Ph.D. Psychology

Gina Jaccarino Hiatt

COGNITIVE-ORGANIZATION DEFICIT AFTER TEMPORAL LOBECTOMY

IMPAIRMENT OF COGNITIVE ORGANIZATION IN PATIENTS WITH TEMPORAL-LOBE LESIONS

by

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The role of the temporal lobes in organizing random information and in using pre-organized information to aid memory was investigated. Forty patients with unilateral temporal lobectomies and twenty normal subjects were tested in four experiments. The first two studies demonstrated a material-specific impairment in left or right temporal-lobe patients in the sorting of unrelated words or designs, respectively. Part II compared recall and recognition of unrelated or categorized words. Left temporal-lobe patients could use the categorized list to improve recall, but showed reduced clustering and a high rate of intrusions. The serial position curve of the unrelated list showed that left temporal-lobe patients were sensitive to interference, and that the left hippocampus is important for the consolidation of early-list items. Increased primacy in the categorized-list recall of a patient with bilateral hippocampal lesions, and a greater categorization effect in patients with left hippocampal removals, was interpreted as reflecting a role of the hippocampus in recalling unrelated words.

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Résumé

L'étude porte sur le rôle joué par les lobes temporaux dans l'organisation d'information, présentée de façon aléatoire, ainsi que sur l'utilisation d'information organisée dans le but de faciliter la mémorisation. Quarante patients, ayant subi une lobectomie temporale unilatérale, ainsi que vingt sujets contrôles, ont été examinés dans quatre expériences. Les deux premières épreuves ont mis en evidence que, suivant une lobectomie droite, ou gauche, il existe un déficit relatif au matériel, soit dans la capacité à classer des mots, soit dans la capacité à classer des dessins non apparentés. Dans la deuxième partie, on a comparé le rappel et la reconnaissance des mots non apparentés et des mots organisés en classe. Les patients ayant subi une lobectomie temporale gauche ont utilisé la liste de mots organisés pour améliorer leur capacité de rappel; cependant, on relève des regroupements moins nombreux ainsi qu'un taux élevé d'intrusions. La courbe de position sérielle, pour la liste de mots non apparentés, montre que les patients ayant subi une lobectomie temporale gauche sont sensibles aux intérferences, et que l'hippocampe gauche joue un rôle important dans la consolidation des premiers items de la liste. L'effet de primauté accru pour la liste de mots apparentés, observé chez un patient ayant subi une lésion bilatérale de l'hippocampe, ainsi que l'augmentation de l'effet de catégorisation observé chez les patients ayant subi une ablation de l'hippocampe gauche ont été analysés comme représentatifs du rôle joué par l'hippocampe dans l'acquisition mnésique pure.

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The treatment of intractable focal epilepsy by surgical removal of epileptogenic brain tissue is a reliable method of reducing or eliminating seizure tendency (Rasmussen, 1975). The type of epilepsy amenable to such an operation most often originates from temporal-lobe structures. Surgical treatment then involves unilateral temporal-lobe excision, including the anterior portion of the temporal neocortex, the amygdala, and varying amounts of hippocampus and parahippocampal gyrus.

It is now well-known that patients who undergo such operations demonstrate material-specific memory disorders preoperatively, which are usually accentuated postoperatively (Milner, 1958). Thus, temporal lobectomy in the speech-dominant left hemisphere has been shown to impair verbal memory (Meyer & Yates, 1955; Milner, 1958), regardless of whether the words are spoken or written (Blakemore & Falconer, 1967; Milner, 1967), and regardless of whether a recall or recognition technique is used (Milner, 1958; Milner & Kimura, 1964). For example, such patients are impaired in both immediate and delayed recall of the word pairs and stories from the Wechsler Memory Scale (Milner, 1958, 1975), the recognition of recurring words, nonsense syllables, or numbers (Milner & Kimura, 1964; Milner & Teuber, 1968), the recall of consonant trigrams in the Peterson and Peterson (1959) technique (Corsi, 1972), and the immediate and delayed verbal recall of pictures of common objects (Jaccarino, 1975). Memory for perceptual material such as faces (Milner, 1968), melodies (Shankweiler, 1966), or nonsense patterns (Kimura, 1963) is not impaired in these patients.

Conversely, removal of the right, nondominant temporal lobe leaves verbal memory essentially intact but causes deficits in remembering visual and auditory material that cannot be easily mediated verbally, such as complex geometric shapes (Taylor, 1969), unfamiliar faces (Milner, 1968; Warrington & James, 1967) or familiar and unfamiliar tunes (Milner, 1962; Shankweiler, 1966).

Perceptual Deficits After Temporal Lobectomy

There is some evidence of perceptual impairment without a memory component in patients with right temporal-lobe lesions. This is a subtle deficit that has been demonstrated only when normal perceptual cues have been reduced, as in tachistoscopic presentation (Kimura, 1963) or when some of the contours have been eliminated (Meier & French, 1965; Milner, 1968). Patients who have undergone right temporal-lobe excisions show deficits in estimating the number of dots flashed on a screen (Kimura, 1963), and perform poorly on tests requiring the understanding of sketchy or incomplete drawings, such as those of the McGill Picture Anomaly Series (Milner, 1958), the Picture Arrangement subtest of the Wechsler Intelligence Scale (Meier & French, 1965), and the Mooney Closure Test (Lansdell, 1968).

A similar deficit in the perception of verbal material may follow left temporal lobectomy. Patients with either left or right temporal-lobe lesions were shown to be impaired in the recognition of tachistoscopically-presented letters (Dorff, Mirsky, & Mishkin, 1965). Kimura (1963) found a deficit after left, but not right, temporal lobectomy, in the identification of familiar objects, tachistoscopically presented. The perceptual deficits that have been revealed in patients with temporal-lobe lesions probably depend more on the posterior than the anterior temporal cortex (Newcombe & Russell, 1969).

Cognitive Deficits After Temporal Lobectomy

A number of studies have indicated that patients with temporal-lobe lesions may have reduced cognitive abilities. Rausch (1977) has studied the cognitive strategies of such patients by means of a hypothesis test. Subjects were given several sets of two letters, each of which varied along four dimensions: form, color, size or position. The task was to determine which of the four dimensions was relevant to the solution of the task. She found that both left and right temporal-lobe groups solved fewer problems than did control subjects. Inspection of the strategies used revealed that patients with left temporal-lobe lesions failed to maintain a given hypothesis, even when it was indicated to be correct. Patients with right temporal-lobe lesions showed the opposite pattern: they tended to stay with a hypothesis indicated to be incorrect. These results held even when no memory load was imposed.

Because Rausch's task requires the subjects to be able to shift from one mode of solution to another, one would expect that patients with dorsolateral frontal-lobe lesions would also have difficulties with the task, as they do with the Wisconsin Card Sorting Test (Milner, 1963, 1964). Rausch does not, however, report any data for patients with frontal-lobe lesions. Meanwhile, it is interesting to note that patients with temporal-lobe lesions appear to perform normally on the Wisconsin Card Sorting Test (Milner, 1963), suggesting that this test and Rausch's hypothesis test may tap somewhat different functions.

Further evidence for some cognitive loss after temporal-lobe damage comes from a study by Wilkins and Moscovitch (in press). They found that patients with left, but not those with right, temporal-lobe lesions were impaired in their ability to classify drawings or object names, under time pressure, as either living or man-made. They performed normally, however, in classifying the stimuli as larger or smaller than a chair. These patients also showed deficits when asked to name drawings in quick succession. The authors note that these defects seen after left temporal lobectomy cannot be attributed to perceptual processes, because performance on the size classification task was normal. They therefore attribute the classifying and naming deficits to a disruption of semantic memory.

In a verbal fluency task requiring subjects to enumerate objects, then animals, then alternating colors and birds, at 60 seconds for each category, Newcombe (1969, 1973) found a deficit in patients with long-standing missile wounds of the left hemisphere, but no evidence implicating a specific area within that hemisphere. Milner (personal communication) has extended these findings by showing that patients with left temporal-lobe lesions are more impaired on this task than are those with left frontal-lobe lesions. This is particularly interesting in view of the fact that the latter patient group shows large deficits in producing words beginning with a particular letter (as in the Chicago Word Fluency Test, Thurstone & Thurstone, 1943), whereas the left temporal-lobe group remains relatively unimpaired on this kind of fluency measure (Milner, 1964, 1967). The difference may lie in the task requirements: the first requires a semantic memory search, the second a lexical search (Guilford, 1967; Jones-Gotman & Milner, 1977). The results for the patients with left temporal-lobe lesions on these fluency tasks are in agreement with those of Wilkins and Moscovitch in suggesting that the left anterior temporal region plays an important role in semantic memory.

The perceptual or cognitive deficits seen in temporal-lobe patients are not, however, as severe as their memory deficits. Although some studies have reported a decrease in I.Q. ratings in patients tested within the first month after left temporal lobectomy (Meyer & Yates, 1955; Milner, 1958), this loss can often be attributed to transient dysphasia caused by temporary interference with the functioning of the cortex bordering on the excision. On testing one or more years postoperatively, the I.Q. is usually found to be at least as high as before surgery and within the normal range, with no difference in mean I.Q. between left and right temporal-lobe groups (Milner, 1967, 1975a). Most important is the fact that severe material-specific memory impairments can co-exist with average or above-average I.Q. ratings.

Nevertheless, the research reviewed above showing that patients with left temporal-lobe lesions are impaired in some aspects of semantic memory and hypothesis-testing leaves open the possibility that the deficits seen in the acquisition of new information may be caused by abnormal cognitive processing. Of course, even intact ability to perceive and manipulate information in short-term memory does not necessarily imply normal ability to consolidate, store, and retrieve that information (Rozin, 1976).

Role of the Hippocampus

Although unilateral temporal-lobe removals normally produce material-specific memory deficits that are not incapacitating to the patient, several cases have been reported where such unilateral procedures have resulted in severe global memory loss (Baldwin, 1956; Dimsdale, Logue, & Piercy, 1964; Penfield & Milner, 1958; Walker, 1957). There is evidence that in these instances, damage also existed in the medial temporal region of the unoperated hemisphere (Milner, 1966; Penfield & Mathieson, 1974); the unilateral removal thus produced a bilateral hippocampal lesion.

Studies of patients who have undergone bilateral medial temporal-lobe resection offer more direct evidence of the relation between bilateral hippocampal lesions and memory loss (Scoville & Milner, 1957). This operation, (which is no longer performed) involves removal of the amygdala, uncus, and varying amounts of hippocampus and parahippocampal gyrus bilaterally, with total sparing of the temporal neocortex. Such removals are associated with a continuous anterograde amnesia for most post-operative experiences, and a variable degree of retrograde amnesia for events prior to the operation (Milner, 1972). Recall for events earlier in life seems, however, to be normal (Milner & Teuber, 1968).

Among patients who have undergone unilateral temporal lobectomy, there is considerable individual variation in the severity of the material-specific memory deficits. Since the amount of hippocampus removed in such operations also varies (depending on such factors as the amount of epileptiform abnormality found in these tissues), it is important to determine the extent to which the hippocampal lesion contributes to the memory deficit. In patients with right temporal-lobe lesions, a deficit in maze learning, both visual (Milner, 1965) and tactual (Corkin, 1965), only occurs if the lesion includes the hippocampus. The same may be true for the impairment in recognition of unfamiliar faces that follows right temporal lobectomy (Milner, 1968), although here the findings are more equivocal.

Corsi (1972) investigated the role of the hippocampus more systematically by subdividing each temporal-lobe group into four sub-groups differing with respect to the amount of hippocampus excised (see Milner, 1971, 1972). He showed that the size of the left hippocampal removal was associated with the degree of impairment on two verbal tasks, one involving the learning of supraspan digit sequences in the face of interference from digit sequences presented between trials (Hebb, 1961; Melton, 1963), and the other requiring the recall of spoken consonant trigrams after a short interval occupied with counting backwards (Peterson & Peterson, 1959).

In patients with right temporal-lobe lesions, Corsi demonstrated that the extent of right hippocampal removal was related to the amount of impairment on two non-verbal tasks, the first being formally similar to the supraspan digits task in that it required the learning of a supraspan spatial sequence tapped out on a random arrangement of blocks. In the second task, derived from Posner (1966), the subject had to recall the exact position of a dot on a line following various intervals filled with either distracting activity or a rest.

More recently, Jones-Gotman (Jones, 1975) has shown that the ability to use imagery to mediate verbal memory requires an intact right hippocampus. In an incidental-learning test in which subjects rated words on imageability, only those patients with right temporal-lobe lesions who had large right hippocampal removals were impaired relative to control subjects. A similar result was obtained for a task involving the use of interactive imagery to recall concrete paired-associate words: patients with large right hippocampal removals recalled fewer word pairs correctly than did those with small removals (Jones-Gotman & Milner, in press). Although patients with left temporal-lobe lesions, despite being helped by the use of imagery, were grossly impaired on these difficult verbal memory tasks, there was no relation between their performance and the extent of left hippocampal excision.

The lack of correlation of left hippocampal removal with performance on these verbal-learning tasks introduces an intriguing point: on certain tasks, a clear relation between extent of either left or right hippocampal removal and performance is found whereas on other tasks no such relation has been demonstrated. For example, a deficit in the recall of the Rey-Osterrieth figure (Osterreith, 1944; Rey, 1942), which is associated with a lesion of the right temporal lobe (Milner, 1975; Milner & Teuber, 1968; Taylor, 1969), is not, however, related to the amount of hippocampal destruction (Jones-Gotman & Milner, in press). Conversely, recall of names of pictured common objects, while requiring an intact left-temporal lobe, does not seem to vary with the amount of left hippocampal removal (Jaccarino, unpublished data). Although there is some suggestion that delayed recall of paired-associate words and of stories (a composite score of the two tasks) may depend on the extent of both lateral and medial left temporal-lobe removal, (Milner, 1967), this relationship has not been demonstrated conclusively.

Corsi (1972) suggested that the hippocampal effects found in his tasks were the result of heightened susceptibility to interference, since interpolated activity had been found to increase these effects. The data of Jones-Gotman & Milner (in press) are consistent with this interpretation. Milner (personal communication) has also suggested that stories and word pairs contain a certain amount of inherent organization and thus recall of such material does not depend on the hippocampus as much as does recall of random digits or consonant trigrams.

Most of the studies reviewed here have been concerned with defining the parameters of the memory disturbance found in patients with temporal-lobe lesions. Such factors as type of stimulus (e.g. pictures or words), method of testing (e.g. recognition or recall), and amount of time between presentation and testing were important considerations for discovering the scope and limits of the memory impairment produced by temporal-lobe removal. A more basic issue, and one that has not been fully explored, concerns the cause of the memory loss: at what stage of the memory process does the disturbance exist? The evidence mentioned previously for cognitive impairment suggests that one of the difficulties may lie in the organization of information into a form that may be properly encoded and stored in long-term memory. There has been much research in recent years on the role of organization in normal human memory. A selective review of this literature will be followed by a discussion of relevant studies on patients with temporal-lobe removals.

Organization and Memory

The use of free recall in memory research has a long history (Tulving, 1968), but it has only become prominent in the past two decades. An explanation for its increasing popularity is that it allows the experimenter to discover in what way the subject imposes organization on the stimulus material. As its name implies, free recall places fewer restrictions on the output of the subject than other procedures, such as paired-associate or serial learning. This allows one to study such variables as the order in which the subject produces his responses, the number of intrusions in recall, and the effect of cuing on recall.

Serial position curve. Tulving (1968) has distinguished between two types of organization in free recall. The first is referred to as "primary organization", which is defined as the consistent discrepancies between input and output orders that are independent of the subject's prior familiarity with the input items. The serial position effect (Murdock, 1962), in which the first and last items of a list are the best remembered, is the most important example of primary organization. There are several theories explaining the serial position effect (Murdock, 1974), but the most commonly accepted is the two-storage model (Atkinson & Shiffrin, 1968; Glanzer & Cunitz, 1966; Waugh & Norman, 1965). This model holds that the first few words of the list are retrieved from long-term storage (the primacy effect) whereas later words are retrieved from short-term storage (the recency effect). The primacy effect has also been explained in terms of reduced proactive interference for initial items, or increased rehearsal for those items

(Brodie & Prytulak, 1975; Tulving, 1968). Likewise, the recency effect has been attributed to recall of terminal items first, which would reduce retroactive interference (Baddeley, 1976, p. 103). Middle items, conversely, are not well recalled due to interference effects (Postman & Phillips, 1965). These formulations are not inconsistent with a two-stage model; they serve to clarify the mechanisms involved in short- and long-term memory.

The second kind of organization, as defined by Tulving (1968) is that in which "the output order of items is governed by semantic or phonemic relations among items or by the subject's prior, extra-experimental or intra-experimental acquaintance with the items constituting a list" (p. 16). The basic idea of an organization view of memory is that the subject groups two or more items into a functionally integrated unit; these subjective groupings become the recall unit (Bower, 1969, 1970; Wood, 1969). The forming of such associations between list items can be looked on as increasing the depth or breadth of processing of the items (Craik & Lockhart, 1972; Craik & Tulving, 1975), or as providing retrieval cues (Wood, 1972).

Sorting studies. There are several methods available for studying secondary organization of stimulus material. A technique that uses a direct approach and that "stresses maximal opportunity for organizing material" (Mandler, 1972, p. 140), involves presenting the material to the subject and asking him to organize it into categories. Mandler and Pearlstone (1966) and Mandler (1967) required subjects to sort lists of "unrelated" words into categories of their own choosing, and then to re-sort the words until they reached a stable criterion. In some experiments the subjects were free to use as many categories as they desired; in others, in accordance with Miller's (1956) notion of a limited storage capacity for unrelated items, they were instructed to use from two to seven categories. Recall was then used as a measure of the effect of organization. They found that recall was a linear function of the number of categories used during sorting, but only within a limit of seven categories. This relationship held when sorting time and number of sorting trials were kept constant, and when the number of categories was experimentally assigned rather than subject-defined (Mandler, 1967, 1968). Mandler (1970) has proposed a hierarchical model extending Miller's (1956) hypothesis, in which he postulates that subjects can only recall 5±2 categories and 5±2 words per category; subjects would limit the number of categories produced accordingly. By forming higher-order categories, a subject would be able to increase the number of categories that he could recall.

More recent studies, however, have found a linear relation between recall and number of categories even when no limit was put on the number of categories a subject might use (Basden & Higgins, 1972; Melkman, 1975). Basden and Higgins suggest that this divergence of results may be due to methodological differences; the later studies allowed the subject to rearrange the words until he was satisfied with his categorization, whereas Mandler's studies allowed for no such rearrangement. A further difference is that these recent studies did not require the subject to sort to a stable criterion.

Nevertheless, an important factor in determining the number of words that a subject will recall does seem to be, as Mandler's theory states, the number of categories that the subject is capable of recalling. Melkman (1975) showed that subjects who prefer to use a high number of categories (11 or more) recall fewer words when forced to use 4 or 8 categories, but that subjects who prefer a low number of categories (6 or less) are not affected by being forced to use 8 or 12 categories. She concluded that each subject adopts a strategy of classification that, given his cognitive abilities, optimizes recall. These categorization studies give evidence that organization of stimulus material does not just occur at the time of retrieval, but is important in the registration of stimulus material. Furthermore, subjects differ in their strategies of organization, and these strategies are related to their ability to remember the material.

Free recall of categorized lists. Another method for measuring the organization of items in memory is to examine the subject's output order in free recall. One of the earliest studies of this type was by Bousfield (1953), who showed that if items in the list represented instances of several categories, the instances of a given category tended to be recalled together even though they were not presented together. This phenomenon is termed category clustering. Because clustering can be quantified (Roenker, Thompson, & Brown, 1971; Shuell, 1969), and because it provides clues as to the underlying hierarchical organization of subjects' memories, many other studies of category-clustering have appeared since that time (Cofer, 1966; Cofer, Bruce, & Reicher, 1966; Pellegrino, 1974). Clustering has been shown to increase as a function of study trials (Bousfield & Cohen, 1953) and to correlate positively with the number of words recalled (Tulving, 1962). This would suggest that clustering is causally related to recall; support for this hypothesis comes from experiments that show that when a subject's clustering is disrupted, recall is impaired (Bower, Lesgold, & Tieman, 1969; Tulving & Osler, 1967). It is not known whether clustering reflects storage or retrieval processes, or both (Shiffrin, 1970).

It has been found that recall of organized lists of words is generally superior to recall of unrelated words (Bousfield, Cohen, & Whitmarsh, 1958; Cofer et al., 1966; Kintsch, 1968). The effect of organized word lists on recognition performance is not as clear as the effect on recall (Mandler, 1972). In general, recognition of categorized lists is not superior to recognition of unrelated words, the presumed reason being that recognition does not depend on a retrieval process as does recall (Kintsch, 1968).

There are two major interpretations (one offering an associative, and the other an encoding viewpoint) that have attempted to explain how categorized lists aid recall performance. The associative interpretation (Bousfield & Puff, 1965; Cohen, 1963; Deese, 1968) assumes that the presentation of a stimulus word activates associations to that word. These associations can then act as mediators in recall, thus increasing the likelihood that the stimulus word will be generated at the time of recall. A stimulus list containing related words would produce overlapping, and thus stronger, associations, thereby improving recall (Rothkopf & Coke, 1961).

The second interpretation is based on Miller's (1956) concept of "chunking", or grouping of words by the subject into categories <u>at the</u>

time of presentation (Mandler, 1967; Tulving, 1968). The category label, or some representation of it, can then be used as a retrieval cue at the time of recall. Presumably a list that is limited to a few obvious categories is more easily coded into such an organized form, and therefore better recalled, than a list of unrelated words. It is not clear, however, which of these two interpretations is correct. It is possible that both categorical and associative relationships among words represent some common underlying process (Shuell, 1969), although there is evidence that the two operate independently (Marshall, 1967; Baddeley, 1976, p. 276).

Cuing with category names at the time of recall testing has been found to improve recall performance (Tulving & Osler, 1968; Tulving & Pearlstone, 1966), showing that information can be available, but not accessible for recall. Cues are not helpful, though, unless there is a strong pre-established association between the cue and the to-be-recalled word (Tulving & Osler, 1968; Wood, 1972), implying that organization may affect both encoding and retrieval mechanisms.

Impairment of Organization in Patients with Temporal-Lobe Lesions

The research that has been reviewed here emphasizes the importance of organization in normal human memory. It seems possible that the memory deficits of patients with temporal-lobe lesions may reflect an impairment of the ability to organize random information adequately, or to make use of already organized stimulus material. Only two studies, both of which focus on clustering as a measure of organization, have examined the ability of temporal-lobe patients to organize information.

Weingartner (1968) found that left temporal-lobe patients (as compared to patients with right temporal-lobe lesions) showed reduced clustering in free recall of associatively-related words. Despite their lower clustering scores, left temporal-lobe patients recalled more words from the associatively-related list than from a list of unrelated words. This showed that although the words were not manipulated adequately in memory, as the clustering measure implied, their associative nature could be used to improve recall. Unfortunately, this study had several flaws. First, there was no normal control group. Second, both the associatively-related and un-related word lists were given in the same session, in that order; therefore, the apparent improvement of related over un-related words could have been merely the result of increased proactive interference for the second, un-related list. Finally, it is not clear whether the clustering measure that was used took into account the lower overall recall of the patients with left temporal-lobe lesions. If not, this could have artificially reduced their clustering scores.

