Material-Specific Memory in Temporal Lobe Epilepsy: Effects of Seizure Laterality and Language Dominance

Hongkeun Kim
Daegu University

Sangdoe Yi and Eun Ik Son
Keimyung University

Jieun Kim
Catholic University of Daegu

This study investigated the effects of seizure laterality and language dominance on material-specific memory in temporal lobe epilepsy (TLE). Left TLE (LTLE) patients with left-hemisphere language dominance (LHLD) showed significantly higher nonverbal than verbal memory capacity, whereas right TLE patients with LHLD showed significantly better verbal than nonverbal memory capacity. LTLE patients with non-left-hemisphere language dominance (NLHLD) showed significantly better verbal memory capacity compared with LTLE patients with LHLD. Thus, selective verbal or nonverbal memory deficits that are dependent on side of seizure onset were apparent in patients with LHLD but not in patients with NLHLD. Relative sparing of verbal memory capacity in LTLE patients with NLHLD may reflect interhemispheric reorganization of verbal memory function.

Temporal lobe epilepsy (TLE) may be the most common form of human epileptogenic disorders (Engel, 1996). Pre- or postsurgical neuropsychological studies of TLE patients have greatly contributed to the current understanding of the brain-behavior relationship. A classical finding in this field is that surgical removal of the left mesial temporal structures (i.e., left temporal lobectomy) results in reduction of verbal memory capacity, whereas surgical removal of the right mesial temporal structures (i.e., right temporal lobectomy) diminishes nonverbal (or visuospatial) memory capacity. Consequently, left temporal lobectomy patients show superior nonverbal compared with verbal memory capacity, whereas right temporal lobectomy patients show better ability to learn verbal than nonverbal material. These findings are consistent with the hypothesis that the learning of verbal material is dependent more on the left than the right mesial temporal structures, whereas the capacity to learn nonverbal material relies more on the right than the left mesial temporal structures (Milner, 1975).

The common pathology underlying TLE is mesial temporal sclerosis and other abnormalities in the mesial temporal lobe structures (McMillan, Powell, Janota, & Polkey, 1987; Meencke & Veith, 1991; Wolf et al., 1993). Thus, it may be hypothesized that material-specific memory deficits are present not only in postsurgical TLE patients but also in presurgical TLE patients, although to a lesser degree. However, prior investigations of this hypothesis have yielded, at best, mixed results. Only a relatively small proportion of these studies (Delaney, Rosen, Mattson, & Novelly, 1980; Fedio & Mirsky, 1969; Helms, Pohl, & Elger, 1995; Hermann, Wyler, Richey, & Rea, 1987; Ladavas, Umitta, & Provinciali, 1979) have confirmed the hypothesis. In the majority of the relevant prior studies, the hypothesis has been only partially confirmed or not supported at all. Thus, certain studies (Bornstein, Pakalnis, & Drake, 1988; Cohen, 1992; Giovagnoli & Avanzini, 1999; Gold et al., 1995; Moore & Baker, 1996; Selwa et al., 1994) have found that the left TLE (LTLE) group shows verbal memory deficits relative to the right TLE (RTLE) group but that there is no difference in nonverbal memory capacity between the two. On the other hand, others (Abrahams, Pickering, Polkey, & Morris, 1997; Baxendale, Thompson, & van Paesschen, 1998; Baxendale, van Paesschen, et al., 1999; Hermann, Seidenberg, Schoenfeld, & Davies, 1997; Loring, Hermann, Lee, Drane, & Meador, 2000) have reported that RTLE is associated with poor ability to learn nonverbal material relative to LTLE but that there is no difference in nonverbal memory capacity between the two. Still other studies (Ellis, Hillam, Cardno, & Kay, 1991; Glowinski, 1973; Hermann, Connell, Barr, & Wyler, 1995; Lendt, Helms, & Elger, 1999; Loring, Lee, Martin, & Meador, 1988; Mayeux, Brandt, Rosen, & Benson, 1980; Naugle, Chelune, Schuster, Lüders, & Comair, 1994) have failed to find a significant difference in either verbal or nonverbal memory capacity between the LTLE and RTLE groups. One thing that is clear from these variable results is that any difference in material-specific memory capacity between the LTLE and RTLE groups is of relatively subtle magnitude.
Multiple factors may be involved in the lack of reliable material-specific memory differences between the LTLE and RTLE groups. One critical factor may be that not all verbal or nonverbal memory tasks are equally valid measures of hemisphere-dependent memory capacity. Thus, there is evidence that certain nonverbal memory tasks are more sensitive to the effects of RTLE than others (Abrahams et al., 1997; Breier et al., 1996; Giovagnoli, Casazza, & Avanzini, 1995; Helmstaedter et al., 1995; Loring, Lee, & Meador, 1988; Piguet, Saling, O’Shea, Berkovic, & Bladin, 1994; for a review, see Barr, 1997). The other important factor may be that not all TLE patients may show equally large material-specific memory impairment. For example, in Breier et al.’s (1997) study, TLE patients were classified into reading-deficient (RD) and non-reading-deficient (non-RD) groups. They found that selective deficits in verbal or nonverbal memory are evident in the non-RD group but not in the RD group. In Sawrie et al.’s (2001) study, unilateral TLE patients were divided into groups with bilaterally normal hippocampal volumes, unilateral atrophy, or bilateral atrophy, on the basis of magnetic resonance imaging (MRI) volumetry. Results showed that verbal memory capacity is significantly lower in LTLE relative to RTLE only in the group with bilateral atrophy. Thus, at least in certain studies, subject characteristics may have contributed to failures to find significant material-specific memory differences between LTLE and RTLE groups.

