td>
</tr>
<tr>
<td>114</td>
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<td>118</td>
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<td>75</td>
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<td>phenytoin</td>
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<td>phenobarbital, phenytoin</td>
</tr>
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<td>75</td>
<td>phenobarbital, phenytoin</td>
</tr>
<tr>
<td>122</td>
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<td>60</td>
<td>phenytoin</td>
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### Left Temporal

<p>| | | | |</p>
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<th></th>
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</tr>
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<tbody>
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<td>204</td>
<td>50</td>
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</tr>
<tr>
<td>205</td>
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<td>55</td>
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</tr>
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<td>75</td>
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<td>75</td>
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<tr>
<td>223</td>
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<td>55</td>
<td>carbamazepine</td>
</tr>
</tbody>
</table>

^a Measured (in millimetres) along the Sylvian fissure (Sylv) and base of the temporal lobe (Base).

^b (Tegretol®).

^c (Dilantin®).

^d (Mysoline®).
Appendix D

Verbal Memory Test
**Appendix E**

**Possible Four-tuple Patterns of Correct (C) and Error (E) Responses**

**Recall Trial**

<table>
<thead>
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<th>1a</th>
<th>1b</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>C</td>
<td>C</td>
<td>C</td>
<td>E</td>
</tr>
<tr>
<td>C</td>
<td>C</td>
<td>E</td>
<td>C</td>
</tr>
<tr>
<td>C</td>
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</tr>
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</tr>
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</tr>
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</tr>
<tr>
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<td>E</td>
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</tr>
</tbody>
</table>
Appendix F

Analytic Equations²

Goodness-of-fit Tests

Necessity Test: \( \chi^2(5) = \left[ (-2\ln L_6) - (-2\ln L_{11}) \right] \)

Where: \(-2\ln L_6\) is the maximum likelihood value (MLV) for a 6 parameter model, and \(-2\ln L_{11}\) is the MLV for the 11 parameter model.

Sufficiency Test: \( \chi^2(4) = \left[ (-2\ln L_{11}) - (-2\ln L_{15}) \right] \)

Where: \(-2\ln L_{11}\) is as defined as above, and \(-2\ln L_{15}\) is the MLV for a 15 parameter model.

Experimentwise Test

\( \chi^2[k \times (11) - 11] = \left[ (-2\ln L_{111}) + (-2\ln L_{112}) + \ldots + (-2\ln L_{11k}) \right] - (-2\ln L_{11\text{pooled}}) \)

Where: \(k\) is the number of study groups, \(-2\ln L_{111}\) is the MLV for the first group's data, \(-2\ln L_{112}\) is the MLV for the second group's data, \(-2\ln L_{11k}\) is the MLV for the \(k\) group's data, and \(-2\ln L_{11\text{pooled}}\) if the MLV for the data pooled across the \(k\) groups.

Conditionwise Test

\( \chi^2(11) = \left[ (-2\ln L_{11i}) + (-2\ln L_{11j}) \right] - (-2\ln L_{11ij}) \)

Where: \(-2\ln L_{11i}\) is the MLV for condition \(i\), \(-2\ln L_{11j}\) is the MLV for condition \(j\), and \(-2\ln L_{11ij}\) is the MLV for the data pooled across conditions \(i\) and \(j\).
Parameterwise Test

\[ \chi^2(11) = [(-2\ln L_{1j}) + (-2\ln L_{1y})] - [(-2\ln L'_{1j}) + (-2\ln L'_{1y})] \]

Where: \(-2\ln L_{1j}\) and \(-2\ln L_{1y}\) are defined as above, and the term, \([(-2\ln L'_{1j}) + (-2\ln L'_{1y})]\), represents the joint MLV of the two conditions with the parameter of interest held constant.

\^Adapted from Howe (1990).
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Press.
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Rausch, R. (1985). Differences in cognitive function with


VITA AUCTORIS

Michael C. S. Harnadek was born on July 24, 1961 in Winnipeg, Manitoba. In June, 1979 he graduated from Stanley Humphries Secondary School, Castlegar, British Columbia. In September, 1985 he enrolled at the University of Victoria. He graduated with the Bachelor of Sciences (Honours) degree in May, 1987. In September, 1987, he enrolled in the Master's programme in clinical neuropsychology at the University of Windsor. He graduated with the Master of Arts degree in 1989. Since September 1989 he has been enrolled in the Doctoral programme in clinical neuropsychology at the University of Windsor.

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