An unpublished study by Moscovitch (1974) measured verbal and spatial clustering of pictures of common objects that had been chosen from four taxonomic categories and were drawn in four different spatial orientations (Frost, 1971). His results suggested that patients with left and right temporal-lobe lesions show reduced verbal and spatial clustering, respectively.

The experiments reviewed both here and in the section on impaired cognitive abilities lend some support to the idea that patients with left temporal-lobe lesions encode or categorize verbal information abnormally. The study by Moscovitch also suggests that a deficit in categorizing non-verbal spatial information may exist in patients with right temporal-lobe lesions. In order to determine to what extent such deficits in organization contribute to the memory deficits of temporal-lobe patients, research must be done that examines many different measures of organization. The experiments to be reported here approach this problem by using techniques employed in the study of organization in normal human memory.

THE PRESENT INVESTIGATION

The aim of this thesis is to evaluate the role of the temporal lobe in organizing information in memory, by studying patients who had undergone unilateral temporal lobectomy. There are two parts to the thesis, each of which explores different levels of organization in memory.

The experiments described in Part I were designed to investigate the extent to which an inability to organize material at the cognitive level (i.e. with little or no memory load) contributes to the memory deficit of patients with temporal-lobe lesions. Two tests were used, one consisting of word stimuli and one of abstract designs, in order to test the hypothesis that patients with left or right temporal-lobe lesions would be impaired in categorizing the verbal or non-verbal stimuli, respectively.

The experiments in Part II were highly verbal and thus were primarily aimed at patients with left temporal-lobe lesions. The purpose of these tasks was to investigate the ability of such patients to organize information in memory. The serial position curve of a list of unrelated words was used as a measure of "primary organization". It was predicted that primacy effects would be reduced after left temporal lobectomy, but that recency effects would remain normal.

In order to study "secondary organization", the recall and recognition of a word list containing taxonomic categories were compared to those of the unrelated, or non-categorized list. A clustering measure and a cued-recall procedure were also used to help clarify the nature of any deficit in organizing the stimulus material that may exist in patients with left-temporal-lobe lesions.

Subjects

The experimental groups consisted of 40 patients at the Montreal Neurological Hospital, each of whom had undergone a unilateral temporal lobectomy for the relief of focal epilepsy. Twenty had lesions in the right temporal lobe, and twenty had lesions in the left. Twenty normal control subjects were also tested.

Patients with clear electrographic abnormalities in the opposite temporal lobe, or with Full-Scale Wechsler-Bellevue I.Q. ratings below 70 were excluded from the study, as were patients with bilateral or right-sided speech representation as determined by pre-operative intra-carotid-Amytal tests (Branch, Milner, and Rasmussen, 1964; Wada, 1949). Four left-handed patients, three with left temporal-lobe removals and one with a right temporal-lobe removal, all of whom had left-sided speech representation, were included. Except for one case of indolent cerebral tumour in the left temporal-lobe group, all pre-operative epileptogenic lesions had been static and atrophic, dating from birth or early life.

Left Temporal-Lobe Group

In this group, the mean extent of surgical removal as measured along the Sylvian fissure was 4.9 cm, ranging from 3.5 to 5.5 cm. The mean extent of removal along the base of the temporal lobe was 5.7 cm, ranging from 4.0 to 7.5 cm. In 5 patients, the removals included at least the pes and part of the body of the hippocampus. The remaining 15 had smaller hippocampal removals, including 4 whose hippocampus was spared. The amygdala was completely removed in 17 cases and partially removed in 3. Nine patients were tested in follow-up study one year or more after operation. Two patients in this group were French-speaking.

Right Temporal-Lobe Group

The mean extent of surgical removal in this group, as measured along the Sylvian fissure, was 5.8 cm, with a range from 4.5 to 7.0 cm. The mean extent of removal along the base of the temporal lobe was 6.5 cm, ranging from 5.0 to 9.3 cm. The surgical removals in this patient group were significantly larger than those of the left temporal-lobe group ($t = 8.9$, $p < .001$, Sylvian fissure; $t = 5.56$, $p < .001$, base of temporal lobe). This difference stems from the need to spare the posterior temporal speech zone, which is mapped out by cortical stimulation during operation on the left hemisphere.

In 6 right temporal-lobe patients, the removals included at least the pes and part of the body of the hippocampus. The remaining 14 had smaller hippocampal removals, including 1 patient whose hippocampus remained intact. The amygdala was completely removed in 19 cases and partially removed in 1. Eight patients were tested two to three weeks post-operatively, and twelve in follow-up study one year or more after operation. Six patients in this group were French-speaking.

Normal Control Group

Twenty right-handed normal control subjects, recruited from the hospital staff and relatives of patients, were tested. Their intelligence was not assessed, but an effort was made to match the control group to the patient groups with respect to age, sex and level of education. Four control subjects were French-speaking.

Table 1 shows the age and sex distribution for both patient groups and for the normal control group. In addition, the mean Wechsler-Bellevue Full-Scale I.Q. scores are given for the patient groups.

Patient H.M.: Bilateral Medial Temporal-Lobe Removal

In addition to the patients with unilateral temporal-lobe excisions, the patient H.M. (Scoville & Milner, 1957), who underwent a radical bilateral medial temporal-lobe resection for the relief of generalized seizures, was studied. The surgical removal extended posteriorly along the medial aspect of the temporal lobes for a distance of 8 cm from the tips of the temporal lobes, destroying bilaterally the anterior two-thirds of the hippocampus and parahippocampal gyrus, as well as the uncus and amygdala, but sparing the lateral neocortex. At the time of testing, 23 years after operation, H.M. was 50 years old, with a Wechsler-Bellevue I.Q. of 116 (Verbal 107, Performance 125).

Table 1

Main Subject Groups

Group	Age Mean	Age Range	Sex M	Sex F	Wechsler IQ Mean	Wechsler IQ Range
Left Temporal	24.4	14-43	8	12	104.9	74-126
Right Temporal	29.4	15-54	10	10	113.9	90-146
Normal Control	27.8	15-48	9	11	Not Assessed	

PART I: SORTING STUDIES

The experiments reported in this section make use of the sorting technique originated by Mandler and Pearlstone (1966). Two sorting tasks were devised, one consisting of words, as in previous studies (Basden & Higgins, 1972; Melkman, 1975; Weist, 1970), and one consisting of abstract designs. The design-sorting task was a perceptual analogue to the word-sorting task, created to test the role of the right temporal lobe in categorizing non-verbal information.

If, as in the above-cited studies, the number of categories produced in these tasks by normal control subjects could be shown to correlate with their subsequent recall, then the number of categories could be used as a measure of each temporal-lobe patient's ability to categorize information in order to optimize recall. It was predicted that, since a small number of categories has been found to be correlated with lower recall scores in normal subjects (e.g. Melkman, 1975), patients with left or right temporal-lobe lesions would produce fewer word or design categories, respectively.

Material

Both sorting tasks contained 30 stimuli, each presented on a separate 8 cm by 13 cm card. The material from the word-sorting task will be described first, since the design-sorting task was modeled after it.

Word Sorting

The stimuli used in the word-sorting task were unrelated nouns, all having relatively high (A) Thorndike-Lorge (1944) frequencies. In a more recent statistical analysis of American English (Kucera &

Francis, 1967), the mean frequency of these words was 41.93 per 50,406 words, ranging from 15 to 129. The mean concreteness, imagery, and meaningfulness ratings (Paivio, Yuille, and Madigan, 1968) were 4.87, 5.33, and 6.03, respectively.

Each word was printed in block capital letters, 9 mm high, on the top line of the index card, using a black felt-tipped pen. These words are illustrated in Figure 1 in the original hand-printed form, and in the order in which they were presented.

The recognition test contained 90 words, printed six to a column along the length of each of 15 index cards. For each of the 30 original target words in the sorting task, one semantic and one phonemic distractor were chosen. Each semantic distractor was similar in meaning to the target word (e.g., castle for palace). Each phonemic distractor began with the same first two letters as the target word and had the same number of syllables (e.g., paddle for palace). Each recognition card contained two target words and four distractors, two of these semantic and two phonemic. In an attempt to make the recognition test more difficult, a distractor item was never placed on the same recognition card as its target word, as it was found in pilot testing that subjects were more often misled by a distractor when they could not compare it with the correct item. Three sample cards from this recognition test are shown in Figure 2.

For the French-speaking subjects, the word-sorting material was translated into French, substituting appropriate phonemic distractor items in the recognition test. Although no French-Canadian norms are available for word frequency, they are assumed to be roughly similar

AVENUE	STEAM
SHADOW	PRIDE
WINE	DUST
ANGER	SALARY
THEORY	PUPIL
FORTUNE	HAPPINESS
SNAKE	COLONY
ARTIST	AUTHOR
STRING	SAFETY
DEVIL	CREATURE
CODE	VICTORY
PALACE	METAL
ENGINE	PRAYER
CHARM	GIFT
MAJORITY	PRISON

Figure 1. Words (each printed on a separate card), as seen by the subject, after they had been placed, one at a time, on the table. Reduced to 3/5 original size.

A.	B.	C.
cold	safety	demon
devil	device	string
wealth	rope	CASTLE
PALACE	motor	crater
animal	PADDLE	forum
wire	author	engine

Figure 2. Word sorting task; examples of three cards from the recognition test. For purposes of exposition, one of the target words, and its phonemic and semantic distractors, are in capital letters on cards A, B, and C, respectively. Each recognition card contains two target words, with two phonemic and two semantic distractors for target words not on that card.

to those of English.

Design Sorting

This task was devised to be analogous to the word-sorting task. Thirty abstract designs were drawn by the author with a black felt-tipped pen on blank cards. The size of each drawing was approximately 2 cm by 2 cm. The drawings were not created randomly; the idea was to make many different sorting strategies available. Examples of potential categories purposely included are shape, orientation, increasing or decreasing size, curved or straight lines, symmetry, closed or open figures, and number of parts. Of course, any one design could be sorted many ways, as is the case with words. The designs are illustrated in Figure 3, in the original order of presentation.

The recognition test again consisted of 90 items, but with only three drawn on each card. As in the word-sorting task, two distractor stimuli were created for each target item. One distractor item was very similar to the target item, with only one or two details changed. For example, the orientation or relative placement of parts of the drawing might be altered, or the relative size changed. The other distractor was intended to be totally unlike any of the 30 target drawings. Each recognition card contained one target item and one of each type of distractor. To increase the difficulty of the test, a distractor was never placed on the same card as its own target. Three cards from the design-sorting recognition test are illustrated in Figure 4.

Procedure

The two sorting tasks were always given on different days, in

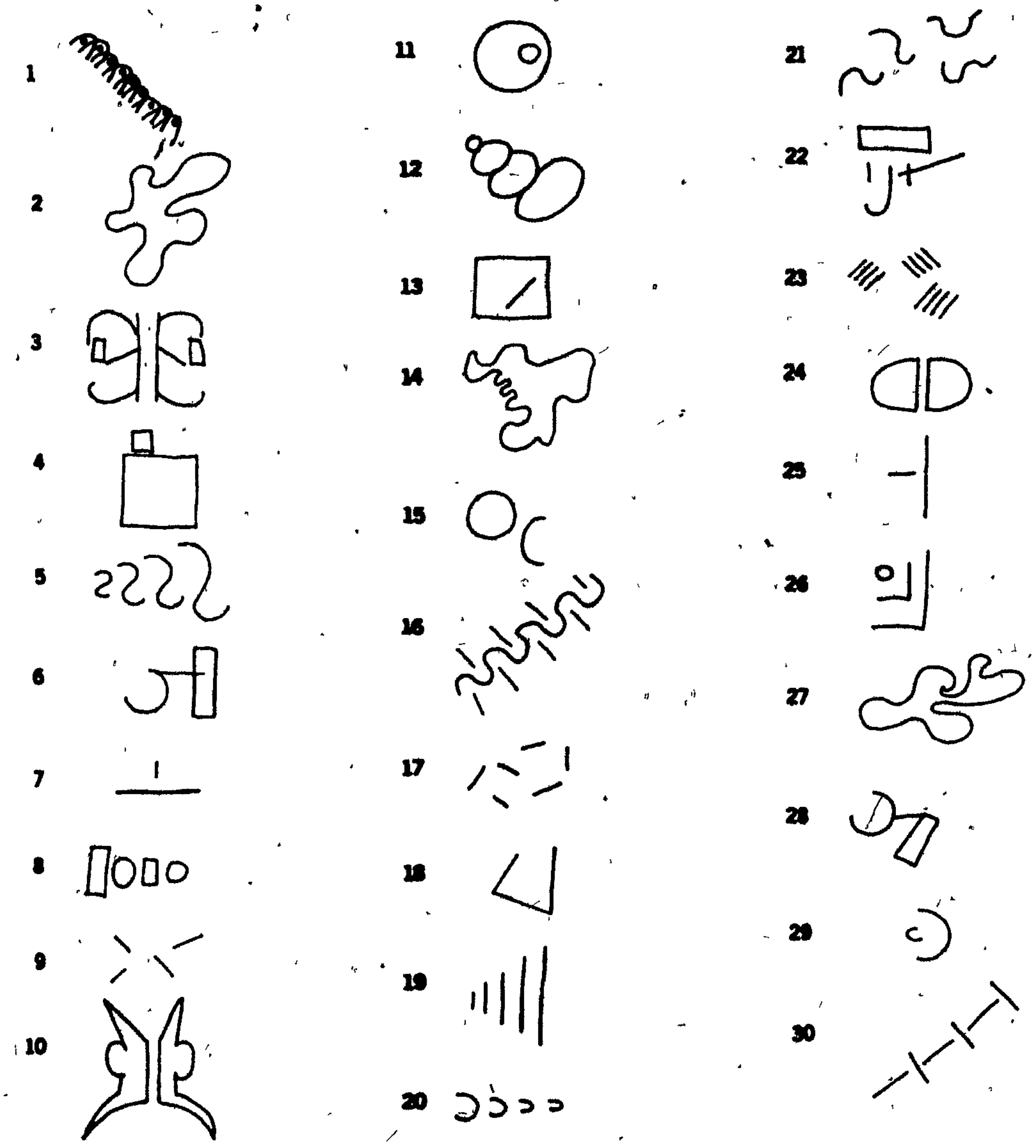

Figure 3. Designs (each drawn on a separate card), as they were seen by the subject, after they had been placed, one at a time, on the table. The numbers were not visible to the subjects; designs are reduced to 2/3 original size.

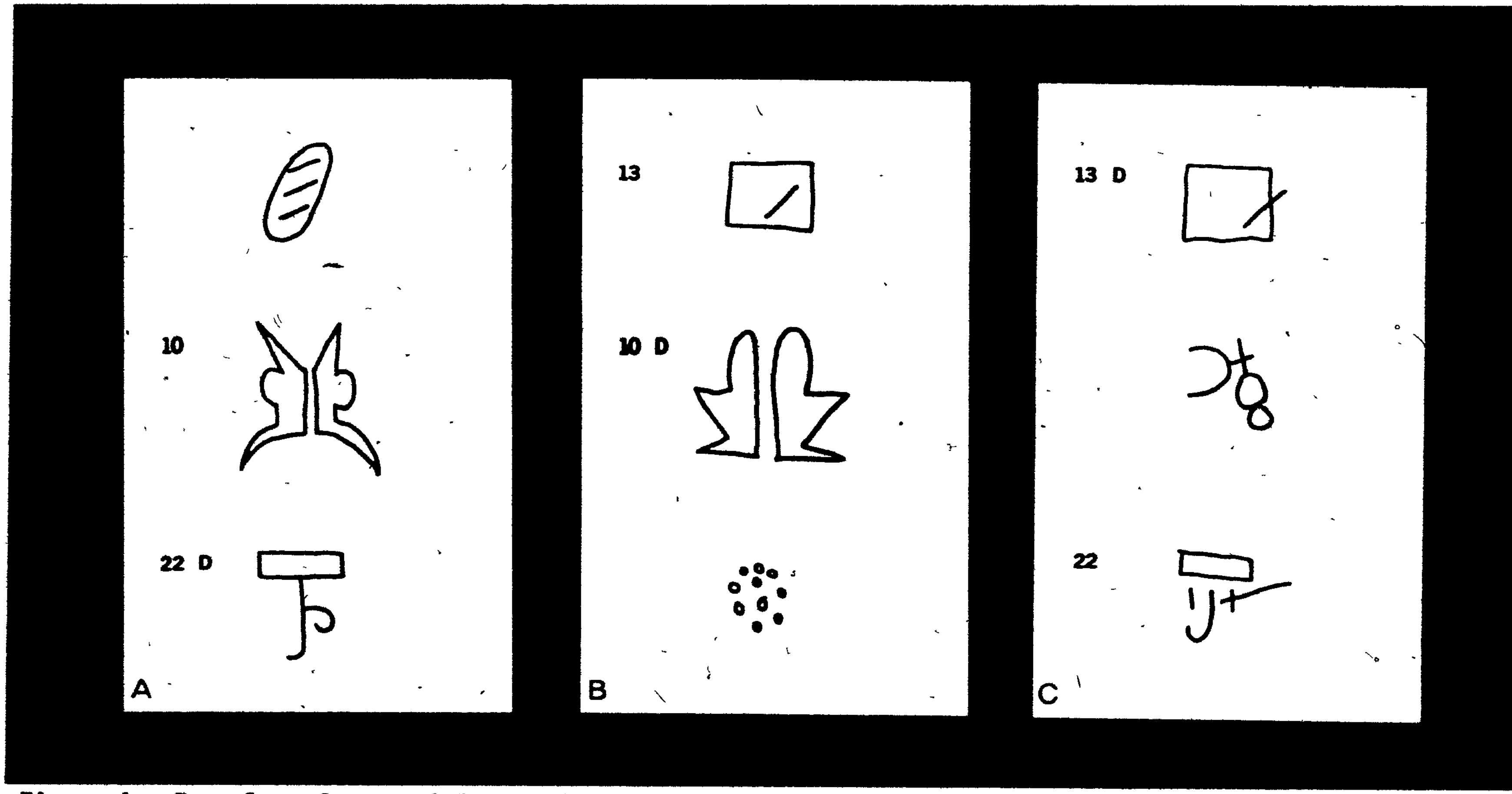

Figure 4. Examples of recognition cards for the design-sorting task, reduced to 3/4 the original size. Items numbered 10, 13, and 22 are target items (numbers refer to Figure 3); those designated 10 D, 13 D, and 22 D are distractors that closely resemble the corresponding target item. Note that these distractors are never on the same card as their target. Non-numbered designs are also distractors, but are not intended to resemble any target item.

order to reduce any tendency of a subject to attempt to reproduce his performance on the first task by using the same number of categories on the second test. Because of the possibility that the word-sorting task might introduce a bias towards using verbal strategies if it were given first, the design-sorting task was performed on the first day by all subjects, and it will therefore be discussed first throughout.

Design Sorting

The subject was seated in front of a large, empty table. He was told that he would be given some unrelated pictures, and that he would be required to sort them into as many groups as he wished, with any number of items in each group. He was told that there was no right or wrong answer, and that any grouping he chose would be allowed. The only requirement was that each group should look as though they belonged together. The subject was also told that when he had finished sorting the pictures, he would be asked to go to another table and draw as many of them as possible from memory.

The experimenter then placed the designs on the table in three columns, at the rate of one card every three seconds. The subject was told to proceed with the sorting task, and his performance was timed. While the subject sorted, the experimenter made sure that all cards remained visible, including cards that had already been placed into categories. This was to minimize any memory component involved in the sorting task. If the subject stated that he could not sort the remaining cards, he was asked to try to sort them all. This request was not repeated, however.

When the subject had completed the sorting task, he was asked to sit at a table, which faced away from the sorting table, and to draw as many of the designs as he could remember. A time limit of five minutes, which proved ample for most subjects, was allowed for the recall test. If a subject completed his recall before two minutes had elapsed, he was urged to continue trying for another minute.

Following the recall, the recognition test was administered. The subject was cautioned to choose only items that were exactly the same as those that he had seen previously. Subjects were allowed unlimited time for making their choices, and were forced to guess if unsure of an answer.

The subject was then asked to return to the sorting table and explain the principles that had been used to form each category. All answers were recorded verbatim.

Scoring. A scoring system was devised for assessing the accuracy of recall. In this system, each drawing was allowed a total of three credits. One was a general credit, which was given if it was possible to tell which design the subject was trying to draw, and if the subject had not already been given a point for drawing that design elsewhere. The second credit was given for drawing the correct shape. This included the number of lines in the drawing, and the relative size of different parts of the drawing. The third credit was given for the relative placement or orientation of different parts of the drawing. For example, this credit was not given if the drawing was rotated 45°. If a drawing was given a credit for shape or for relative placement, then the general credit was automatically given for that drawing.

As a check on the reliability of this scoring system, an independent judge scored a subsample of recall protocols. This subsample consisted of the protocols of half of the subjects from each subject group, randomly selected. All identifying information was eliminated from each protocol. A Pearson product-moment correlation was computed between the judge's score and the author's score for each subject in the subsample. This correlation was very high(r = .97, p < .001), indicating that the scoring system is quite reliable. The correlation for the three subject groups were: r = .96, normal control group; r = .98, left temporal-lobe group; r = .99, right temporal-lobe group.

Word Sorting

The procedure for the word-sorting task was the same as that of the design-sorting task, except that the words were placed on the table by the experimenter in two columns of 15 words each. This was to reduce the width of the display, since the words were wider than the designs. Also the experimenter said the word aloud as each card was placed on the table during presentation, and the subject was required to read his recognition choices aloud during the recognition test to ensure that the words were being perceived correctly.

Results

The results of both the word and design-sorting tasks will be presented together, in order to facilitate comparisons of the two tests. All *a posteriori* *t* tests to be reported used the procedure suggested by Scheffé (1953) for making all possible comparisons. This method was chosen because it is conservative with respect to Type I error, and allows for pooled comparisons. All *t* tests used two-tailed significance levels.

Number of Categories as Related to Subsequent Recall

Before testing the hypothesis that patients with left temporal-lobe lesions would sort the words into fewer categories than would normal control subjects, it was important to show that in this study, as in others, there was a positive correlation between the number of categories used by normal subjects, and their subsequent recall. This correlation was found to be significant ($r = .57$, $t = 2.95$, $p < .01$); thereby replicating several studies (Mandler, 1967; Melkman, 1975). In the same manner, it was necessary to study the relation between the number of categories that normal subjects chose to use for the designs and subsequent recall of the designs. This correlation, too, was significant ($r = .63$; $t = 3.44$, $p < .005$), extending the findings for the word-sorting test into the non-verbal domain.

For the patient groups, the relationship between number of categories used and recall was not as clear. The left temporal-lobe group showed a marginally significant tendency to recall more words if they had sorted them into a larger number of categories ($r = .46$, $t = 2.16$, $p < .05$), whereas right temporal-lobe patients showed a slightly negative trend ($r = -.30$, $t = 1.34$, $p > .10$). Neither patient group tended to obtain higher design-recall scores if they had sorted the designs into more categories, however ($r = .32$, $t = 1.45$, $p > .99$, left temporal-lobe; $r = .03$, $t = .12$, $p > .80$, right temporal-lobe).