The present study investigated the effects of another subject variable, hemispheric language dominance, on material-specific memory of TLE patients. Data from the intracarotid amobarbital procedure (IAP; Benbadis, Dinner, Chelune, Piedmonte, & Lüders, 1995; Dinner, 1991; Kurthen et al., 1994; Loring et al., 1990) clearly show that patterns of hemispheric language dominance in TLE patients are highly diverse, although the most common type is left-hemisphere language dominance (LHLD). The diversity is found in both LTLE and RTLE patients, but it is especially pronounced in LTLE patients, reflecting interhemispheric reorganization of language following early left-hemisphere damage (Rasmussen & Milner, 1977). It is generally accepted that hemispheric language dominance is an important variable in hemispheric specialization research. Nevertheless, only a few studies have actually addressed the question of whether TLE patients with LHLD versus non-left-hemisphere language dominance (NLHLD) show differential material-specific memory capacity.

Helmstaedter, Kurthen, Linke, and Elger (1994) found that LTLE patients with right-hemisphere language dominance (RHLD), despite left mesiotemporal dysfunction, show better verbal than nonverbal memory performance. Rausch, Boone, and Ary (1991) reported that LTLE patients with RHLD do not exhibit verbal memory loss following left temporal lobectomy, which is evident in LTLE patients with LHLD. The authors suggested that in LTLE patients with RHLD, verbal memory as well as general language functions may be supported primarily by the right hemisphere. Glosser, Saykin, Deutsch, O’Connor, and Sperling (1995) investigated lateralization of material-specific memory processing in TLE patients using an IAP memory test.

In this study, TLE patients with LHLD demonstrated left-hemisphere specialization for verbal memory and right-hemisphere specialization for nonverbal memory. In contrast, TLE patients with NLHLD showed no lateral specialization for either verbal or nonverbal memory processing, indicating interhemispheric reorganization of memory functions. On the basis of these findings, we hypothesized that selective verbal or nonverbal memory deficits that are dependent on side of seizure onset would be apparent in TLE patients with LHLD but not in TLE patients with NLHLD.

Method

Subjects

The subjects were 92 patients who ultimately underwent left or right mesial temporal lobe surgery for treatment of medically intractable epilepsy of unilateral temporal origin. They were selected from a consecutive series of patients undergoing temporal lobe surgery in an epilepsy surgery center who met the following criteria: (a) completion of relevant memory measures as a part of presurgical workup, (b) age greater than 15 years, and (c) seizure-free or near seizure-free status (Class I or II; Engel, van Ness, Rasmussen, & Ojemann, 1993) at 1-year postsurgery follow-up. The last criterion was included as a means of establishing an ultimate standard of the correct localization–lateralization of the epileptogenic foci. Of the 92 patients, 48 had left mesiotemporal foci and 44 had right mesiotemporal foci. Fifty-nine were males, and 33 were females. Eighty-three were right-handed, and 9 were left-handed, as determined by a 13-item questionnaire (Chapman & Chapman, 1987). The mean age at the time of testing was 28.9 years (SD = 6.8). The mean age of recurrent seizure onset was 13.6 years (SD = 6.7). All patients had their seizure onset lateralized to a single mesial temporal lobe in a presurgical evaluation. The presurgical evaluation included seizure semiology, prolonged interictal and ictal video electroencephalograph (EEG) from scalp–sphenoidal electrodes, MRI scanning, interictal single photon emission tomography, IAP, neuropsychological testing, and if necessary, EEG from chronically implanted bilateral subdural strip electrodes.