Sorting Time

It was of interest to assess the relation between the amount of time spent sorting the stimuli and subsequent recall, in order to ensure that the correlations in normal subjects between number of categories and subsequent recall, which are discussed above, were not solely a function of time spent looking at the stimuli. No significant contribution was found, for any of the three subject groups, on either test, between sorting time and recall, although in the case of normal control subjects sorting designs, the correlation approached significance ($r = .43$, $t = 2.02$, $.10 > p > .05$.

The amount of time spent sorting the stimuli does, however, give an indication of the difficulty of the task. Figure 5 shows the mean sorting times for the subject groups on the two sorting tasks. A two-way analysis for groups and tasks gave a significant effect of sorting task ($F = 44.7$, $p < .001$). It can be seen in Figure 5 that all three groups sorted the words more slowly than the designs. There was a significant group effect ($F = 4.72$, $p < .025$), resulting from the normal control group sorting more quickly than the left temporal-lobe group ($t = 2.97$, $p < .05$); the right temporal-lobe group did not differ from the control group ($t = .61$, $p > .5$). The analysis also produced a significant interaction effect ($F = 5.91$, $p < .01$): whereas there were no group differences on the design-sorting task, the left temporal-lobe group sorted the words more slowly than either the normal control ($t = 4.19$, $p < .001$) or right temporal-lobe group ($t = 3.45$, $p < .01$).

Number of Categories

Since sorting into fewer categories is related to inferior recall performance in normal subjects, it was hypothesized that patients with left or right temporal-lobe lesions would use fewer categories than normal subjects on the word or design-sorting task, respectively. Figure 6 shows the mean number of categories used by the subject groups,

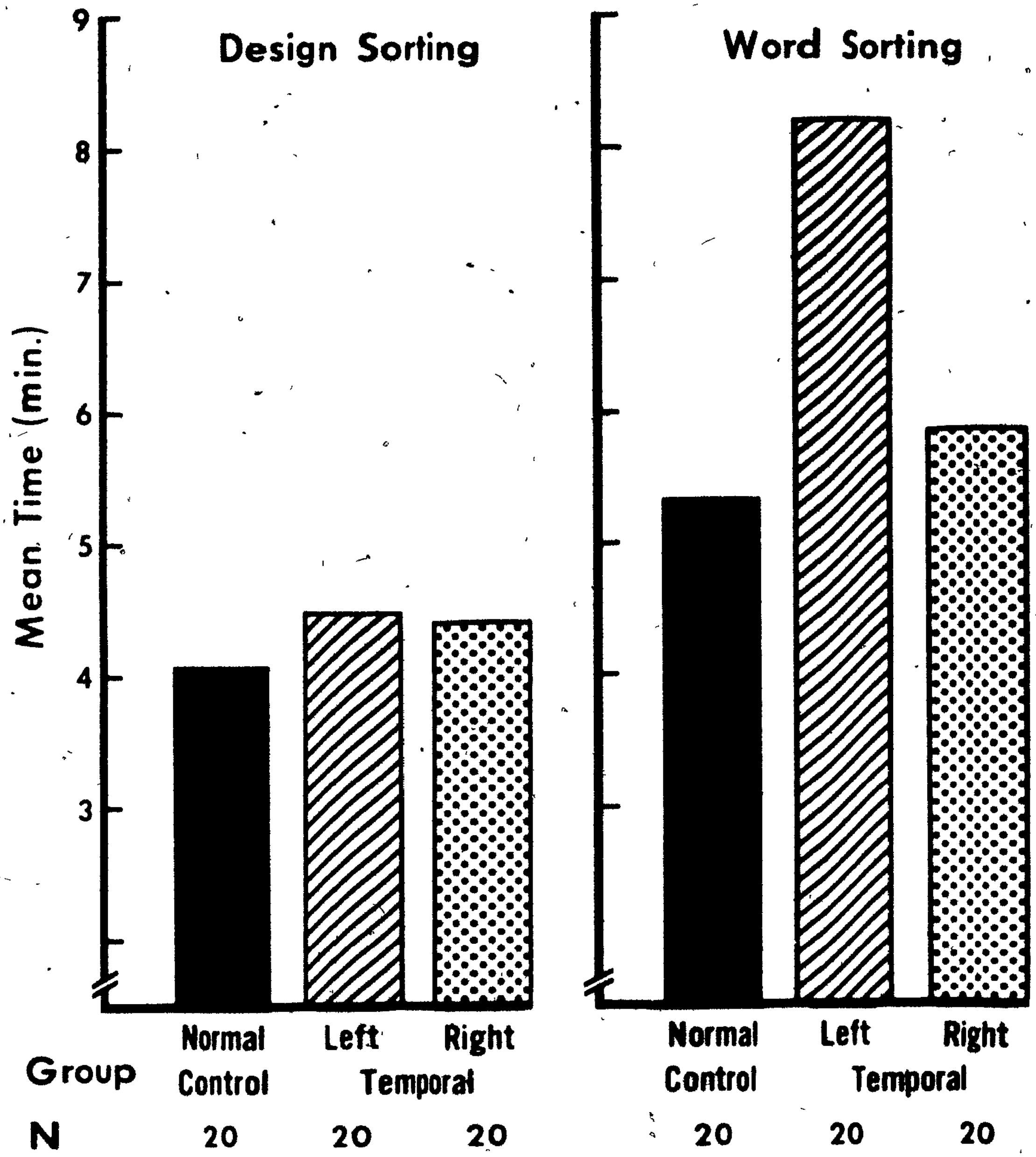

Figure 5. Sorting tasks: time. Mean number of minutes spent sorting the designs and words, for each of the three subject groups.

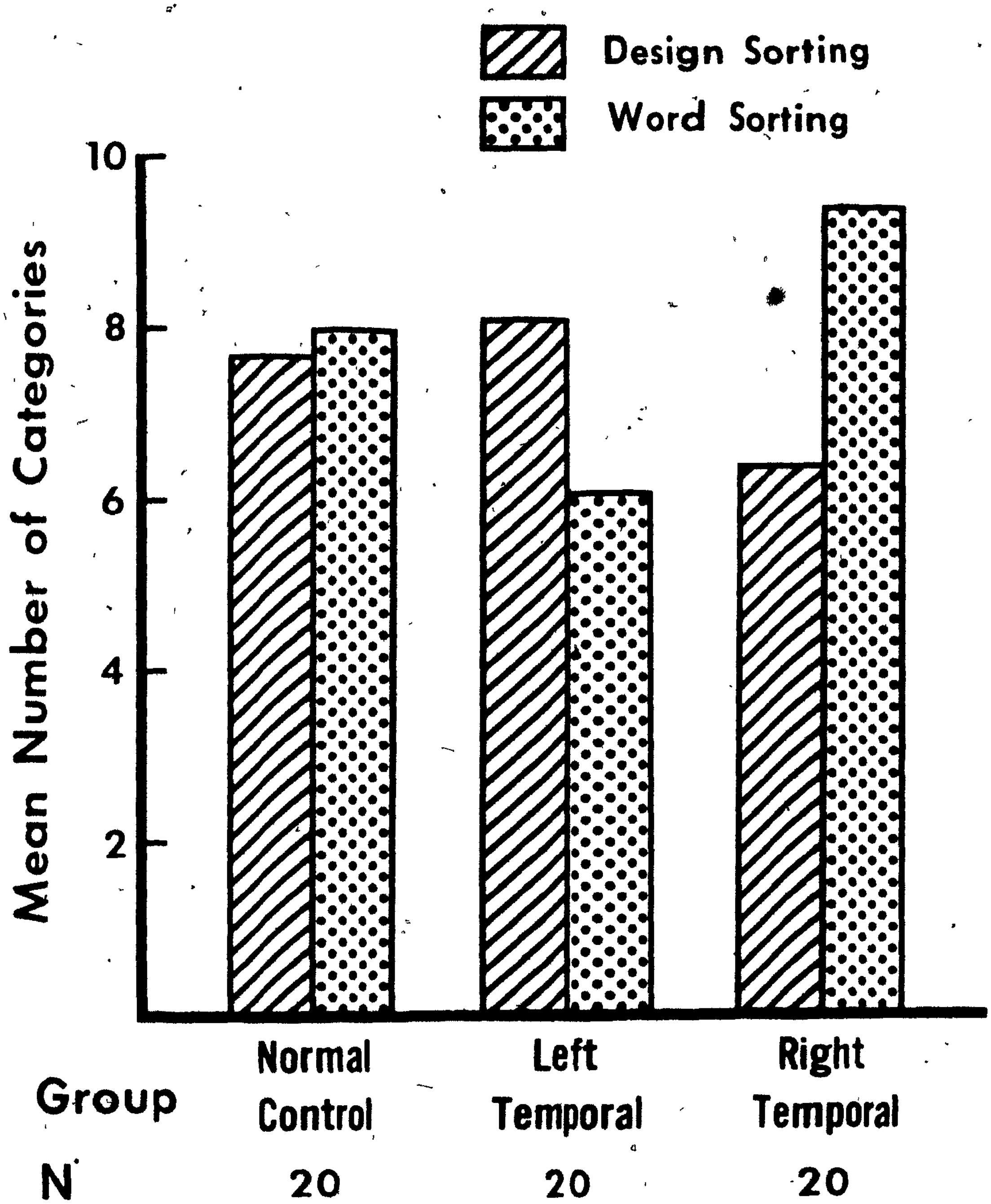

Figure 6. Sorting tasks: categories. Mean number of categories made by the three groups in the design and word-sorting tasks, respectively.

in the two tasks. A two-way analysis of variance showed no reliable group ($F = .93$, $p > .25$) or test ($F = 1.39$, $p > .10$) effects.

The interaction effect, however, was significant. Subsequent t tests showed that neither of the patient groups differed significantly from the normal control group within each sorting task, although the right temporal-lobe group did use more word categories than the left temporal-lobe group ($t = 4.14$, $p < .001$). The interesting results involved comparing the number of categories used in both tasks separately for each subject group. The normal control subjects did not differ in the number of categories used for sorting designs or words ($t = .47$, $p > .50$). However, the left temporal-lobe patients used more design than word categories ($t = 3.14$, $p < .005$), whereas the right temporal-lobe patients used more word than design categories ($t = 4.69$, $p < .001$).

The nature of this interaction can be seen more clearly if one considers the relative number of categories used by each subject for both tests. Table 2 compares the number of subjects in each group who used more design than word categories to the number who showed the opposite pattern ($\chi^2 = 20.69$, $p < .001$). The incidence of subjects using an equal number of design and word categories was not included in the analysis, so as to maintain high expected frequencies in all cells. It is apparent from this table that nearly all left temporal-lobe patients used more design than word categories, whereas most right temporal-lobe patients had more word than design categories. The normal control group was evenly divided among subjects who showed either of these two patterns, or those who had an equal number of words and design categories.

Table 2

Incidence of Subjects Differing in the Number of Categories Used in Each Sorting Test

Group	n[a]	Incidence: Word < Design	Incidence: Word > Design
Normal Control	14	7	7
Left Temporal	19	16	3
Right Temporal	19	2	17

Note. $\chi^2 = 20.69$

$p < .001$

[a]Those subjects having an equal number of word and design categories were not included in the analysis.

Recall

Separate analyses were performed for the recall of the two tasks, as the scoring systems were not directly comparable.

Design sorting. Figure 7 shows the mean design-recall score for the three subject groups. Since there were 30 designs with three possible credits for each design, the maximum recall score a subject could obtain was 90. A one-way analysis of variance was performed on the recall scores, yielding a significant group effect ($F = 14.77$, $p < .001$). It is clear from Figure 7 that the normal control subjects received higher recall scores than either the left ($t = 3.90$, $p < .005$) or the right temporal-lobe group ($t = 5.23$, $p < .001$).

These scores, however, did not take into account the fact that guessing was allowed in the recall. It was possible for subjects to make as many drawings as they wished, with no penalty for a drawing which received no credit at all. By counting the number of subjects who produced at least one drawing that received no credit, it becomes apparent that the left temporal-lobe patients were more cautious than the other two subject groups ($\chi^2 = 12.18$, $p < .005$; see Table 3). In order to take this factor into account in assessing the ability of subjects to recall the designs, an adjusted score was then computed for each subject, in which his total recall score was divided by the number of drawings that he had attempted. This gives the average score for each drawing produced. The mean adjusted scores for the subject groups are illustrated in Figure 8.

Analysis of the adjusted scores again revealed a significant group effect, but this time the right temporal-lobe group received lower

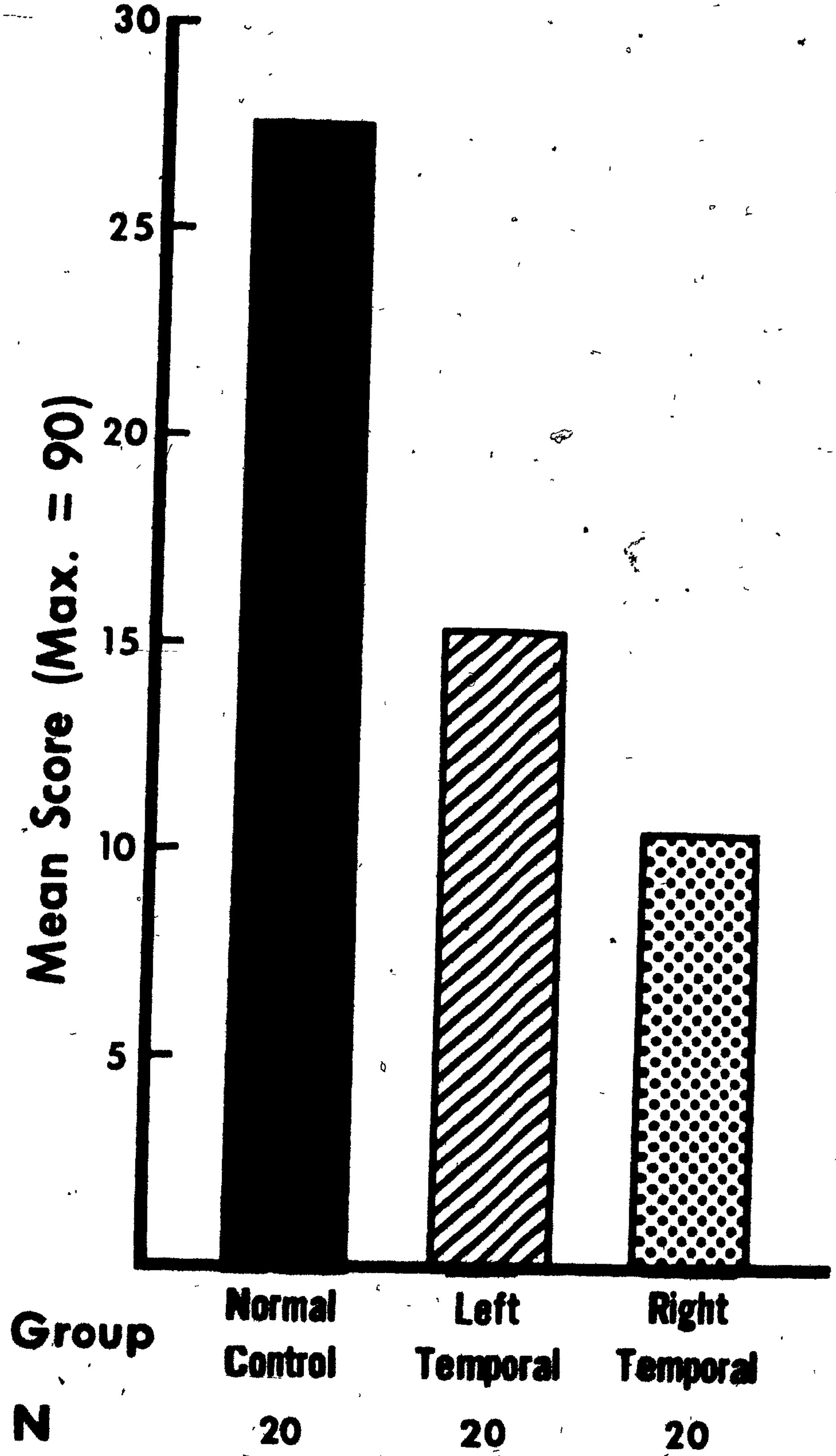

Figure 7. Design sorting: recall. Mean recall scores for the normal and temporal-lobe groups. Each drawing attempted could receive a maximum of three credits.

Table 3

Design Sorting Recall: Incidence of Subjects Receiving No Credit for at Least One Item

Group[a]	Incidence
Normal Control	11
Left Temporal	5
Right Temporal	16

Note. $\chi^2 = 12.18$

$p < .005$

[a] $n = 20$.

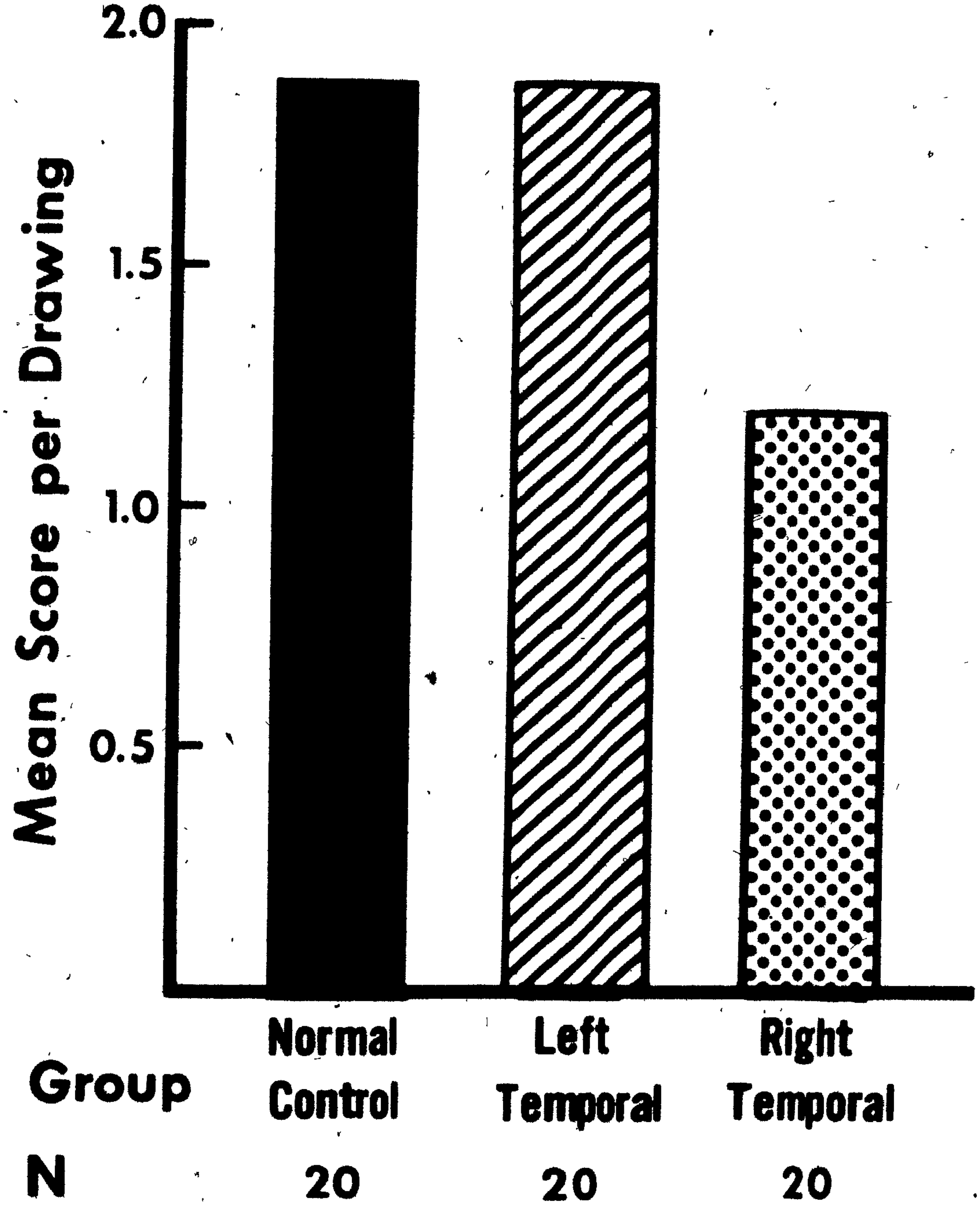

Figure 8. Design sorting: recall. Mean adjusted recall score: each subject's total recall score was divided by the number of attempted drawings, including those that received no credit. This provided a mean score per drawing, and penalized those subjects who tended to guess.

scores than either the normal control (t = 4.54, p < .001) or the left temporal-lobe group (t = 4.56, p < .001). There was no longer any difference between the design recall scores of the normal control and left temporal-lobe groups (t = .02, p > .99).

Word sorting. The converse pattern emerged in the recall of words, as can be seen in Figure 9. A one-way analysis of variance yielded a significant group effect (F = 18.13, p < .001), reflecting the inferior performance of the left temporal-lobe group relative to either the normal control (t = 5.91, p < .001) or the right temporal-lobe group (t = 3.96, p < .001). The difference between the normal control and right temporal-lobe groups was not significant (t = 1.95, p > .25).

In summary, these results demonstrated the material-specific deficits of the left and right temporal-lobe groups in recalling the word and design stimuli, respectively.

Recall as related to extent of hippocampal removal. The extent of unilateral hippocampal resection has been shown to be associated with the performance of certain memory tasks (Corsi, 1972) but not others (Jones-Gotman and Milner, in press). Because the results of the recall tests in the present study had revealed specific memory deficits for each of the temporal-lobe groups, it became of interest to investigate a possible role of the hippocampus in the recall of material that had been organized previously by the subject.

To accomplish this, each of the patient groups was divided into two subgroups, one containing patients with small hippocampal removals (subgroup SM) and one containing those with large removals (subgroup LG). In subgroup SM, the hippocampus was either spared or the removal did not

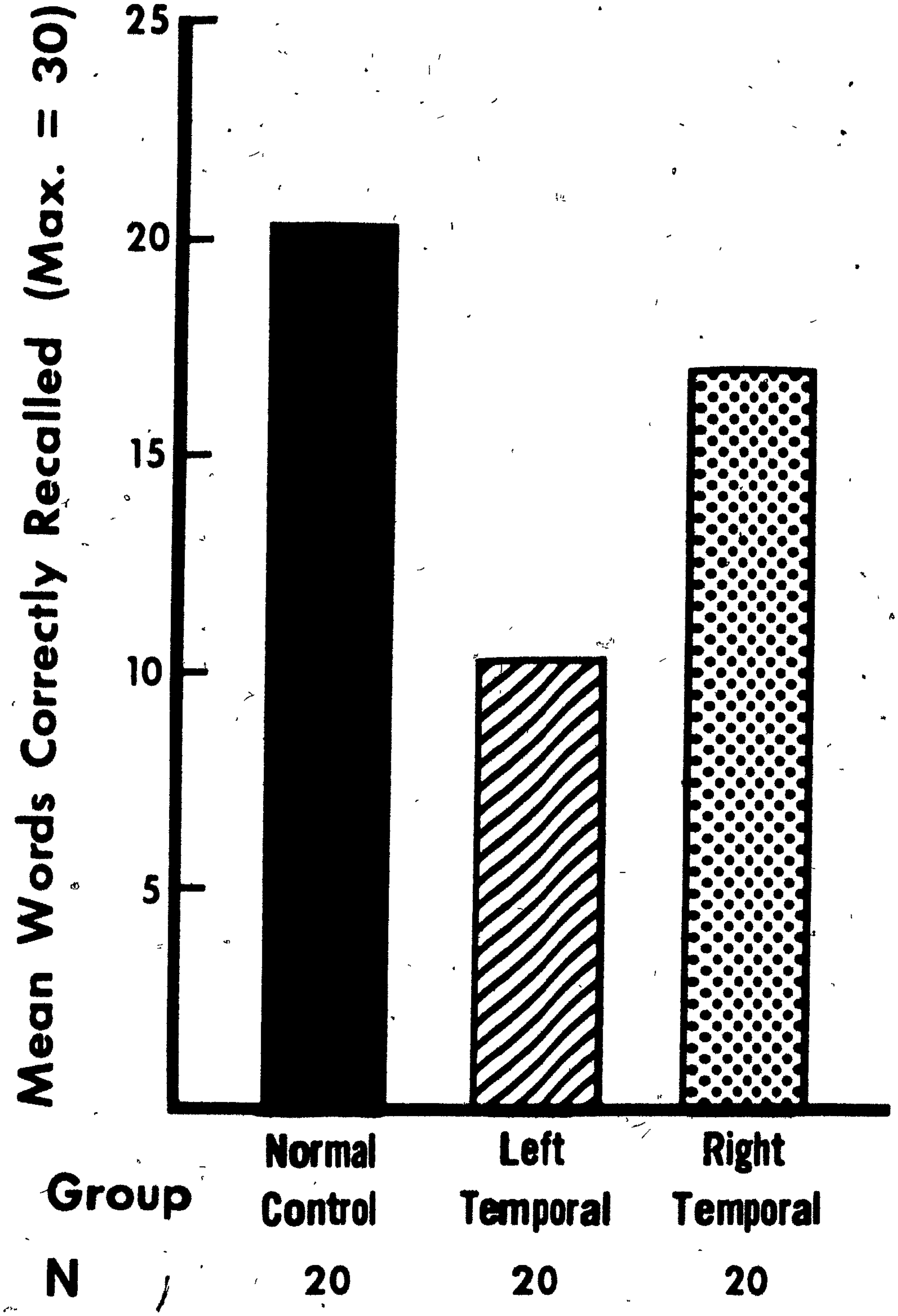

Figure 9. Word sorting: recall. Mean number of words correctly recalled by each of the three subject groups.

exceed the pes of the hippocampus; subgroup LG was composed of all patients having hippocampal removals larger than the pes. Within the right temporal-lobe group, 14 were in subgroup SM and 6 in subgroup LG. Fifteen left temporal-lobe patients were in subgroup SM and five in subgroup LG. In order to reduce the variance in these small subgroups, three left temporal-lobe patients who were noticeably dysphasic during testing were eliminated from the *t* tests for hippocampal effects. This is the case for all such *t* tests performed in the present investigation. One dysphasic patient was in subgroup LG and two were in subgroup SM.

Subgroup analyses were performed only on those comparisons in which the entire patient group had shown a deficit relative to normal control subjects. For the recall tests, no differences were found for any hippocampal subgroup comparisons. The right temporal-lobe subgroups did not differ on the recall of the designs ($t = .0003$, $p > .99$), and the left temporal-lobe subgroups showed no difference on the recall of words ($t = .52$, $p > .6$).

Recall as related to extent of neocortical removal. To explore the contribution of the neocortex to recall performance, correlational analyses were made comparing recall scores on each sorting test with the extent of removal both along the base of the temporal lobe and along the Sylvian fissure. In no case did the correlation approach significance. Correlations for the right temporal-lobe group on the design-sorting recall were: $r = .10$, $t = .43$, Sylvian fissure; $r = .03$, $t = .13$, base of temporal lobe. For the left temporal-lobe group, the correlations for the word recall were: $r = -.15$, $t = .64$, Sylvian fissure, $r = .10$, $t = .43$, base of temporal lobe ($p > .50$ for all comparisons). It should be noted that the three dysphasic left temporal-lobe patients mentioned above were retained in all such correlations.

Recognition

Figure 10 shows the recognition scores of the normal control, left and right temporal-lobe groups for the design and word-sorting tasks, respectively. Because of a ceiling effect in the normal control and right temporal-lobe groups on the word-sorting task, arcsin transformations were performed on all recognition data. A two-way analysis of variance yielded a significant group effect (F = 6.77, p < .005), and a significant task effect (F = 25.15, p < .001), the design-recognition task being more difficult than the word-recognition for all three subject groups. A significant interaction effect (F = 6.16, p < .005) was also found. This interaction reflected the superior performance of the normal control group relative to the right (t = 3.55, p < .005), but not to the left temporal-lobe group (t = 1.92, p > .10) on the design-recognition test, and converse effect on the word-recognition test: normal control subjects recognized more words correctly than left temporal-lobe patients (t = 3.55, p < .005), but did not differ from right temporal-lobe patients in this respect (t = .56, p > .80).

Types of recognition error. Because of the low number of errors made by normal control subjects on the recognition tests of both sorting tasks, the type of distractor items chosen by patients could not be compared statistically to those chosen by control subjects. For the design-sorting task, 92% of the errors made by control subjects involved choosing similar distractors (see Figure 4), as opposed to non-similar distractors. The left and right temporal-lobe groups erred

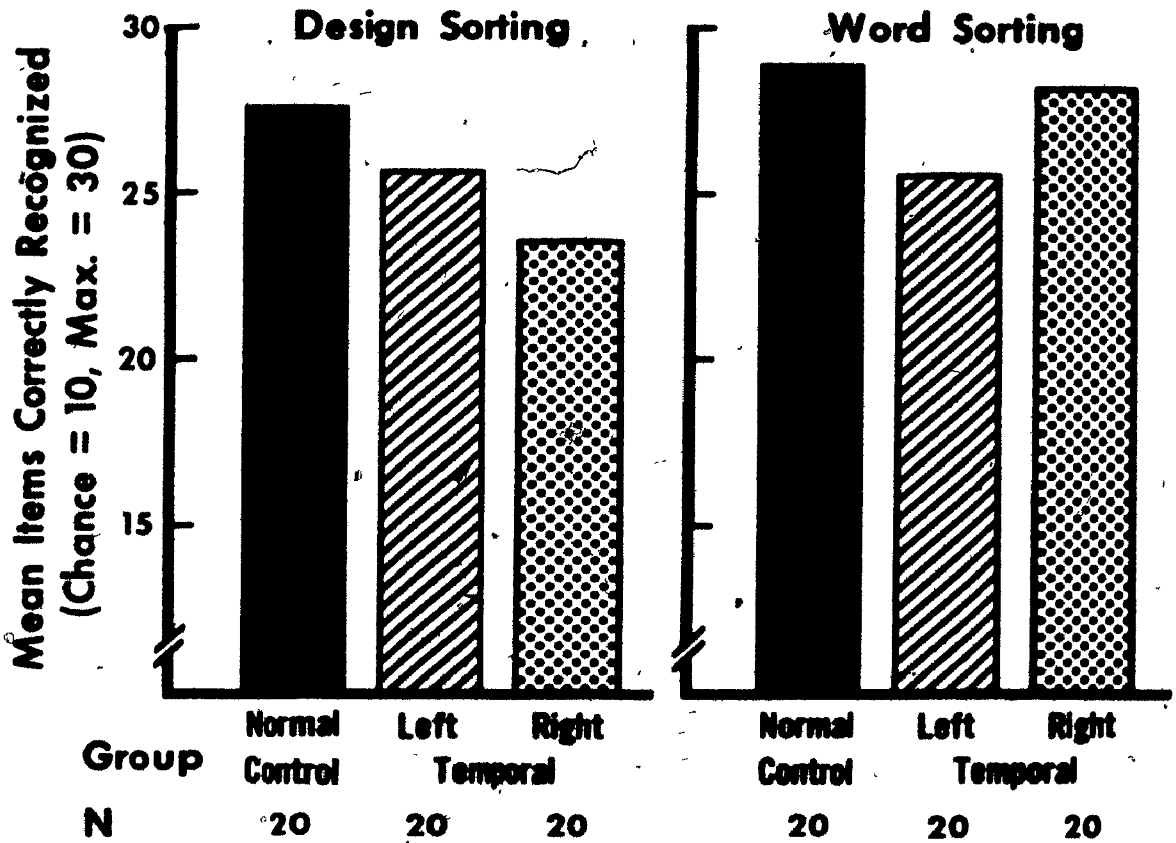

Figure 10. Sorting tasks: recognition. Mean number of items from the design and word-sorting tasks that were correctly recognized by the three subject groups.

by choosing the similar distractor 79% and 85% of the time, respectively. Thus, of those subjects who made an incorrect choice, most had retained some knowledge of the original item, although both patient groups were more likely than the control group to be led astray by items that bore little resemblance to the original designs.

In the word-sorting recognition task, there seemed to be no difference between the subject groups in the type of distractor chosen. Of the total number of recognition errors made by each group, the percentage of semantic distractors chosen was 73, 68, and 77 for the normal control, left and right temporal-lobe groups, respectively. Left temporal-lobe subjects were therefore just as likely as control subjects to remember some aspects of the meaning of a word, even if the word itself had been forgotten.

Recognition as related to extent of surgical removal. Comparisons of the arcsin transformed recognition scores of the hippocampal subgroups yielded no significant differences (t = .16, p > .80, left temporal-lobe subgroup: word recognition; t = .05, p > .99, right temporal-lobe subgroups: design recognition). Correlational analyses of recognition scores with size of neocortical removal were also performed. There was no trend for left temporal-lobe patients with larger cortical removals to perform more poorly on the word recognition task (r = -.15, t = .64, Sylvian fissure; r = -.05, t = .21, base of temporal lobe; p > .50 for both correlations). There was likewise no trend for right temporal-lobe patients with larger removals along the Sylvian fissure to recognize fewer designs correctly (r = -.09, t = .38, p > .50). However, those right temporal-lobe patients with larger removals along the base of the temporal lobe tended to perform more poorly on the design recognition test ($r = -.48$, $t = 2.32$, $p < .05$).

Sorting Strategies

Since the principles that each subject had tried to apply when sorting the stimuli had been recorded verbatim, it was possible to examine these sorting strategies to see if there were any systematic differences between either of the patient groups and normal control subjects in this respect.

Design sorting. It was noted that the category descriptions that some subjects gave did not accurately describe the category. For example, one subject with a right temporal-lobe removal (El. Bo., I.Q. 102) described one of her categories as: "anything with a circle in it". This included numbers 11, 12, 26, 8, 15, 1, 22, and 4 (see Figure 1). The latter two items of this category do not contain circles, and the last item (a large and a small square) does not even contain a curved line. Another right temporal-lobe patient (Jo. La., I.Q. 117) made a category which he said contained "squares or rectangles": numbers 13, 22, 4, 8, and 16. Again, the last item has nothing resembling a square in it. An analysis was made of the number of subjects in each group who made such errors of classification at least once. It can be seen from Table 4 that the incidence is higher in patients with right temporal-lobe lesions than in the other two subject groups ($\chi^2 = 6.95$, $p < .05$).

Another strategy used by some subjects was to label the designs as real objects and group them accordingly. An interesting example of this was produced by a right temporal-lobe patient (Ro. Sm., I.Q. 119),

Table 4

Design Sorting: Incidence of Subjects Making Categories that Contained Classification Errors, Semantic Labeling, or Combinations

	Incidence		
Group[a]	Classification Errors*	Semantic Labeling**	Combinations***
Normal Control	7	1	4
Left Temporal	9	6	3
Right Temporal	15	8	9

[a] $\underline{n} = 20$ for each group.

*$\chi^2 = 6.95$, $\underline{p} < .05$

**$\chi^2 = 6.93$, $\underline{p} < .05$

***$\chi^2 = 5.29$, $\underline{p} > .05$

who grouped numbers 21, 16, 5, and 1 together, and explained that they indicated "rain on the mountains, electricity, fog and temperature change". It was found that both patient groups tended to name the designs more than did normal subjects ($\chi^2 = 6.93$, $p < .05$; see Table 4: semantic labeling).

There were certain sorting principles that almost all subjects used, such as straight lines, curves, or squares. Subjects only differed in the extent to which they would include items within each category; for example, squares could be a separate category, or be included in a category of straight lines. Presumably, the tendency to use larger categories when sorting designs, as compared to words, which was shown by the right temporal-lobe patients, was a function of this over-inclusiveness. In fact, these patients tended to combine two sorting principles in one category; for example, a group described as containing "rectangles, cubes, or triangles", and consisting of numbers 18, 4, 3, 28, 13, 22, 6, and 8, was made by a right temporal-lobe patient (Ha. Gr., I.Q. 111). This trend, however, was not significant ($\chi^2 = 5.29$, $p > .05$; see Table 4: Combinations).

Word sorting. As in the design-sorting task, there were certain categories that were used by a large number of subjects, with varying degrees of inclusiveness. For example, the group "live being" could include any of the following: author, artist, pupil, creature, snake, or devil; it could also include majority or colony, since these usually refer to people. Some subjects broke this into separate categories, such as "professions", "animals" or "evil beings". It must be assumed that the larger categories used by patients with left temporal-lobe lesions when sorting words as opposed to designs reflected a tendency to be overly inclusive. It proved difficult to delineate more specifically the nature of this inclusiveness, because of the wide variation from subject to subject.

A strategy that was used by many subjects was to devise sentences incorporating several of the stimulus words in order to form a grouping. Statistical analysis of the number of subjects who used this strategy at least once revealed that patients with right temporal-lobe lesions devised sentences more often than did the normal control or left temporal-lobe groups ($\chi^2 = 10.72$, $p < .005$; see Figure 11). The following examples from the groupings of right temporal-lobe patients illustrate the nature of these sentences. "In early times, Jewish lawmakers were <u>authors</u> of various <u>theories</u> which evolved into <u>codes</u>; and all had <u>pupils</u>, lived in <u>palaces</u>, and did not believe in the <u>devil</u>" (Sh. Fr., I.Q. 90). "If you don't have the proper <u>code</u>, you won't last long in the <u>palace</u>" (Ca. Sc., I.Q. 137). "The <u>dust</u> won't settle and the <u>shadow</u> won't remove until the constitution is brought back to this country, which is being treated like a <u>colony</u>" (Ka. Fi., I.Q. 118).

<u>Performance of H.M. on Sorting Tasks</u>

<u>Design sorting</u>. H.M. sorted the designs in three minutes, 56 seconds, into six categories. This number of categories is slightly below the mean of the right temporal-lobe group (6.4 categories). His sorting strategies could not be considered to be as good as those used by normal control subjects. For example, one category that he made, containing numbers 16, 1, 14, 2, and 27 (see Figure 1), he said consisted of "signs of water, a lot of water; lakes". This tendency to name the

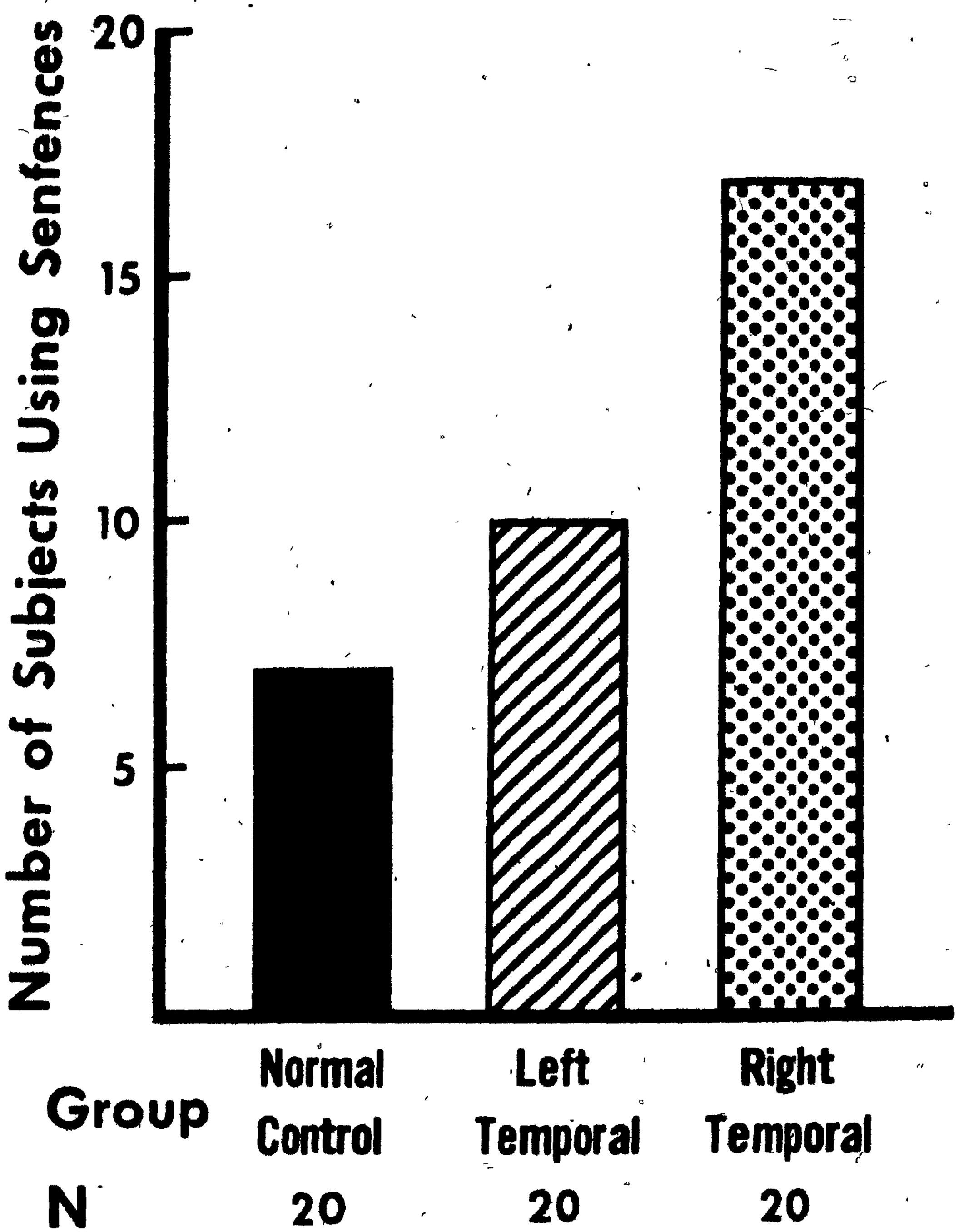

Figure 11. Word sorting: sentence strategy. Incidence of subjects in each group who formed at least one category by building the stimulus words into a sentence.

designs, as mentioned above, occurred significantly more often in the patient groups than in the control group.

H.M.'s recall and recognition of the designs were very poor, as expected. He received a recall score of 6 (see Figure 7 for comparisons with temporal-lobe and control groups), although he made a large number of drawings (9) for such a low score (the mean number of attempts for the normal control, left and right temporal-lobe groups were 14.5, 8.6, and 10.1, respectively). His recognition score was 11 correct out of 30, 10 being chance performance. The error scores were evenly divided between similar and non-similar distractors. Thus, H.M. was less likely than patients with unilateral temporal-lobe removals to retain partial information about designs that he was unable to recognize.

Word sorting. H.M.'s sorting of the word stimuli was generally better than his design sorting. He made ten categories, using such common groupings as: creature, devil, and snake ("low spirits"); safety, steam and engine ("motors"); and pupil, author and artist ("all write"). He recalled one word correctly, string, which was the last word that he had sorted. He also produced five other words that seemed totally unrelated to any of the word-sorting stimuli, and which, it should be noted, are highly concrete words ("squares, ladders, lightning bolt (flash), clouds, and lock"). On the recognition test he again performed at chance, choosing 12 out of 30 stimuli correctly. Of the distractor items that he chose, 11 were semantic and 7 acoustic; thus 62% were semantic, roughly the same percentage found in all subject groups in this study.

Discussion

The sorting tasks were designed to determine whether patients with temporal-lobe lesions differed from normal control subjects in their ability to organize random information, as measured by the number of categories that each group used to sort either verbal or nonverbal stimuli. The outcome was that the patient groups produced a different pattern of sorting than did the control group. Whereas normal control subjects were as likely to form more word than design categories as to show the opposite pattern, patients with temporal-lobe lesions tended to produce fewer categories when sorting the material that they subsequently would have the greater difficulty remembering. Thus patients with left temporal-lobe lesions used fewer word than design categories, and patients with right temporal-lobe lesions used fewer design than word categories.

Although the above relation of word to design sorting differentiated the temporal-lobe groups from the control group, the patient groups did not differ from the control group in the number of categories used for each sorting task considered separately. A possible reason for this lack of difference is that the "deficit" shown by each patient in sorting material that would be poorly-recalled may be a very subtle one, which only becomes apparent when compared to the performance of the same patient when sorting more easily-remembered material.

There are other factors that may have obscured any differences between the control and patient groups. The expected correlation between the number of categories used to sort the material, and subsequent recall of that material was clearly shown by normal control subjects on both the word and design-sorting tasks; the same correlations were not found in the patient groups except for the case of left temporal-lobe patients sorting words, where the correlation was marginally significant. This relative independence of sorting strategy from recall may indicate that patients with temporal-lobe lesions are not able to modify their strategies on sorting tasks in order to optimize recall, as Melkman (1975) has suggested that normal subjects can do. This in itself represents a deficit, which is not material-specific, in the ability of temporal-lobe patients to organize random information. Such an inability to modify one's sorting strategy according to one's own cognitive and mnemonic limitations would tend to obscure group differences when using quantitative measures, such as the number of categories produced.

Another variable that complicates the interpretation of the "number of categories" results is the type of sorting strategies used by the patient groups. For example, both right and left temporal-lobe patients tended to use semantic labeling of the designs as a strategy in sorting the designs, and right temporal-lobe patients tended to make sentences in order to sort the words. Since normal control subjects rarely used such strategies, it is not known how this variation in sorting strategy among subject groups affected the relationship of the number of categories to subsequent recall. A consideration of these differences in sorting strategy may indicate that it is more valid to compare the performance of each patient group on one sorting task to its performance on the other, rather than to compare each task to the performance of a normal control group.

Despite these limitations in comparing the control group to the patient groups in terms of the number of categories used in each sorting task, the fact remains that this measure did show that temporal-lobe groups used fewer categories when sorting mnemonically-difficult material as compared to their own performance on the other sorting task. Two explanations can be considered to account for this finding. One possibility is that these sorting tasks require a certain amount of memory processing if the subject is to keep track of the items that he is grouping together. If this were the case, then a patient with a material-specific memory disorder would be unable to perform adequately. Since the stimuli were kept in full view at all times, however, it seems unlikely that a memory component could have been solely responsible for the results.

The second, and most plausible interpretation of the data is that the two patient groups were impaired in their cognitive processing of the stimulus material at the time of sorting. For example, patients with temporal-lobe lesions may be unable to assign a wide variety of specific attributes (Underwood, 1969) to each stimulus. Thus, a patient with a left temporal-lobe lesion may think of a snake as being alive, and not consider other semantic attributes, such as its being an animal, being associated with evil, and so on. This would lead to the formation of larger categories, each of which would contain loosely associated items.

If it is the case that temporal-lobe patients are impaired in their ability to form small, relatively specific categories when sorting mnemonically-difficult material, it is still not clear whether such an impairment would contribute to the material-specific memory deficits of these patients. There is some evidence, however, that encoding of verbal material into larger, less specific categories may be detrimental to recall performance in normal subjects. Fraise and Kamman (1974) have shown, within an incidental learning paradigm, that subjects recall more words if the search task has involved instances of a specific class (e.g., names of vegetables) rather than of a more general class (e.g., food). Klein and Saltz (1976) have suggested that when a list is differentiated into only a few categories, the attributes or levels of meaning attached to each category are not closely associated to most of the items within each category. These authors showed that greater specificity of semantic processing, as measured by the number of relevant attribute dimensions introduced at the time of learning, led to improved recall performance.

In terms of the levels-of-processing model (Craik & Lockhart, 1972), one could postulate that subjects who sort into specific categories are forced to evaluate more features for each item, in order to determine if that item will be suitable for a certain category. More detailed feature evaluation will lead to a greater breadth of processing (Craik & Tulving, 1975), and thus to better recall. Patients with temporal-lobe lesions are perhaps unable to perform such feature evaluation adequately, leading them to use larger, less differentiated categories. The recall performance of these patients would be expected to suffer as a result.

The lack of correlation for the patient groups between recall score and number of categories, however, would preclude the assertion of a causal relationship between impaired cognitive ability and defective recall. Although patients with temporal-lobe lesions show qualitative and quantitative impairments in their ability to sort mnemonically-difficult stimuli, the present data do not permit conclusions to be drawn about the effect that such impairments may have on memory.

Since the design-sorting task was an original test, devised to be analogous to the word-sorting task, it is worth noting that the average numbers of categories produced by all three groups in the word- (7.83) and design- (7.4) sorting tasks were nearly identical. This suggests that whatever principles are involved in sorting words may also be in operation in sorting designs. The number of categories produced by the normal control subjects in the word-sorting task of the present study (8) is somewhat lower than the number found in the Melkman (1975) study (9.8) or the Basden and Higgens (1972) study (8.6), but is remarkably similar to these values considering that those two experiments used 50 and 52 words respectively, whereas the present one used only 30 words. In addition, the subjects in both previously-mentioned studies were undergraduates, and thus more highly educated than most subjects in this study.

Patient H.M.

The pattern of sorting shown by H.M. on the two tasks resembles that of the right temporal-lobe patients in that he produced fewer design than word categories. This patient's poor sorting of the designs was unexpected, as he had been shown to perform normally on many non-verbal tasks that do not contain a memory component (Milner & Taylor, 1972;

Prisko, 1963; Sidman, Stoddard & Mohr, 1968). H.M.'s impaired design sorting should be interpreted cautiously, however, as normal subjects show marked individual variation on these tasks.

Since H.M.'s sorting of the words was in the normal range, it cannot be assumed that the hippocampal region plays a critical role in the performance of the sorting tasks. Unlike the patients with unilateral temporal-lobe removals, H.M. has an intact temporal neocortex bilaterally. His adequate word-sorting performance would tend to implicate the left temporal neocortex in the ability to categorize verbal information, because left temporal-lobe patients had shown an impairment on the word-sorting task. Perhaps the correlation between the number of categories produced and subsequent recall performance depends on intact connections between the cortex and the hippocampal structures, thus explaining the breakdown of this relationship in the temporal-lobe groups and in H.M.

The results of the sorting studies reported here help to clarify the nature of the categorization process. It is neither purely perceptual nor purely verbal, but depends instead on the type of material being categorized. In a reaction-time study of normal subjects, Harris, Morris and Bassett (1977) showed that the categorization of words or of pictures of common objects depends on two distinct codes. The present investigation suggests that these categorization processes are at least partially separable systems within the cerebral cortex, with the left hemisphere more involved with verbal, and the right with non-verbal, categorization.

PART II: MEMORY FOR NON-CATEGORIZED AND CATEGORIZED LISTS

In the experiments in this section, the recall and recognition of two word lists containing different degrees of taxonomic organization were studied. The performance of patients with temporal-lobe lesions and of normal control subjects was measured in terms of "primary" and "secondary" organization (Tulving, 1968), in order to determine to what extent deficits in the ability to organize verbal material in memory may contribute to the verbal memory difficulties of patients who have undergone left temporal-lobe removal.

Material

Two word lists were prepared, one consisting of unrelated words (the non-categorized list) and one of words from five different taxonomic categories. Each list contained 30 words. Stimuli for both lists were obtained from the category norms of Battig and Montague (1969), all words being chosen from the 12 most frequent words in each category. The items in the non-categorized list each came from a different category, and were therefore considered to be semantically unrelated. The categorized list contained five sets of six words each, taken from the following categories: fruit, clothing, vehicles, geographical features, and furniture.

Three different pseudo-random presentation orders were prepared for each list, with the stipulation that no two words should be adjacent on more than one presentation, and that no adjacent words should begin with the same sound. In the categorized list no words from the same category occurred consecutively.

The 30 words in the non-categorized list, given in the first presentation order, were: fork, nose, penny, football, governor, pine, ruler, guitar, rat, doll, ruby, storm, motel, waltz, captain, paper, velvet, window, gold, brandy, canoe, daffodil, corn, boot, church, spider, cannon, nephew, ketchup, and china. The first presentation order of the categorized list was: valley, apple, stool, dress, wagon, cherry, volcano, television, pants, chair, plum, car, lamp, coat, sofa, lake, apricot, cliff, hat, bus, river, tie, bureau, truck, pear, bicycle, canyon, blouse, lemon, and train. The words in both lists were matched for frequency, word length, and number of syllables. These are shown in Table 5.

A recognition test was constructed for each list. For the non-categorized list, each target word had two distractors, one semantic and one phonemic. The semantic distractor was chosen from the top 20 in the same category of the Battig and Montague norms (e.g., spoon for fork, nickel for penny). The phonemic distractors began with the same first two letters as their target item and had the same number of syllables (e.g., fort for fork, pebble for penny). Each of the five pages of the recognition test contained 18 words; 6 target words and 12 distractors. To make the test more difficult, the distractor items never occurred on the same page as their target word, because pilot testing had shown that subjects were more often deceived by a distractor when they could not compare it with the correct item.

The recognition test for the categorized list contained only semantic distractors. This was the same method used by Kintsch (1968) for testing item recognition rather than category recognition. Each

Table 5

Composition of Word Lists

	Frequency per 50,406 words[a]		Number of letters		Number of syllables	
List	Mean	Range	Mean	Range	Mean	Range
Non-Categorized	41.23	1-384	5.37	3-8	1.7	1-3
Categorized	41.83	1-274	5.07	3-7	1.6	1-3

[a]Kucera and Francis, 1967.

page of 18 words in the recognition test contained all of the 6 words from one category, together with 12 distractor items chosen from the top 20 in that same category.

Both word lists and their recognition tests were also translated into French, selecting appropriate phonemic distractors for the non-categorized recognition test. An attempt was made to match the English and French versions for word length. The frequency of these words among speakers of Canadian French is assumed to approximate their frequency in English.

Procedure

The non-categorized list was always given first, on a different day than the categorized list. This order was kept constant to reduce inter-subject variance. Except where otherwise stated, the procedure was the same for both word lists.

The subject was told that he would be read a long list of words, that at the end of the list the experimenter would say "OK", and that the subject should then immediately say all the words he could remember from the list, in any order. It was emphasized that he should only give his recall, and not say anything else, because preliminary testing had shown that some subjects tended to insert complaints about the length of the list (and thus reduce recency effects), unless forewarned not to talk.

Two minutes were allowed for recall of the list, with the experimenter recording the subject's responses. The list was then read again, but in a different order, with the instruction that the subject should say all the words he could remember, including any he had said in the first recall. This reminder was necessary because it had been noted that some subjects tried not to say items that had been previously recalled. Two minutes were allowed for this second recall. The list was then read a third time in a different order, with another two-minute recall. The subject was then warned that he would be asked to recall the words again later.

After a 45-minute interval, which was filled with tasks of a non-verbal nature, the subject was again given two minutes in which to recall all the words that he could remember from the list.

The delayed recall of the non-categorized list was followed by the recognition test for that list. The subject was given the five pages of the test and asked to circle the six words on each page that he thought had been on the list. He was told only to choose words that were exactly the same as those that had been read to him. If unsure of an answer, subjects were asked to guess.

Following the delayed recall of the categorized list, the subject was asked whether he had noticed whether any of the words seemed to go together, and, if so, which of these category names he could recall. As he gave the category names he was asked to recall all the words in each category. If a subject could not name all five categories, he was given the remaining category names and asked to recall as many words from each category as possible. All words recalled at this time, whether the category name was recalled by the subject or provided by the experimenter, constituted the "cued recall". The categorized recognition test followed the cued recall, the procedure being the same as that of the non-categorized recognition test.

Results

Recall

Figure 12 compares the learning curves and the mean delayed-recall scores of the three subject groups for the non-categorized and categorized word lists. A three-way analysis of variance comparing subject groups, word lists and recall trials (first, second, third and delayed) was performed. This produced a significant group effect ($F = 21.12$, $p < .001$), left temporal-lobe patients having lower recall than both normal control subjects ($t = 6.27$, $p < .001$) and right temporal-lobe patients ($t = 4.77$, $p < .001$). There was no difference between the right temporal-lobe and normal control groups ($t = 1.49$, $p > .25$).

The difference between recall trials was highly significant ($F = 236.93$, $p < .001$), as was the subject-group by recall-trial interaction ($F = 10.20$, $p < .001$). This interaction is illustrated in Figure 13, in which the mean recall of each subject group has been pooled over both word lists. The interaction results from the fact that the performance decrement of the left temporal-lobe group, as compared to that of the pooled normal control and right temporal-lobe groups, progressively increased over each succeeding recall. The mean differences for such comparisons on each of the four recall tests were: 4.43, ($t = 4.16$); 5.52, ($t = 5.18$); 5.88, ($t = 5.52$); and 9.14, ($t = 8.58$), respectively ($p < .001$ for all recall tests).

The effect of lists was also highly significant ($F = 122.93$, $p < .001$); the categorized list helped all subjects to improve their recall as compared to the non-categorized list. In addition, the interaction of list with recall test was significant ($F = 9.95$, $p < .001$).

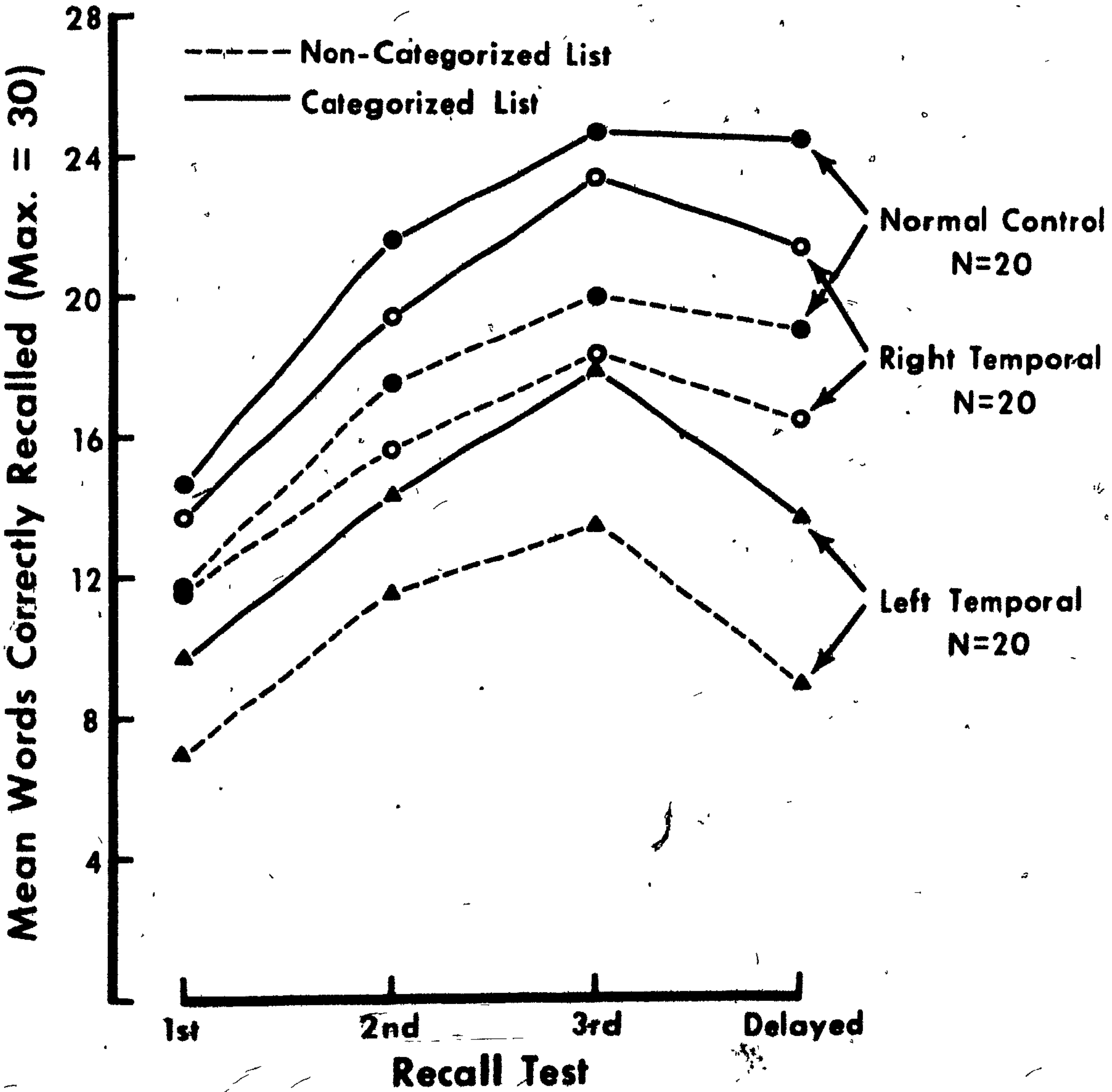

Figure 12. Word lists: recall. Learning curves and delayed recall for the non-categorized and categorized word lists, showing the mean number of words correctly recalled per trial. Results are given for each of the three subject groups.

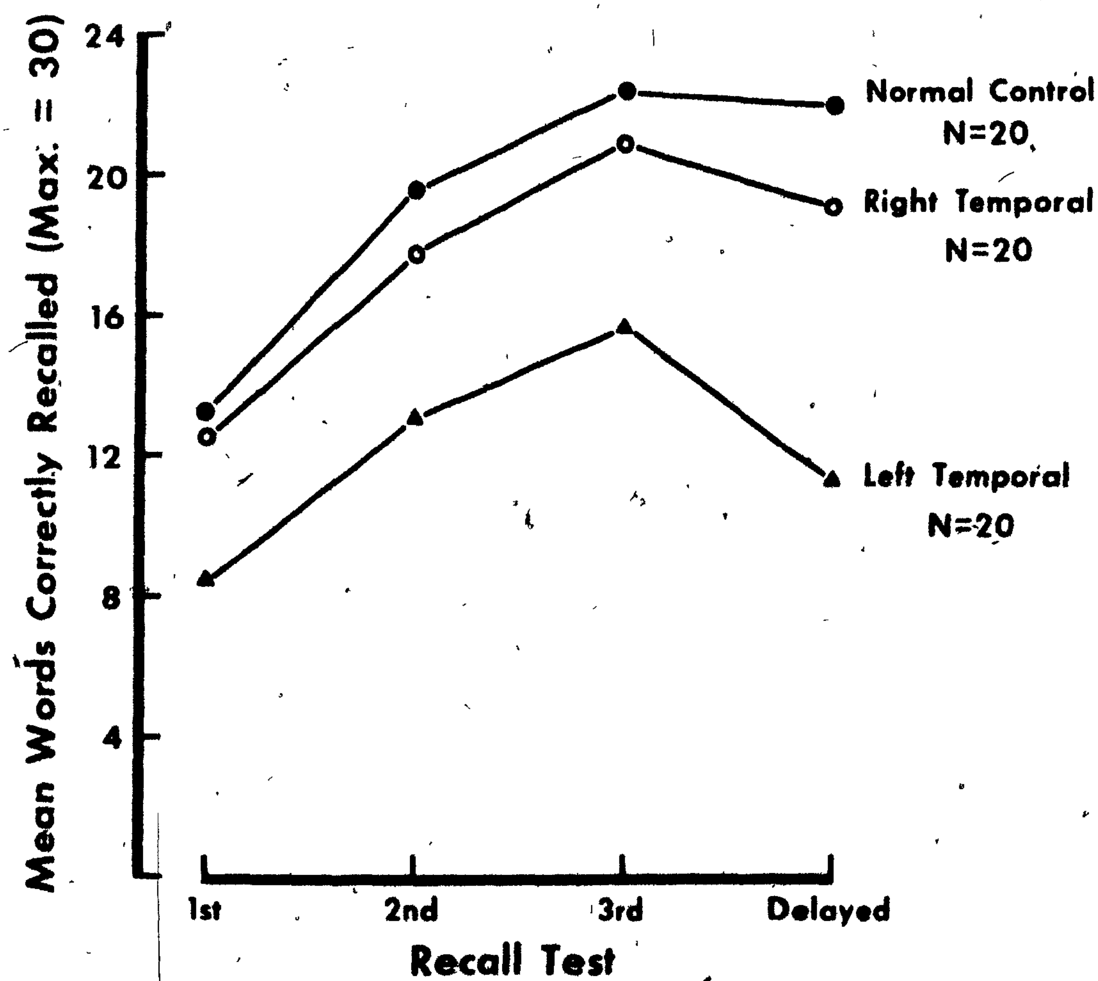

Figure 13. Word lists: recall. Learning curves and delayed recall for the three subject groups. The mean number of words correctly recalled per trial have been pooled over the non-categorized and categorized lists.

This effect can be seen in Figure 14, where the mean first, second, third and delayed recall for each word list is pooled over all three subject groups. The categorized word list became more helpful in improving recall with each succeeding presentation, and in delayed recall. The mean differences between the word lists for each recall trial were: 2.62, (t = 5.55); 4.2 (t = 8.9); 4.72 (t = 10.0); and 5.05 (t = 10.7), respectively (p < .001 for all recall trials). Note that the rate of improvement was greatest from the first recall test to the second, there being little change in subsequent recall tests. The amount of improvement in recall did not vary across subject groups; the interaction of groups with word lists was not significant (F = .31, p > .5), nor was the group-by-list-by-recall-test interaction (F = .40, p > .5).

Recall as related to extent of hippocampal removal. As in the analysis of the sorting experiments, the left temporal-lobe group was divided into two subgroups: SM, containing patients with small hippocampal removals, and LG, containing patients with large hippocampal removals. A three-way analysis of variance was performed on the recall scores of the two left temporal-lobe subgroups, comparing large and small hippocampal removals, word lists, and recall trials. The results are illustrated in Figure 15, which shows the mean recall scores of subgroups SM and LG for each recall trial. Results for the non-categorized and categorized lists are graphed separately, to illustrate the significant interaction of subgroup with word list (F = 4.8, p < .05). Although the subgroups did not differ in their non-categorized recall scores (t = .78, p > .2), there was a difference in the amount of improvement each group

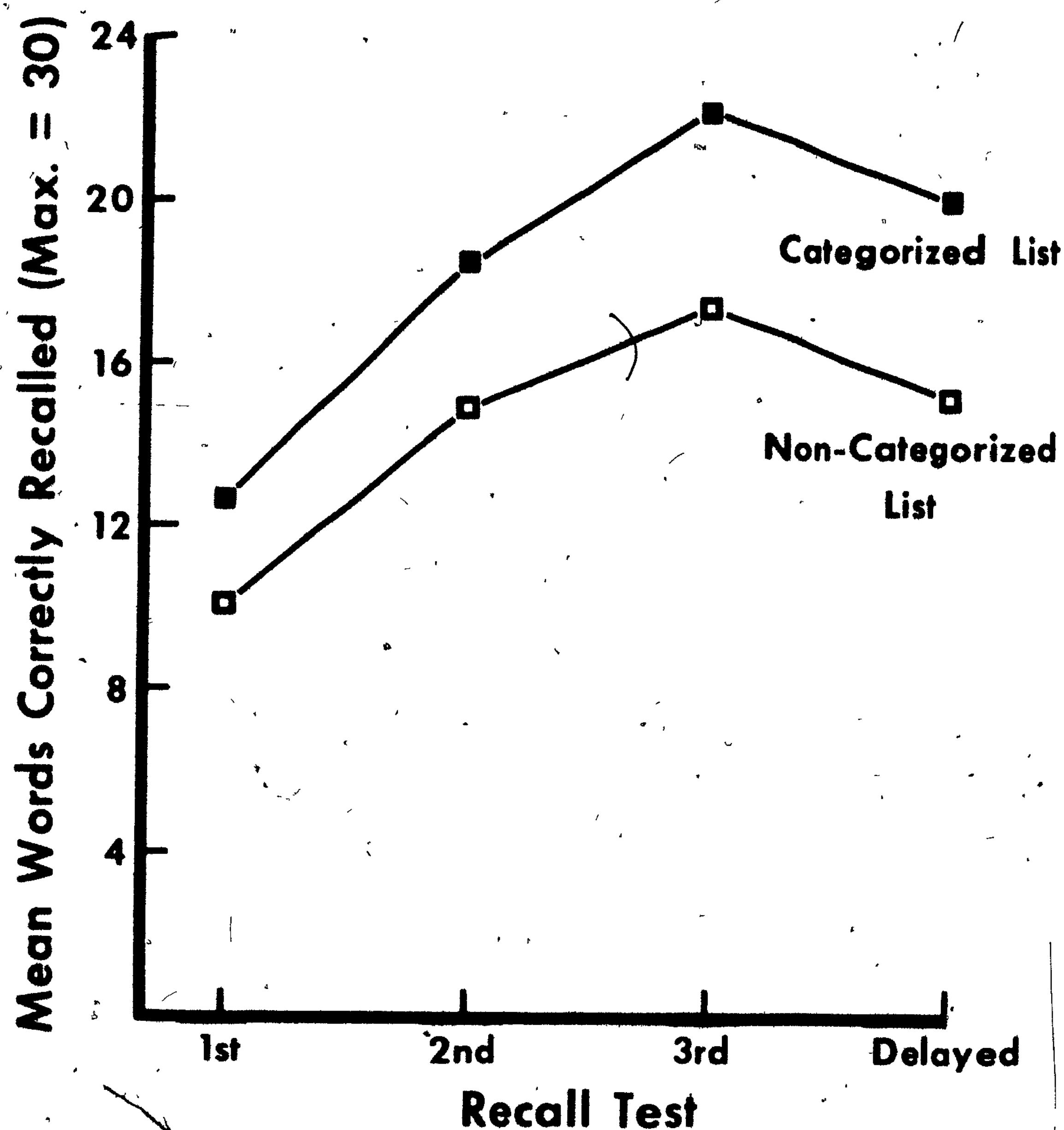

Figure 14. Word lists: recall. Learning curves and delayed recall for the non-categorized and categorized lists. The mean number of words correctly recalled per trial have been pooled over the three subject groups.

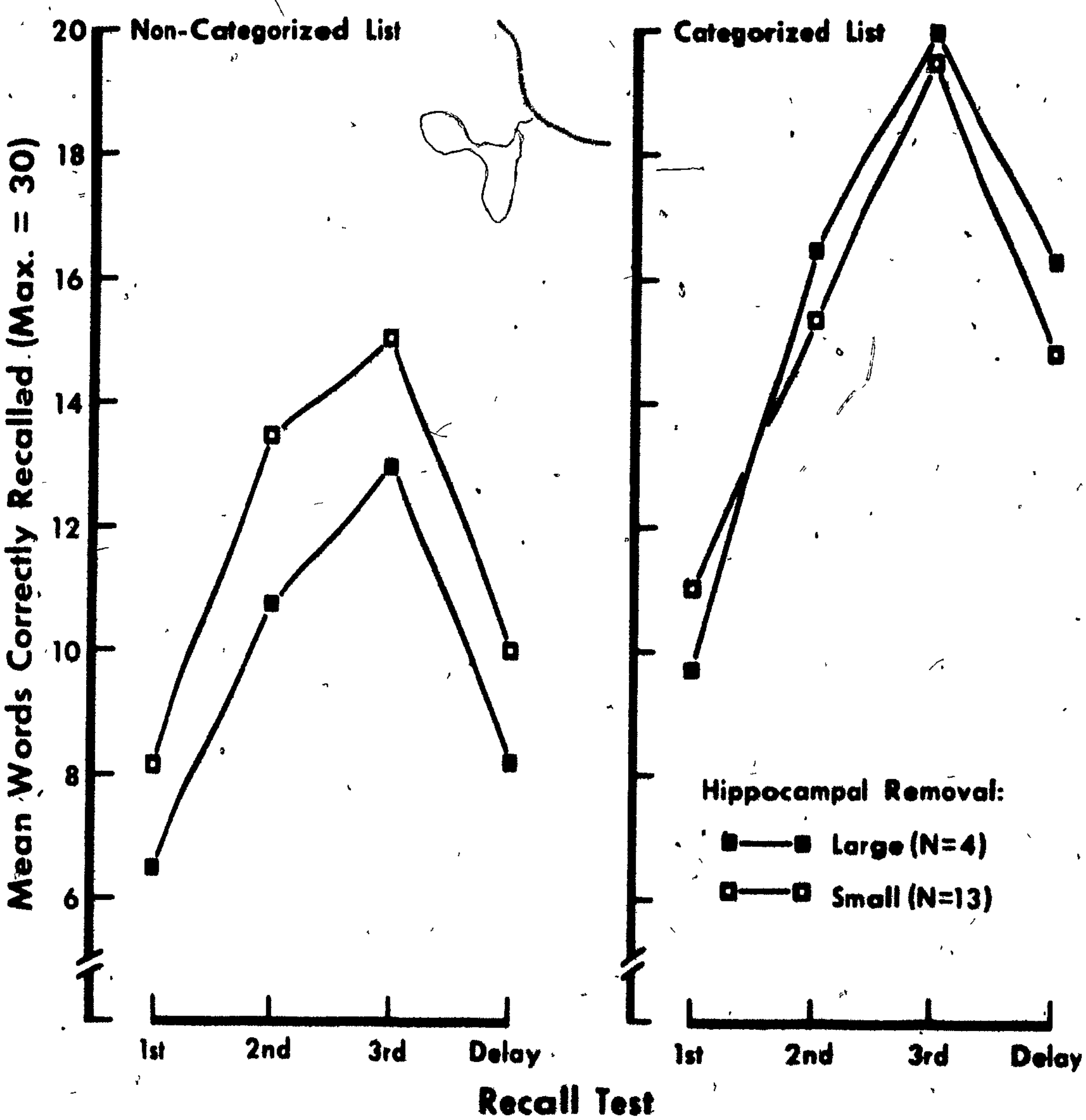

Figure 15. Word lists: recall. Learning curves and delayed recall scores for the left temporal-lobe subgroups, showing the mean number of words correctly recalled on each recall trial of the non-categorized and categorized word lists.

showed on the categorized list. Both groups made a significant increase from the non-categorized to the categorized list, but the patients with larger hippocampal removals showed a more significant gain ($t = 4.11$, $p < .005$, subgroup SM; $t = 7.21$, $p < .001$, subgroup LG). This result suggests that the hippocampal region is important for the recall of non-organized information. As before, the main effects of word lists ($F = 65.15$, $p < .001$) and recall trial ($F = 45.09$, $p < .001$), and the list-recall interaction ($F = 15.01$, $p < .005$) were significant. The interaction of subgroup with recall trial was not significant ($F = .22$, $p > .80$).

Recall as related to extent of neocortical removal. Correlations were made between the extent of neocortical removal, measured both along the left Sylvian fissure and along the base of the temporal lobe, and performance on each recall trial of both the categorized and non-categorized lists. In no case did these correlations approach significance, although almost all were in the appropriate direction; i.e., larger lesions correlated with poorer performance, particularly in earlier recall trials (see Table 6).

Non-Categorized List: Serial Position Curve

In order to explore the contribution of interference to the memory deficit of patients with left temporal-lobe lesions, and to examine their ability to consolidate verbal information, the serial position curve of the first recall trial in the non-categorized list was examined statistically. For this trial, the recall of each subject was tabulated according to the position each word recalled had occupied during presentation. For purposes of analysis, these input positions were grouped

Table 6

Correlations Between Recall and Size of

Neocortical Removal for Left Temporal-Lobe Group

	Recall Trial			
Word List	First	Second	Third	Delayed
Sylvian Fissure				
Non-Categorized	-.34	-.20	-.15	.06
Categorized	-.36	-.22	-.24	-.15
Base of Temporal Lobe				
Non-Categorized	-.17	-.11	.13	.12
Categorized	.05	-.01	-.14	.07

Note. $p > .1$ for all correlations.

into six sections of five words each. Thus the primacy effect would involve recall of any of the first five words that had been read to the subject.

The normal control, left temporal- and right temporal-lobe groups were compared in a two-way analysis of groups and recall positions. Figure 16 presents the serial position curves for the three subject groups; each portion of the curve represents the mean number of words recalled of the five that had been presented in those positions. As expected, significant group ($F = 16.24$, $p < .001$) and position ($F = 24.89$, $p < .001$) effects were obtained; the former reflecting the overall inferior recall performance of the left temporal-lobe group, and the latter indicating the serial position effect: superior performance in the first and last positions over the middle positions, for all groups.

The most interesting finding, which can be seen in Figure 16, was that the recall of the left temporal-lobe group did not differ from that of the normal control or right temporal-lobe group in the primacy or recency portions of the curve. The only striking deficit was in the four middle sections; those that are thought to be most affected by interference. This was born out by a significant interaction effect ($F = 1.84$, $p < .05$). Subsequent t-tests comparing the left temporal-lobe group to the pooled normal control and right temporal-lobe groups (beginning with the primacy and ending with the recency portion of the curve) illustrate this effect clearly: $t = 1.71$, $p > .1$, section one; $t = 4.34$, $p < .001$, section two; $t = 5.79$, $p < .001$, section three; $t = 3.93$, $p < .001$, section four; $t = 2.73$, $p < .05$, section five;

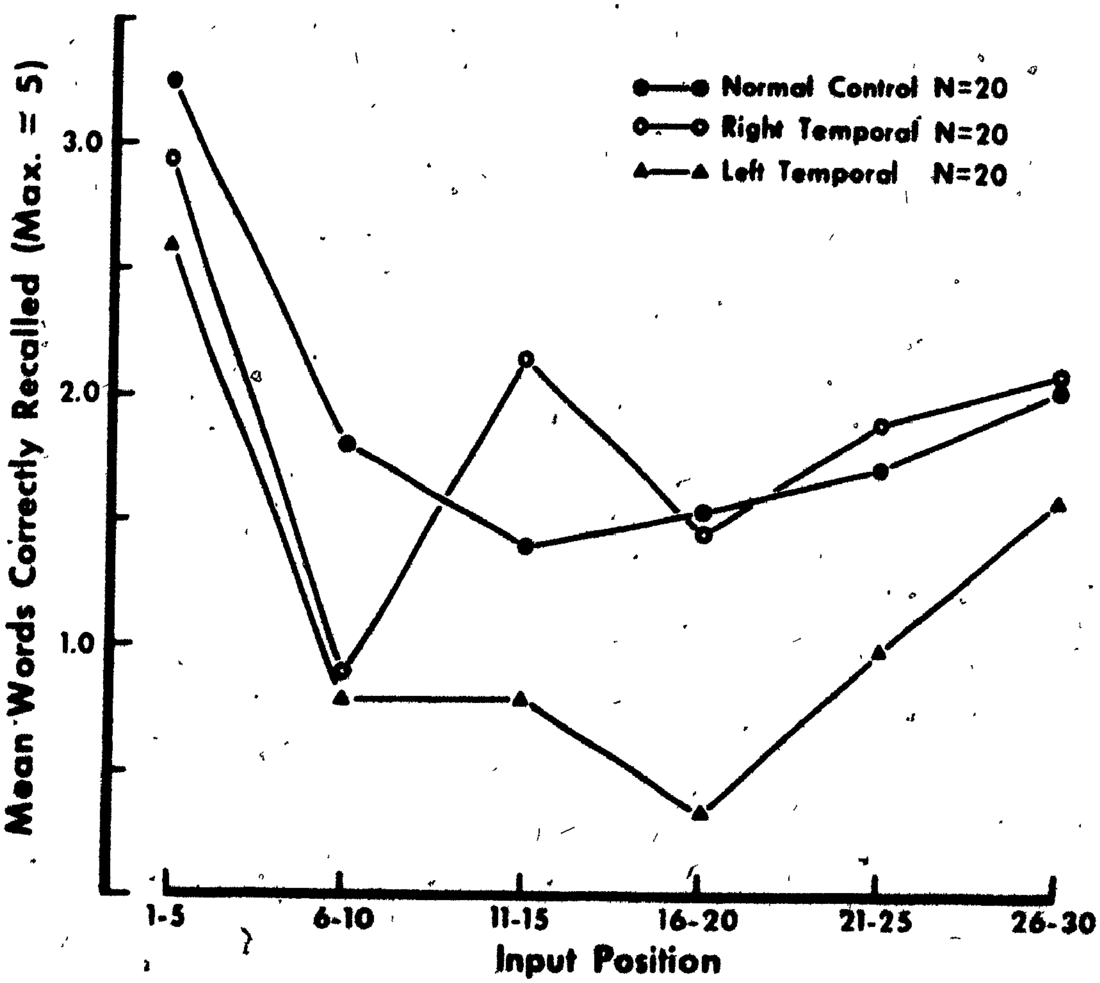

Figure 16. Non-categorized word list: serial position. Mean number of words correctly recalled from each presentation position. These have been grouped into sections of five words each. Results for the normal control and temporal-lobe groups.

$\underline{t} = 1.62$, $\underline{p} > .25$, section six.

It should be noted that the right temporal-lobe group, although showing generally the same pattern as the normal control group, produced a lower mean recall than the latter group on section two of the curve ($\underline{t} = 2.66$, $\underline{p} < .05$). On section three, however, the right temporal-lobe group had a slightly (although not significantly) higher recall score than control subjects ($\underline{t} = 2.22$, $\underline{p} > .05$). These results would have to be attributed to greater variability in this patient group than in the normal control subjects.

Relation of hippocampal removal to serial position effects. The increased susceptibility to interference that the left temporal-lobe patients had shown could mean that an intact hippocampus is required to reduce interference. In addition, though the left temporal-lobe group as a whole had produced a normal primacy effect, and thus presumably normal consolidation, one would predict an inverse relation between the amount of hippocampal removal and size of the primacy effect, if the hippocampus were involved in consolidation.

An analysis was therefore performed comparing the recall performance of subgroups SM and LG of the left temporal-lobe group on the six serial positions. The group effect was not significant ($\underline{F} = 1.18$, $\underline{p} > .25$) but the position effect was ($\underline{F} = 12.27$, $\underline{p} < .001$), demonstrating the expected serial position curve for the two subgroups considered together. Figure 17 illustrated the finding of interest: a significant interaction effect ($\underline{F} = 2.78$, $\underline{p} < .02$). It can be seen that subgroup LG exhibited a markedly reduced primacy effect ($\underline{t} = 3.64$, $\underline{p} < .001$) as compared to subgroup SM; whereas in all other points on the curve the

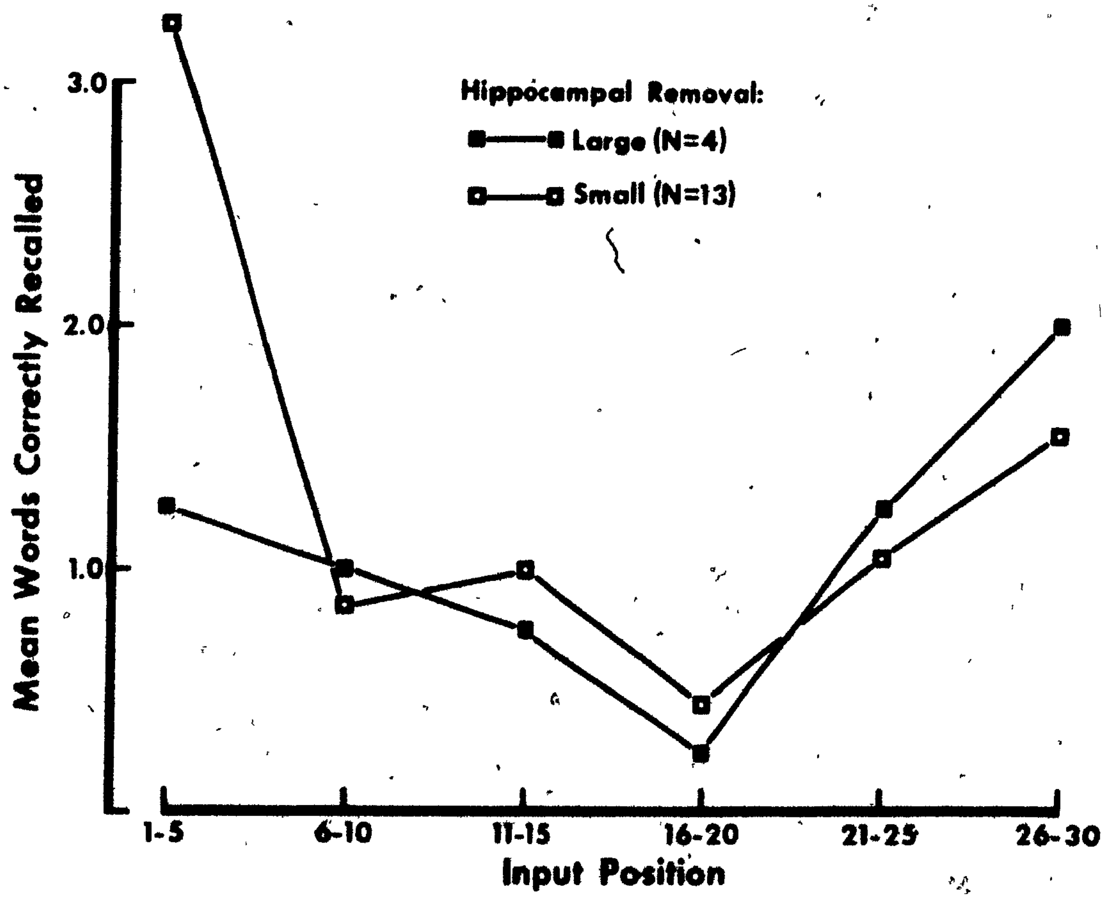

Figure 17. Non-categorized word list: serial position. Mean number of words correctly recalled from each presentation position by left temporal-lobe subgroups. Input positions have been grouped into sections of five words each.

two subgroups did not differ: $t = .15$, section two; $t = .25$, section three; $t = .21$, section four; $t = .77$, section five; $t = .85$, section six; ($p > .2$ for positions two through six). Note that in the last section the recall of subgroup LG was slightly, though not significantly, higher than that of subgroup SM, probably because all of the patients in subgroup LG recalled first the last few words that had been read to them, whereas only 5 of the 13 patients in subgroup SM did this.

The contribution of the left hippocampus to the recall of the first few items of the list can be emphasized by further subdividing the two left temporal-lobe subgroups into four subgroups (Corsi, 1972) and performing a correlation between these groups and recall in each of the sections of the serial position curve. For these correlations, the three dysphasic patients were again included. Subgroup SM thus consisted of a group whose hippocampus was completely spared, containing five patients; and a group whose removal did not exceed the pes, containing nine patients. In subgroup LG, there were three patients with removals exceeding the pes, but with some hippocampus remaining, and two with total removals. The correlations of extent of hippocampal removal with recall for successive sections of the serial position curve were as follows: $r = -.73$, $t = 6.63$, $p < .001$, section one; $r = .03$, $t = .13$, $p > .8$, section two; $r = -.30$, $t = 1.29$, $p > .2$, section three; $r = .04$, $t = .17$, $p > .8$, section four; $r = .0$, $t = 0$, $p > .99$, section five; $r = .34$, $t = 1.63$, $p > .1$, section six. Thus, the only significant correlation was found in the first part of the serial position curve, where the larger hippocampal excisions were associated with lower recall scores.

Relation of serial position effects to extent of neocortical removal. The correlations between recall in each of the six sections of the serial position curve and size of removal along either the Sylvian fissure or the base of the temporal lobe were not significant.

Intrusions in Free Recall

In recalling the lists, many subjects produced words that had not been presented by the experimenter, especially in the first recall trial. Figure 18 shows the mean number of such intrusions made by each group, pooled over all three immediate recall trials, for both the non-categorized and categorized lists. Incorrect responses were only counted as intrusions the first time that they occurred and were ignored if they were repeated on subsequent trials.

A two-way analysis of variance yielded no difference for word lists ($F = 2.02$, $p > .2$), subjects tending to produce as many intrusions in recalling the non-categorized as in recalling the categorized list. There was, however, a significant group effect ($F = 5.59$, $p < .01$), with left temporal-lobe patients producing many more intrusions than the right temporal-lobe patients ($t = 3.02$, $p < .025$) or the normal control subjects ($t = 2.75$, $p < .05$).

There were too few intrusions in delayed recall to permit an analysis of variance, but a χ^2 was computed based on the number of subjects in each group who had produced at least one intrusion in either of the two lists. This was significant ($\chi^2 = 6.02$, $p < .05$); the number of subjects producing intrusions in delayed recall was 5, 13, and 6 for the normal control, left and right temporal-lobe groups, respectively. Thus, both in the immediate and delayed recall of words,

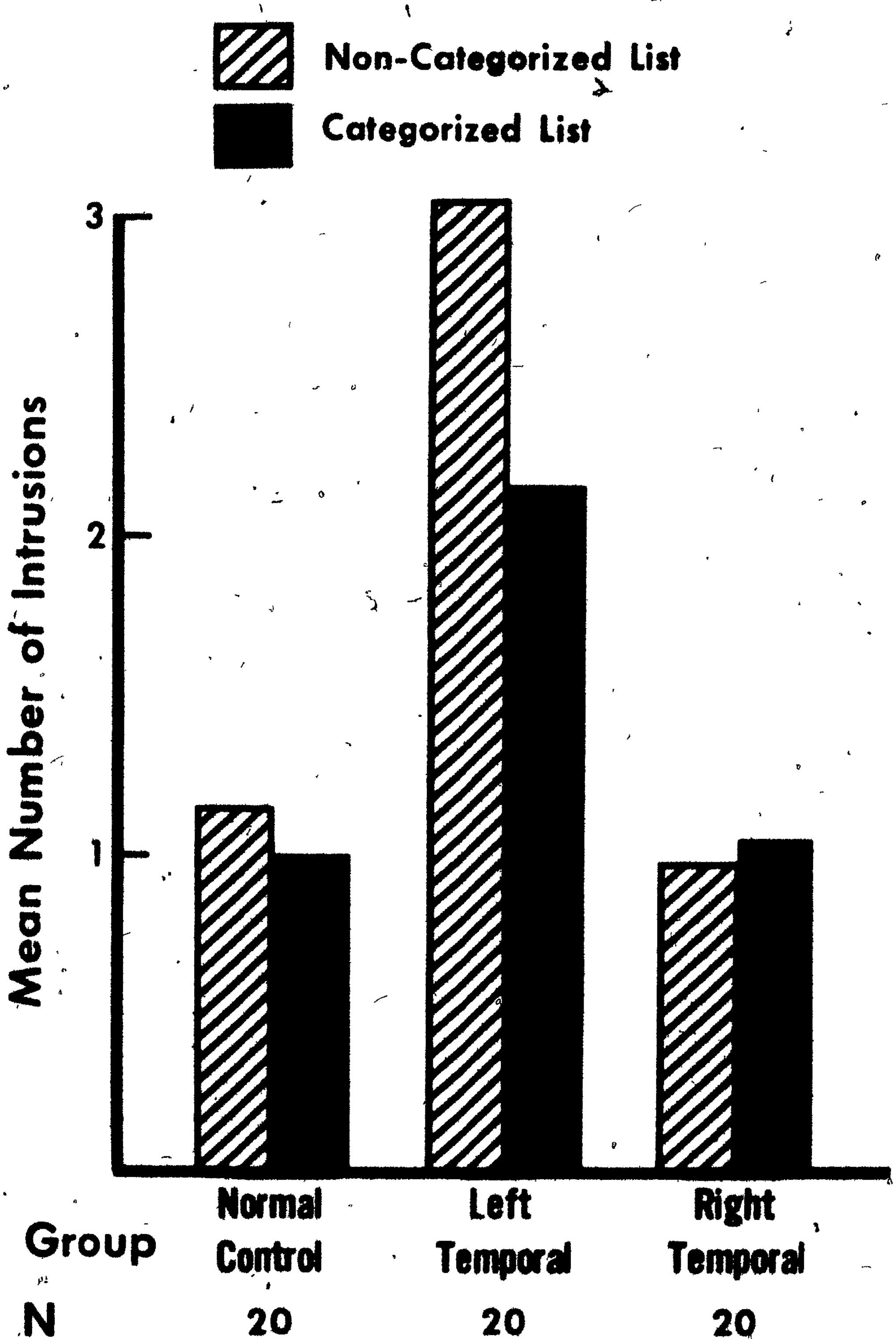

Figure 18. Word lists: intrusions. Mean number of intrusions made by the three groups on all immediate recall trials of the non-categorized and categorized lists. Intrusions on the second or third recall trial were not tabulated if they had occurred on any previous trial.

the left temporal-lobe patients were not as cautious about avoiding incorrect responses as they had been in the recall of designs in the design-sorting task.

Recognition

Figure 19 depicts the recognition scores of the three subject groups for both the non-categorized and the categorized word lists. A two-way analysis of the arcsin transformed scores yielded a significant effect of group ($F = 23.42$, $p < .001$), the left temporal-lobe group performing more poorly than either the normal control or right temporal-lobe group ($t = 5.93$, $p < .001$ for both comparisons). There was also a significant effect of word list ($F = 4.01$, $p < .025$); all three groups found the recognition test for the categorized list slightly more difficult than that for the non-categorized. The interaction effect was not significant ($F = 1.25$, $p > .25$).

Types of recognition error on the non-categorized list. Only 15 recognition errors in all were made by the normal control subjects and 14 by right temporal-lobe patients on the categorized list (as compared to 102 by the left temporal-lobe group), making it difficult to compare statistically the relative number of semantic or phonemic distractors chosen by the left temporal-lobe group to the pattern of choice shown by the other two subject groups. The results suggest, however, that the left temporal-lobe group was more likely to err by choosing a semantic distractor, as 70 of their 102 recognition errors, or 69% were semantic. The normal control and right temporal-lobe groups showed no such bias in their error scores as far as can be judged from the few errors that they made. These groups chose the semantic distractor

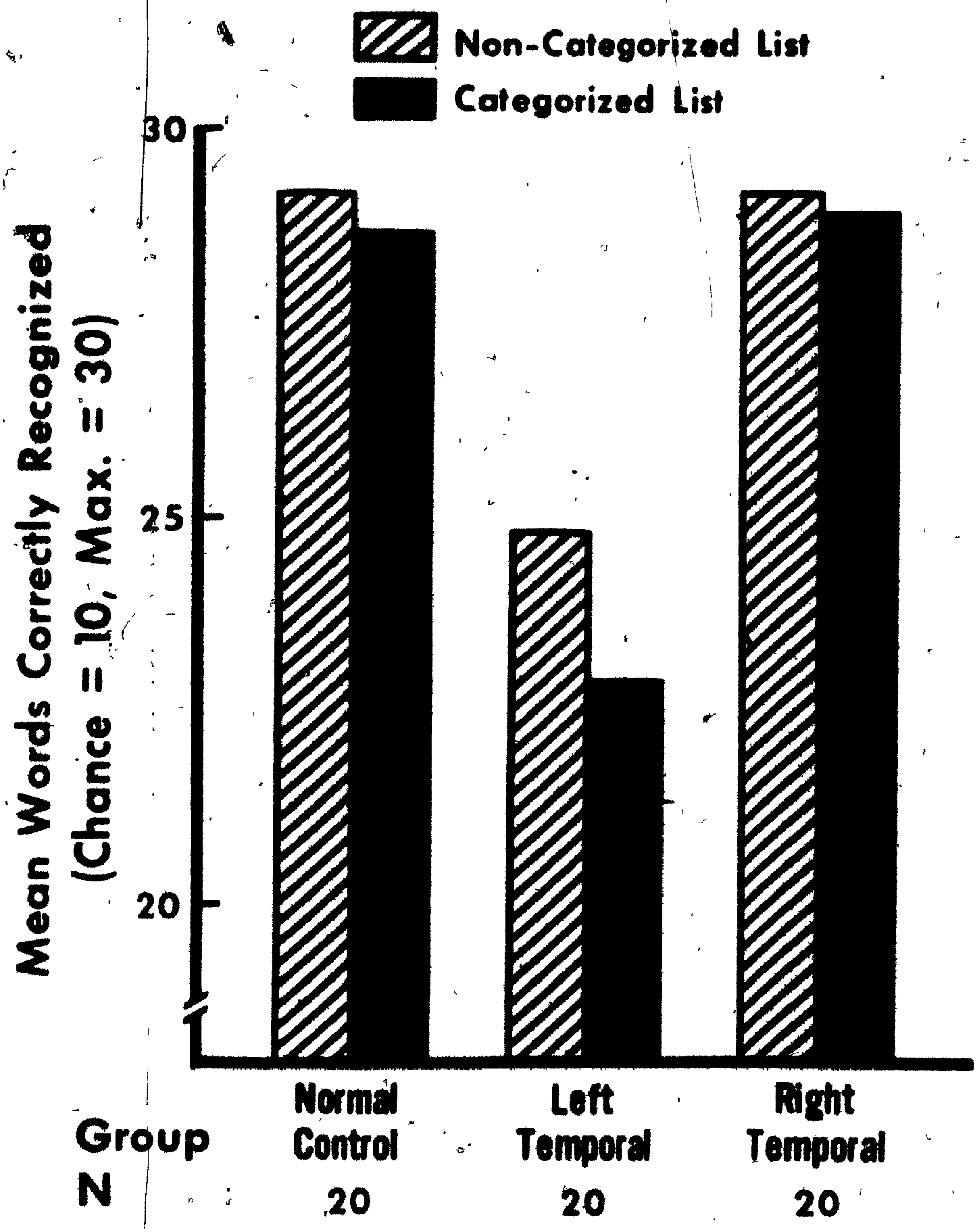

Figure 19. Word lists: recognition. Mean number of words from the two word lists that were correctly recognized by the normal control and temporal-lobe groups.

item on 47% and 57%, respectively, of the occasions that they made errors.

Recognition scores as related to extent of surgical removal. On neither recognition test was there any relation between the scores of the left temporal-lobe patients and the size of removal along the Sylvian fissure, the base of the temporal lobe, or the hippocampus.

Clustering Scores in the Recall of the Categorized List

Although the categorized-list recall of the left temporal-lobe patients was superior to their recall of the non-categorized list, it was still not equal to the recall of the normal control or right temporal-lobe groups on either list (see Figure 12). In order to assess whether left temporal-lobe patients were making optimum use of the categorized information, a clustering score was computed for each subject, on each of the four recall trials. To achieve this, the recall protocols were scored by counting the number of category repetitions (two adjacent words from the same category) in each recall trial for each subject. Intrusions and repeated items were excluded from the analysis.

The measure used to score the repetitions was the Adjusted Ratio of Clustering (ARC) suggested by Roenker, Thompson, and Brown (1971), which adjusts for chance, and has a fixed upper bound (chance clustering is 0, perfect clustering is 1). This measure is independent of the number of words recalled and allows the comparison of relative amounts of clustering for different groups of subjects in different experimental situations. The computational formula for the ARC is:

$$ARC = \{R - E(R)\} / \{maxR - E(R)\}$$

where R = total number of observed category repetitions

max R = maximum possible number of category repetitions (total number of items recalled minus total number of categories recalled).

E(R) = number of repetitions that would occur by chance

$= (n_i^2/N) - 1$

where n_i = total number of words recalled from category i

N = total number of words recalled.

Chance occurs when R = E(R). Note that negative scores are possible, and would tend to occur, for example, if a subject recalled the words in the order in which they had been presented (where no two words from the same category were adjacent).

A two-way analysis of variance was performed on these clustering scores, comparing the subject groups on the four recall tests of the categorized list. Figure 20 shows the significant group effect (F = 6.4, $p < .01$); the left temporal-lobe group having lower clustering scores than both the normal control (t = 3.42, $p < .001$) and right temporal-lobe (t = 2.75, $p < .05$) groups, who did not differ from each other (t = .63, $p > .25$). It can also be seen that all groups clustered more on each successive recall trial (F = 14.0, $p < .001$). There was no significant interaction effect (F = .79, $p > .25$). It is interesting to note that the clustering scores of the left temporal-lobe patients increased in delayed recall whereas their recall decreased. This is evidence that the clustering measure can vary independently of recall.

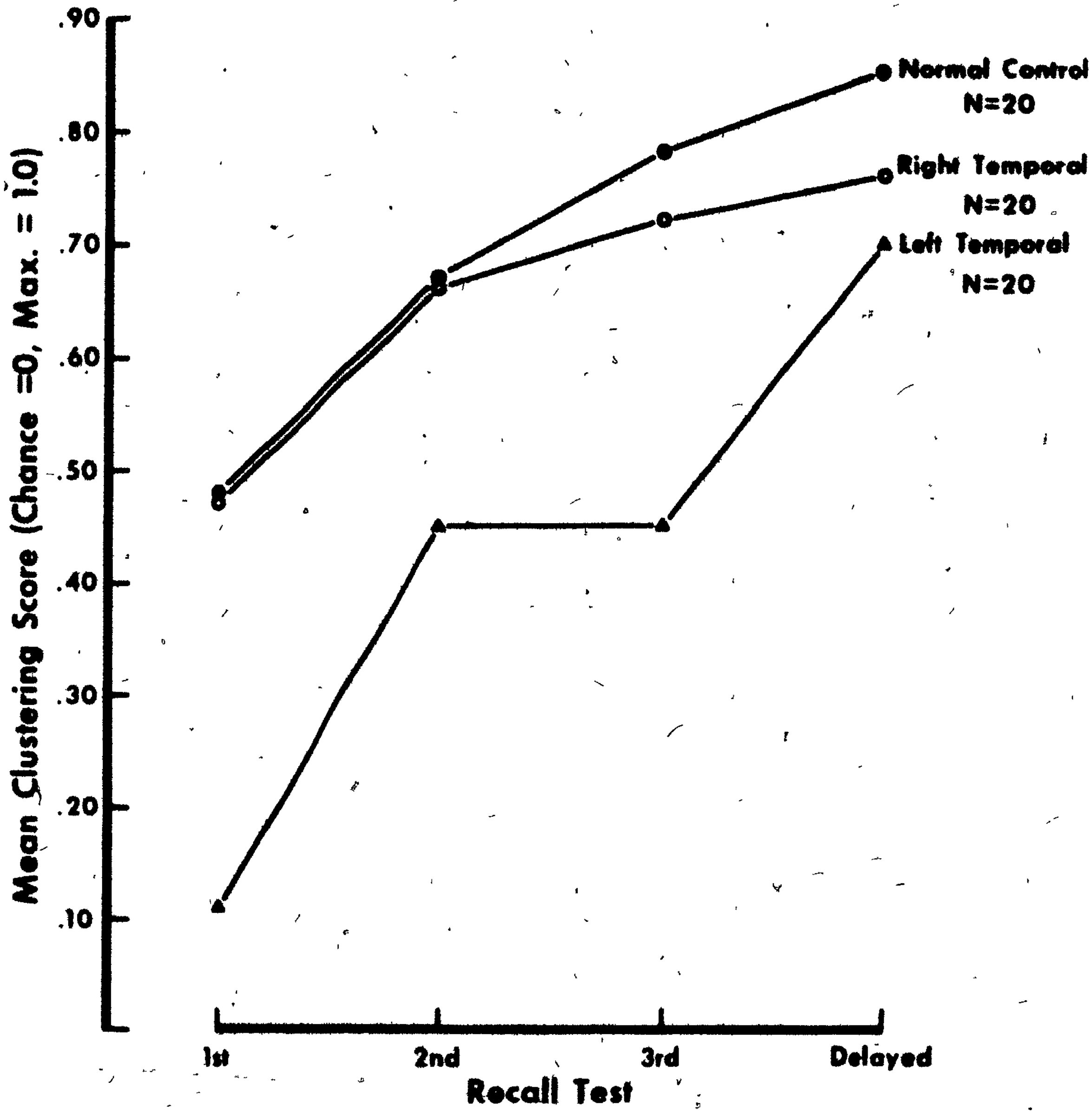

Figure 20. Categorized word list: clustering. Mean Adjusted Ratio-of-Clustering scores obtained by the three subject groups on all recall trials of the categorized list.

Clustering scores as related to extent of surgical removal. Since patients with left temporal-lobe removals had demonstrated a reduced tendency to group categorized words in free recall, it was of some interest to determine to what extent the neocortical or hippocampal structures of the left temporal lobe were involved in this ability. No correlations between the extent of removal along the Sylvian fissure or the base of the temporal lobe with clustering scores were significant. To explore the role of the hippocampus, a one-way analysis of variance comparing the clustering scores of subgroups SM and LG on the four recall trials was performed, producing no overall difference between subgroups ($F = .11$, $p > .5$).

In addition to the expected effect of recall trial ($F = 16.77$, $p < .001$), a significant interaction effect was revealed ($F = 4.70$, $p < .01$), which is illustrated in Figure 21. Although the two left temporal-lobe subgroups did not differ significantly from each other at any recall trial, there was a difference in the amount of increase in clustering that each subgroup demonstrated from the first recall trial to the second. The mean increase of subgroup LG was .82 ($t = 5.43$, $p < .001$), compared to a mean increase by subgroup SM of only .15 ($t = .98$, $p > .1$). The latter subgroup thus showed no increase in clustering from the first recall trial to the second, whereas subgroup LG showed a large increase. These results suggest that patients with larger left hippocampal removals need more exposure to the stimulus material to be able to make use of any organization that the material contains.

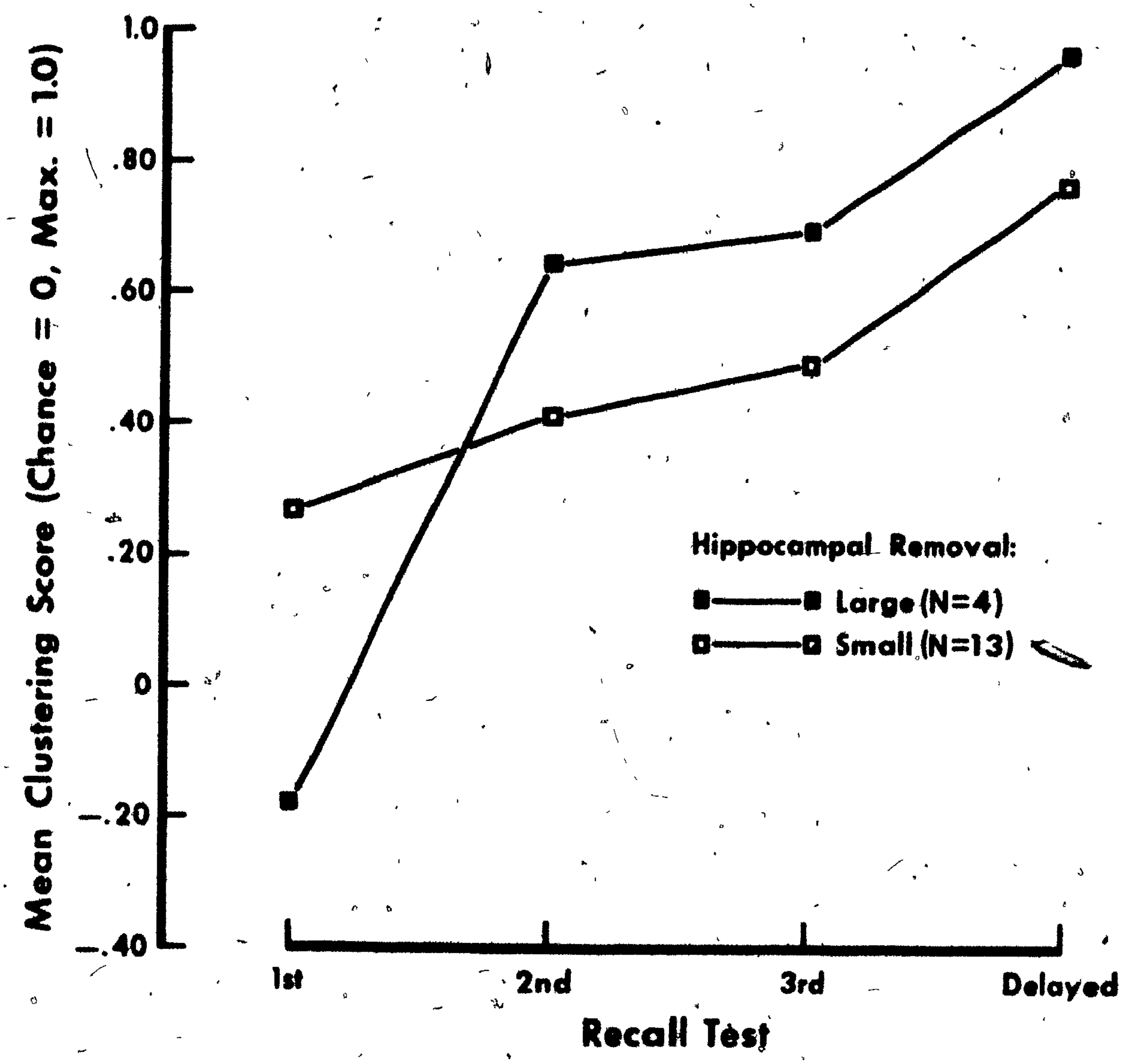

Figure 21. Categorized word list: clustering. Mean Adjusted Ratio-of-Clustering scores obtained by the left temporal-lobe subgroups on the immediate and delayed recall trials of the categorized word list.

Cued Recall of the Categorized Word List

The reason that subjects were asked, following delayed recall of the categorized list, to name all the categories that they could remember, was in order to determine the extent to which patients with left temporal-lobe lesions were aware of the categorical nature of the list. It was found that all subjects could name at least one category; 18 of the 20 left temporal-lobe patients could give at least three of the five category names. This proves that left temporal-lobe patients were aware that the list had contained some categorized items.

A one-way analysis was performed to compare the number of categories that the three groups could name. Three normal control subjects, who had not been given a cued recall, were missing from this analysis. A significant group effect was obtained ($F = 12.06$, $p < .001$), the left temporal-lobe group recalling fewer categories than either the normal control ($t = 4.09$, $p < .001$) or the right temporal-lobe ($t = 4.17$, $p < .001$) group.

Each subject was also asked to name all the words that he could remember from each category; category names that were not recalled were supplied by the experimenter. To measure the relative helpfulness of this cued recall for the different subject groups, the spontaneous delayed recall of each subject was subtracted from his cued recall. A one-way analysis of variance computed on these difference scores revealed a significant group effect ($F = 5.82$, $p < .025$), the normal control subjects profiting less from the cued recall than the left ($t = 3.12$, $p < .025$) or right temporal-lobe patients ($t = 3.04$, $p < .025$). The two patient groups did not differ significantly from each other (t = .07, p > .8).

Table 7 shows the mean recall scores for the third immediate recall, the delayed recall, and cued recall for the three subject groups. It can be seen that the delayed recall scores of both patient groups were lower than that of the normal control group (although not significantly so in the case of the right temporal-lobe group), leaving more room for improvement in the cued recall. Also, it is interesting to note that the cuing procedure helped all three subject groups to return to the level of their last immediate recall trial.

Performance of H.M. on Word Lists

H.M. was tested on the categorized list one year after being tested on the non-categorized list. His recall and recognition scores on both lists are shown in Table 8. Clearly, his overall performance was far below the mean of the left temporal-lobe group (see Figures 13 and 19). It is noteworthy that H.M. showed no improvement with successive presentations of the words, and failed to recall any words at delayed testing.

There are several differences between H.M.'s performance on the non-categorized and on the categorized lists. On all three immediate recall tests he produced more words from the categorized than from the non-categorized list. No beneficial effect of categorization was observed on delayed recall or recognition, however.

The number of intrusions made by H.M. in both immediate and delayed recall also differed: he produced 4 (all in immediate recall) in recalling the non-categorized list and 16 (12 in immediate recall)

Table 7

Comparison of Mean Immediate, Delayed and Cued Recall Scores for all Subject Groups

		Recall Test		
Group	n	Third Immediate	Delayed	Cued
Normal Control	17[a]	24.59	24.29	25.18
Left Temporal	20	17.95	13.75	17.05
Right Temporal	20	23.45	21.55	24.80

Note. Maximum score = 30.

[a]Three control subjects who had not been given a cued recall have been deleted.

Table 8

Recall and Recognition Scores of H.M. on Non-Categorized and Categorized Lists

	Recall Test				Recognition[a]
List	First	Second	Third	Delayed	
Non-Categorized	3	3	2	0	11
Categorized	4	4	4	0	11

Note. Maximum score = 30.

[a]Chance = 10.

in recalling the categorized list. This is in contrast to the left temporal-lobe group, who made more intrusions than the normal control or right temporal-lobe group, but did not differ in the number produced in recalling the two lists (see Figure 18). H.M.'s intrusions usually were associated in some way with the correct words; in recalling the non-categorized words, for example, he gave <u>bishop</u> for <u>church</u>, and <u>emerald</u> for <u>ruby</u>. In comparison, some of his intrusions in recalling the categorized list seemed only distantly related or totally unrelated. For example, intrusions such as <u>hill</u> or <u>glen</u> could belong to the "geographical features" category, but <u>daily</u>, <u>worry</u>, <u>stadium</u> and <u>real</u> are not associated with any words on the list. Such unrelated intrusions were rare in the left temporal-lobe group.

It is interesting that on the delayed recall of the categorized list H.M. produced two words, <u>tree</u> and <u>woods</u>, which had been intrusions in immediate recall. Likewise, although the testing sessions were separated by a year, he gave the word <u>cabin</u> when recalling both the non-categorized and the categorized list (he immediately corrected himself in the non-categorized recall test, however, stating that <u>cabin</u> had not been on the list). It seems that H.M. has a repertoire of verbal responses that he is likely to use in free recall situations.

Owing to the long time interval between the two testing sessions, and the severe nature of H.M.'s memory deficit, the effect of practice could be safely disregarded, and the serial position curves of the two lists could be compared. There was, in fact, a striking difference between the lists in this respect. The input positions of the words recalled by H.M. were 25, 28, 30; 28, 29, 30; and 29, 30 for the first, second, and third recall test, respectively, of the non-categorized list. Thus, H.M. showed a recency, but not a primacy effect, only recalling the last few items that were presented to him. His recall of the categorized list revealed a different pattern; the input positions of the words that he recalled were 12, 2, 30, 1; 30, 27, 10, 29; and 4, 26, 9, 17, for the first, second, and third recall tests, respectively. It can be seen that his recall was not restricted to the last few input positions, as it had been in the non-categorized list recall tests. On the first recall test, in particular, H.M. showed a clear primacy effect in addition to the recency effect.

Related to H.M.'s ability to recall words from the beginning and middle portions of the categorized list is the fact that he tended to cluster words from the same category in his recall, at least in the second and third recall tests (in the first test he recalled one word from each of four separate categories). His second recall showed essentially perfect clustering: cherry, apricot, valley, lake. The clustering in the third recall was not as good, but was still apparent: bus, apricot, car, wagon. This pattern is similar to that of the left temporal-lobe patients with large hippocampal removals, who showed no clustering after one list presentation, but improved to normal levels with succeeding presentations.

In the cued recall test that followed delayed recall of the categorized list, H.M. was asked to name the categories that he thought the list had represented. He named four categories, none of which were correct: "things that grow in the woods", "country-rural", "things in a farm", and "mining". When cued with the 5 original categories he produced 9 correct responses and 15 intrusions. Although this recall seemed high, it was possible that H.M. was merely guessing, as the intrusions indicated. To control for this, H.M. was asked during a testing session one week later to name any items he would think of from each of the five categories (no mention was made of the original categorized list). For each category, only the same number of words as had been produced in the cued recall were counted. Again, H.M. produced 9 words that had been on the categorized list, and 15 that had not. Therefore, it cannot be assumed that the cuing procedure aided H.M.'s recall.

His performance on these two memory tests indicated that H.M. was able to make use of the organization that was inherent in the categorized word list to aid in the recall of words from the beginning portion of the list, and to improve his overall immediate recall performance. The advantage of the organized material, however, did not extend to delayed recall, even when cues were made available.

Discussion

Recall of Non-Categorized and Categorized Word Lists

The experiments in Part II showed that although patients with left temporal-lobe lesions were impaired in their recall of both word lists, they were able to make use of the organization inherent in the categorized list to improve their recall to some extent. Despite this improvement, the performance of this patient group remained inferior to that of the control group, on the categorized as well as on the non-categorized list.

Weingartner's (1968) finding that left temporal-lobe patients could profit from a list containing associatively-related words is thus extended to categorized material, and to delayed recall of that material. The distinction between categorically and associatively-related word lists is an important one: Marshall (1967; see Baddeley, 1976; p. 276) showed that free recall and clustering scores for categorized pairs of words are higher than those for non-categorized pairs of equal associative strength, suggesting that the effect of categorization on recall cannot be attributed solely to direct associations between words within that category.

The results of the present study differ from those of Baddeley and Warrington (1973), who measured the categorized and non-categorized recall of a group of patients with amnesia of varied etiology. They found that although the amnesics were assisted by taxonomically-organized lists, the difference between the recall performance of the amnesic and control groups was larger for the categorized than the non-categorized list. In the experiments reported here, the difference between the normal control and left temporal-lobe groups remained constant for both lists. This discrepancy between the results of the present study and those of Baddeley and Warrington may reflect underlying differences between the patient populations of the two studies (one patient in the latter study had undergone right temporal lobectomy, one had vascular damage, and four were alcoholic Korsakoff patients), or it may reflect methodological differences (the Baddeley and Warrington study used blocked presentation of each category, four presentations before the recall test, and a 30-second interpolated task before recall).

The present study showed that patients with right temporal-lobe lesions were normal in their ability to take advantage of the organization in the categorized list. This result is worth noting, as the right temporal-lobe group's tendency to use "sentence" strategies in the word-sorting task could have been a manifestation of an impaired capacity to perceive words as taxonomically organized. Because the right temporal lobe, particularly the hippocampal region, has been implicated in image-mediated verbal learning (Jones, 1975; Jones-Gotman & Milner, in press), and because there is evidence that imagery may be involved in concept identification (Katz & Paivio, 1975), the demonstration of normal recall of the categorized word list after right temporal lobectomy becomes especially important.

Weingartner (1968) found that patients with left anterior temporal-lobe lesions were less likely than those with right to recall words on the second recall trial that had already been recalled on the first. He interpreted this left temporal deficit in evoking previously-recalled words as indicating difficulty in transferring verbal information from a temporary to a more permanent store. The above finding would lead one to expect a larger difference between the left and right temporal-lobe groups in the second than in the first recall trial, but Weingartner failed to find such a difference. The present study, however, did show a different rate of learning between subject groups. The left temporal-lobe group learned the words over the three immediate recall trials of both the random and organized lists at a much slower rate than either the right temporal-lobe or normal control group (see Figure 13). In addition, the recall-trial by subject-group interaction clearly illustrates the detrimental effect of delayed testing on the recall scores of patients with left temporal-lobe lesions, underlining the difficulty that such patients have with long-term retention of verbal material.

The increased effect of categorization on list recall with each succeeding recall trial (see Figure 14) was unexpected. It is known that normal subjects show increasing subjective organization on succeeding trials when learning random word lists, and that this increase is accompanied by improved recall scores (Tulving, 1962). It may be that the categorized list allowed the subjects to attain optimum organization, and thus better recall performance, at an earlier stage in learning.

Role of the left hippocampus in the recall of random and organized words. Categorization was relatively more beneficial to the recall performance of patients with large hippocampal lesions than to the performance of those with small. This result suggests that patients with a normally functioning hippocampus are better able to impose organization on the words in the non-categorized list; thus the organization that the categorized list provided had a smaller effect. Such an explanation implies that the hippocampal region plays a more important role in the encoding of random information than in the encoding of already-organized information. Further evidence supporting this idea will be given later in the discussion.

Intrusions in the free recall of the non-categorized and categorized list. The high number of intrusions shown by the left temporal-lobe group and by patient H.M. on both word lists had not been anticipated. Patients with left temporal-lobe lesions have been found to be exceedingly cautious on a variety of cognitive tasks (Jones-Gotman & Milner, 1977; Milner, 1952), and on some, but not all, memory tests. In the design-sorting recall of Part I, for example, such patients were less likely than normal subjects to attempt a drawing that would receive no credit (see Table 3). Milner and Kimura (1964) found, in a recognition test involving recurring verbal stimuli, that patients with left temporal-lobe lesions were no more likely than normal control subjects to give false positive responses. Their study thus gave no evidence of over-cautiousness, nor a lack of cautiousness in recognizing verbal material after left temporal lobectomy. Free recall of word lists, however, is a technique that is rarely used with this patient population, and when it has been used, intrusion data have not been presented (Moscovitch, 1974; Weingartner, 1968).

Cofer et al. (1966) showed that normal subjects produce more intrusions when recalling a list containing words that are weakly associated to their respective categories, than when recalling strongly-associated words. This suggests that the high number of intrusions produced by patients with left temporal-lobe lesions may reflect a weakening of associations between exemplars of categories and their respective category labels in semantic memory.

It is not clear why H.M. produced more intrusions when recalling the categorized list than when recalling the non-categorized list, whereas the left temporal-lobe group produced the same number of intrusions on both lists. Baddeley and Warrington (1973) found no difference, in a study of their amnesic patients, between the number of intrusions for phonemically and taxonomically-organized lists. The mechanism underlying the memory deficits in these amnesic patients and in H.M. may differ, however, making it difficult to draw conclusions when comparing Baddeley and Warrington's results to those of the present study.

Recognition

The poor performance of patients with left temporal-lobe lesions in recognizing words from both the non-categorized and the categorized list indicates that their memory deficit is not caused only by difficulties in spontaneous evocation of previously acquired items.

The categorized recognition test was more difficult than the non-categorized for all three subject groups, thereby reversing the trend that was found for recall testing. The difference between the distractor items in the recognition tests for the two lists would probably account for these results. One half of the distractor items in the non-categorized recognition test were phonemic, which may have been less confusing for most subjects than semantic distractors. The left temporal-lobe group in particular was shown to be more likely to choose an incorrect semantic than phonemic distractor.

Serial Position Curve of the Non-Categorized List

In order to interpret the serial position data for left temporal-lobe patients, it is necessary to explore in more depth the various interpretations of serial position effects in normal subjects. As already pointed out in the introduction to this thesis, there is general agreement that a two-process model (Atkinson & Shiffrin, 1968; Glanzer & Cunitz, 1966; Waugh & Norman, 1965) can best account for serial position effects (Craik, 1970; Poltrock & MacLeod, 1977). According to this model, items from the beginning of the list have entered long-term storage, while the remaining items have not. The last few items are presumed to be accessible for recall because they are still in the short-term rehearsal buffer.

This model still leaves unexplained why the mid-list items do not enter long-term storage. There have been several hypotheses offered that deal with this issue. One interpretation is based on the finding that the initial items in a list receive more rehearsal (Brodie & Prytulak, 1975; Bruce & Papay, 1970; Rundus, 1971). This effect persists even when subjects are given instructions or distracting tasks designed to prevent rehearsal (Brodie & Prytulak, 1975; Poltrock & MacLeod, 1977) or when they are unaware that a memory test will follow (Baddeley & Hitch, 1974). Although increased rehearsal would explain the mechanism by which initial items are more likely to be recalled, this hypothesis does not explain why early items are rehearsed more than later items.

A corollary to the quantitative rehearsal notion is the idea that early items undergo a qualitatively different kind of rehearsal than do later items (Craik & Lockhart, 1972; Glanzer & Koppenaal, 1977; Glanzer & Meinzer, 1967). According to this view, the first items in a list receive more elaborate encoding (Craik & Tulving, 1975). Again it is not clear why subjects would not be able to continue processing items throughout the list to the same degree.

In order to explain the poor recall by normal subjects of mid-list items, it appears necessary to invoke the idea of interference. Goodwin (1976), extending the findings of a study by Craik and Birtwistle (1971), has shown that when several lists are presented for recall, the primacy effect decreases in each succeeding list owing to a build-up of proactive interference. It may be assumed that the encoding of mid-list items suffers from interference from early list items (and also retroactive interference from later items) in a similar way. Thus only the first items, free from the effects of proactive interference, can undergo enough rehearsal or sufficiently elaborate encoding to be transferred into long-term memory.

In the present study, left temporal-lobe subgroup SM recalled the early list items of the non-categorized list in a normal manner. This can be explained by supposing that such patients were able to process the words in the list adequately, provided that there was little or no interference from previous items. In the face of proactive interference from the first items in the list, both left temporal-lobe subgroups were deficient in their ability to transfer the mid-list items into a more permanent memory system. The normal recall by both subgroups of the items that had been presented last gives additional evidence for the view that patients with anterior temporal-lobe lesions have unimpaired short-term memory.

Within the left temporal-lobe group, patients with large hippocampal removals (subgroup LG) differed from those with small (subgroup SM) in that they had difficulty not only in recalling mid-list items, but also in recalling items from the first part of the list; thus they showed little or no primacy effect. Apparently, the lack of proactive interference effects for early list items did not help subgroup LG to recall those items. It is not possible to say from these data whether such patients are impaired in the amount or the quality of the rehearsal of early list items, or whether they are more susceptible to the effects of retroactive interference than are patients with small hippocampal removals. What this study does show is that a patient must have an intact left hippocampus in order either to store or to retrieve early list items from a random word list in a normal manner.

Patient H.M.'s performance on the word lists may help to clarify some of the issues discussed above. Like other subjects, H.M. recalled more words from the categorized than from the non-categorized list. His delayed recall and recognition scores were not affected by categorization, indicating that the advantage given by organization of the stimulus material was temporary, aiding only in the acquisition, but not in the later recall of the words.

The most instructive finding in H.M.'s recall pattern was the difference between the serial position curves of the non-categorized and categorized lists. It is well-known that practice can change the shape of the serial position curve (Dallett, 1963; Goodwin, 1976;

Murdock, 1960), subjects tending to recall later items first on succeeding recall tests, thereby increasing recency effects. Hence, the comparison between the two lists could not be made for the left or right temporal-lobe, or normal control group. In the case of H.M., however, any effect of practice from one list to the next was likely to be negligible, in view of the severity of his global amnesia. The important difference between H.M.'s recall of the two lists was that a primacy effect appeared when he recalled the categorized list whereas there was no such effect in his recall of the non-categorized list. His improved ability to recall early list items from the categorized list would account for his higher overall recall score for this list. (Although no such comparison can be made for the serial position curves of the left temporal-lobe subgroups on the two lists, it is possible that the relatively greater improvement of subgroup LG when recalling the categorized as opposed to the non-categorized list [see Figure 15] may also be caused by an improvement in recall of early items from the categorized list.) The appearance of a primacy effect in H.M.'s recall of the categorized list would indicate that the hippocampus plays a role in allowing unrelated items to be adequately encoded in long-term memory; if the items are obviously related in terms of some common category, they would be more likely to be able to be stored in a permanent form or to be accessed more easily without the aid of the hippocampus.

There is some evidence from earlier studies for a primacy effect for organized material shown by other patients with severe anterograde memory deficits. Two patients reported by Penfield and Milner (1958) who had undergone left temporal-lobe excision, including the hippocampus and hippocampal gyrus, but with evidence of damage to the opposite temporal lobe (Penfield & Mathieson, 1974), presented with severe amnesia post-operatively. The memory tests for both patients were reported in detail. The recall by these patients of the two stories of the Logical Memory Test of the Wechsler Memory Scale, although grossly abnormal, almost always included the first few words of the story in a nearly verbatim form. In comparison, no such ability to retain the new word associates in the Associate Learning test of the Memory Scale, which consists of unrelated items, was shown by either patient. Although this study was not a direct test of whether the hippocampus is important in the consolidation of random information into memory, it does provide some support for the findings of the present study.

Another study (Starr & Phillips, 1970) examined a patient with severe anterograde amnesia secondary to an episode of herpes simplex encephalitis. These authors also supplied the patient's story-recall protocols, which showed that he, too, was able to recall the first few words of the stories accurately, while retaining only a general idea of the rest. Starr and Phillips also asked this patient to sort ten unrelated words into categories. After three successive sortings, he showed perfect immediate recall performance (gradually decreasing over a thiry-minute span), which was superior to his performance when recalling visually-presented words that he had not sorted. The authors speculate that the organization provided by sorting may give "additional cues or labels for storage and subsequent retrieval not possible in the usual manner of item presentation and testing" (p. 87). This study, when considered in the light of the present data, strengthens the idea that damage to medial temporal structures is most apparent in patients when they are asked to recall unorganized, random verbal information. Furthermore, the more organization that is inherent in the material, as in a categorized list or a story, the more likely that it will gain adequate access to long-term memory in such patients.

The pattern of recall shown by the left temporal-lobe subgroup LG, and by H.M. on the non-categorized list (i.e. normal recency and reduced primacy), is the same as that found by Baddeley and Warrington (1970) for six patients with amnesias of varied etiology (described in more detail on page 96) when recalling lists of ten unrelated words. These authors concluded that their patients have impaired long-term memory but normal short-term memory. It would be instructive to measure the effect that presenting a categorized list would have on the primacy portion of the serial position curve in their amnesic patients.

Recall of Categorized Word List

Cued recall. When asked for the category names after delayed recall, patients with left temporal-lobe lesions recalled fewer of the categories than did control subjects. This was a conservative estimate of the number of categories that this patient group was aware of at the time of immediate recall, however, since there could have been a substantial amount of forgetting of category names during the delay interval.

Providing category names in cued recall had a more beneficial effect for both patient groups than for the normal control group. But even with cuing, the recall of the left temporal-lobe group did not approach the non-cued delayed recall of the normal control group. Because the left temporal-lobe group had lower delayed-recall scores than did the normal control group, and thus more room for improvement in cued recall, it is difficult to interpret these data. Perhaps a longer list would have allowed the normal control subjects to show a degree of improvement in delayed recall equal to that of the patients.

Clustering in recall of categorized word lists. Even though patients with left temporal-lobe lesions showed improved recall on the categorized as compared to the non-categorized list, categorization did not bring their performance up to the level of normal control subjects. A possible explanation for this fact is that although such patients could make use of the categorization to improve recall, they were still not able to organize the words as well as could normal subjects. The clustering scores of the left temporal-lobe group confirmed this hypothesis. Patients with left temporal-lobe lesions clustered less than normal subjects in all immediate recall tests, thus replicating Weingartner's (1968) results for associative clustering in such patients. Although in delayed recall the clustering scores of this patient group increased relative to immediate recall, their delayed-recall clustering scores remained lower than those of the normal control group. Also, it is interesting to consider the clustering scores in relation to recall performance. In delayed recall, the recall and clustering scores of the left temporal-lobe group diverged: delayed recall decreased relative to immediate recall whereas delayed clustering increased relative to immediate clustering.

The reduced clustering shown by the patients with left temporal-lobe lesions in the immediate recall can be interpreted in several ways. A recent experiment with normal subjects by Puff, Murphy, and Ferrara (1977) compared the list recall of subjects who exhibited a significant amount of clustering to that of subjects whose clustering did not differ from chance. This study offers a possible framework for understanding the present data. Puff et al. found that "high" clusterers recalled more words than "low" clusterers, but only when the categories in the list contained high-frequency associates to each category label. In other words, high clusterers, who have a tendency to use category labels or concepts as conceptual mediators, can only do so successfully when the category label and the items within the category are potent mediators for other items within that category.

Two alternative comparisons can be made between the left temporal-lobe groups and the subject groups in the Puff et al. study. It is possible that temporal-lobe patients are similar to the low clusterers, who are less likely than high clusterers to make use of category labels as mediators in recall. This could be either because they choose not to make use of them, or are unaware of their existence in the list. Pellegrino (1974) has shown that subjects must be aware of the presence of attributes in a list in order to use them to aid recall. A second possibility is that patients with left temporal-lobe lesions correspond to high clusterers recalling weakly-associated categories: they try to make use of the categories, but encounter difficulty because the list items are not potent enough mediators, within their semantic memories, of other category members. The present data do not permit a determination of which possibility is most likely.

Another interpretation of the lower clustering shown by the left temporal-lobe group is that they were encoding according to idiosyncratic (i.e. not experimenter-defined) categories. A corollary to this interpretation is that these patients may have formed large categories (as they did in the word-sorting test), which subsumed two other categories. Both of these explanations are weakened by the fact that left temporal-lobe patients exhibited increased clustering over trials, showing that these patients were aware to some extent of the experimenter-defined categories.

Within the left temporal-lobe group, subgroup LG showed a larger increase in clustering from the first to the second recall test as compared to subgroup SM (see Figure 21). This result probably indicates that subgroup LG was unaware of the categorized nature of the list during the first recall trial. Since such patients have difficulty in holding items in memory in the face of interference (Corsi, 1972), they would be less likely to notice that several list items came from the same category. Evidence that subgroup LG was able to cluster words at the same level as subgroup SM comes from later recall trials, where the two subgroups showed equal clustering. As noted in the Results section, H.M.'s clustering followed a pattern similar to that of subgroup LG: no clustering in the first immediate-recall trial, and increased clustering in the second and third.

The left and right temporal-lobe and normal control groups all showed increased clustering on each successive immediate-recall trial, thus replicating the findings of several studies in normal subjects

(Marshall, 1967; Robinson, 1966; Shuell, 1968). Repeated presentations presumably allow the subject to become increasingly aware of the organization contained in the list and to form stronger associations between list items, as well as between category members and the category name or concept. The increased clustering of all subject groups in delayed recall is not as easily understood. This augmentation of clustering has been noted by other investigators when a five-minute filled interval is used (Gonzalez & Cofer, 1959), although the effect is attenuated somewhat when the immediate recall test is omitted.

The increased clustering scores shown by all groups in delayed recall can best be understood by considering the different properties of short- and long-term memory. It has been shown that semantic relationships between words cannot be used to improve recall of words from short-term memory (Craik & Levy, 1970). It could be, therefore, that many of the words that were not clustered in immediate recall had been read out from short-term storage; that is, the recency portion of the serial position curve. Craik (1970) has shown that recency items have a lower probability of recall in later testing than do other list items. Thus delayed recall would primarily consist of items that had been well-organized and encoded in long-term memory at the time of presentation and also when immediate recall was tested. This would result in higher clustering scores in delayed recall. The low clustering scores shown by left temporal-lobe patients in immediate recall compared with the normal control group indicates that a low percentage of their recall came from long-term memory, and that few items would be available for delayed recall. These items would be well-organized, however. This would account for the increased clustering with low recall shown by patients with left temporal-lobe lesions.

COMMENT

The present investigation has revealed some aspects of the function of the temporal lobe in organizing information, and in making use of pre-organized information. For the sorting experiments in Part I, a new test, design sorting, was created. It was used in addition to a word-sorting test to measure deficits in the categorization of non-verbal as well as verbal material in patients with temporal-lobe lesions. These sorting studies demonstrated material-specific deficits outside the sphere of memory after unilateral temporal lobectomy. In addition, these experiments gave new evidence for hemispheric specialization in the categorization process, the left hemisphere being more involved with verbal, and the right with non-verbal organization.

The studies in Part II were restricted to verbal tasks. These experiments showed that patients with left temporal-lobe lesions could use taxonomically-categorized information to improve their recall. They were clearly not utilizing that information to the fullest extent, however, as suggested by their continued inferior recall performance relative to control subjects, and by their reduced clustering scores. I have argued that the lower clustering scores, and the increased number of intrusions in recalling both word lists shown by the left temporal-lobe group indicate a lack of strong associations between words in semantic memory. Such a view is supported by the sorting studies from Part I, where patients with left temporal-lobe lesions tended to make larger word than design categories. This result was interpreted as showing an inadequate evaluation by patients with temporal-lobe lesions of the attributes of each item, leading to larger, more loosely-associated categories within the sorting task. Presumably, this reduced elaborative encoding of words by patients with left temporal-lobe lesions would lead to weaker associations between words in the semantic memory systems of such patients.

The serial position curve of the unrelated-word list further clarified the role of the temporal lobe in memory. Patients with left temporal-lobe lesions were found to be highly susceptible to interference, as reflected by reduced recall of mid-list items compared to normal control subjects. Although the nature of the increased sensitivity to interference shown by this patient group cannot be determined from the present study, the word-sorting results again offer a possible explanation. That study indicated that patients with left temporal-lobe lesions were not efficient at separating words into specific categories. Research has shown that the more similar to-be-remembered words are to one another, the more they create interference, both proactively (Wickens, 1970) and retroactively (Shuell, 1968). Bjork (1970, 1972) has proposed, based on studies of directed forgetting, that release from the effects of proactive interference depends on the ability to organize and differentiate list items effectively. The difficulty that patients with left temporal-lobe lesions have in doing so, as illustrated by their word-sorting performance as well as by the intrusion and clustering results, suggests that the reduced ability of the patients to separate specific groups of words in memory may contribute to their susceptibility to the effects of interference.

The results of Part II also demonstrated the contribution of the left hippocampus to certain memory functions. A lack of primacy effect in the recall of left temporal-lobe patients with large hippocampal lesions emphasized the role of the left hippocampal formation in allowing the recall of words from long-term memory. Whether this function of the hippocampal area involves consolidation into, or retrieval from long-term memory could not be determined from the data.

In addition, the appearance of a primacy effect when H.M., a patient with bilateral hippocampal lesions, recalled the categorized list was interpreted as reflecting the importance of the hippocampus in the recall of unorganized material from long-term memory. This hypothesis was supported by the fact that patients with large left-hippocampal lesions profited more from the categorized list than did those with small.

It is interesting in this respect to consider the type of tasks that have been found to be sensitive to the extent of hippocampal damage (see pp. 6-8, Introduction). Most of these tasks involved unrelated material (Corsi, 1972; Milner, 1968). The maze-learning tasks (Corkin, 1965; Milner, 1965) also consisted of a "list" of unrelated turns, learned sequentially. These, too, were sensitive to hippocampal damage, but in the right hemisphere. In contrast, tasks that have shown no consistent effect of hippocampal removal include the recall of a previously-copied complex drawing (Jones-Gotman & Milner, in press) and the recall of pictures of common objects, which were presented six times before testing (Jaccarino, unpublished data). The latter two tasks allow organization to take place before recall is required. Additional direct tests of the role of the hippocampus in the recall of unorganized material are necessary, however, before any firm conclusions can be drawn.

It cannot be ascertained from the present experiments if damage to the hippocampus or hippocampal gyrus is critical for impairment to result. Also, it is not known whether the deficits shown by patients with large left-hippocampal removals would result if only the left hippocampal area and amygdala, and not the temporal neocortex, were removed, although the data from H.M. support this idea. Nor do the present data allow the determination of whether the same results would occur if the temporal pole and amygdala were spared.

Semantic memory, which involves pre-existing associations between verbal concepts, is probably mediated not by hippocampal connections, but by connections within the cortex. Evidence for this comes from H.M., who performed normally on the word-sorting task despite his bilateral hippocampal damage. If the hippocampal area is less important in the recall of information that is already organized in semantic memory, then a function of this area may be to help interconnect previously unrelated items within semantic memory. Such a role of the hippocampal area in relation to the cortex would imply direct connections between these two structures. Recent investigations of the rhesus monkey have demonstrated direct efferents from the hippocampal formation to cortical areas in the frontal and temporal lobes (Rosene & Van Hoesen, 1977), and afferents to the hippocampal area from the temporal cortex (Van Hoesen & Pandya, 1975).

The experiments reported in this thesis have demonstrated not only the role of the temporal lobe in organizing random material, but the contribution of the left temporal lobe to the recall of both random and organized words from semantic memory. In addition, these studies have produced new evidence for the importance of the left hippocampal area in long-term verbal recall, and have suggested some mechanisms by which this area may interact with the temporal neocortex.

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