Memory Testing

All patients were administered the Rey–Kim Memory Test (RKMT; Kim, 1999) as a part of presurgical examination. In the RKMT, verbal memory performance is assessed by the K-Auditory Verbal Learning Test (KAVLT), a Korean version of the Rey Auditory Verbal Learning Test (Rey, 1964), and nonverbal memory performance is assessed by the K-Complex Figure Test (KCFT), a Korean version of the Rey Complex Figure Test (Rey, 1941). The KAVLT required serial learning of a list of 15 unrelated words over five consecutive trials, each trial followed by immediate recall. After a delay period of 20 min, the patient was again required to recall the 15 words. Following completion of the delayed recall, the patient was presented with a list of 50 words and required to choose a total of 15 words that were in the original list spoken by the examiner. The KCFT was essentially identical to the standard version of the Rey Complex Figure Test (Lezak, 1983). The patient was required to copy the figure as accurately as possible with no time limit imposed. An immediate recall trial was administered following completion of the figure copy. After a delay period of 20 min, the patient was again required to recall the figure. All KCFT productions were scored according to a standard version of the 36-point scoring system (Lezak, 1983).
IAP

All patients underwent IAP as a part of presurgical evaluation. The IAP was conducted, with the patient supine, immediately following angiography. Amobarbital, 125 mg in a 10% solution, was injected into the internal carotid artery using a transfemoral catheter over a 4–5 s interval. In most patients, the side considered for resection was injected first. Left- and right-hemisphere injections were done on the same day with a minimum of 40 min between the two injections. Following demonstration of hemiplegia, the patient was presented with a series of language tasks that lasted approximately 60–90 s. Assessment of language functions during the course of the IAP has varied slightly over the years but has always included both receptive and expressive language tasks. The core tasks were as follows: following a simple command (e.g., “close your eyes”), reading a short sentence, naming a picture, and repeating a phrase spoken by the examiner.

On the basis of the IAP language test, language dominance was dichotomized into two types, LHLD and NLHLD. A conservative criterion for LHLD was adopted because it was thought to be critical for proper testing of the research hypotheses. Thus, only patients who displayed exclusive left-hemisphere competence in all or nearly all administered language tasks were classified as having LHLD. More specifically, there were 61 patients who failed all language tasks following left-hemisphere injection but performed all language tasks correctly following right-hemisphere injection. These patients were classified into the LHLD group. In addition, there were 3 patients who failed all language tasks following left-hemisphere injection and performed all but one language task correctly following right-hemisphere injection or who failed all but one language task following left-hemisphere injection and performed all language tasks correctly following right-hemisphere injection. These 3 patients, considered as having near exclusive left-hemisphere representation of language, were also classified into the LHLD group. All other patients (n = 28) were classified into the NLHLD group. The incidence of NLHLD was 50% in LTLE patients but only 9% in RTLE patients. This difference in the incidence of NLHLD between LTLE and RTLE patients was highly significant (Fisher’s exact test, p < .001).

Surgical Pathology

A tailored temporal lobectomy, including both anterolateral temporal resection and amygdalohippocampectomy, was performed on all patients. We routinely varied the extent of hippocampal resections, depending on the intraoperative interictal epileptiform abnormalities on preresection electrocorticography (ECoG) recorded from the hippocampus and parahippocampal gyrius (Son, Howard, Ojemann, & Lettich, 1994). After initial removal, postresection recording of ECoG from the remaining hippocampus and parahippocampal gyrius was repeated to decide whether further hippocampal resection was needed. No subjects had major neurologic complications following surgery. A pathological diagnosis of the resected mesial temporal lobe was available for 88 of 92 patients as follows: 60 (68%) had mesial temporal sclerosis (with or without other lesions), 4 (5%) had tumors, 11 (13%) had other pathology, and 13 (15%) had no abnormality detected (for more detailed classification of pathology, see Table 1). The proportion of mesial temporal sclerosis in the present sample corresponds well with estimations of mesial temporal sclerosis in other series of temporal lobe surgery (McMillan et al., 1987; Meencke & Veith, 1991).

Statistical Analyses

We composed four groups on the basis of the cross-classification of patients based on language dominance and seizure laterality: LHLD–LTLE (n = 24), LHLD–RTLE (n = 40), NLHLD–LTLE (n = 24), and NLHLD–RTLE (n = 4). The NLHLD–RTLE group was excluded from further analyses because of the extremely small sample size, although the data for this group are presented for descriptive purposes. The data from the remaining three groups were analyzed in two separate analyses of variance (ANOVA), each restricted to two groups. The first ANOVA, restricted to the LHLD–LTLE and LHLD–RTLE groups, was performed to investigate the effects of seizure laterality on material-specific memory in patients with LHLD. The second ANOVA, restricted to the LHLD–LTLE and NLHLD–LTLE groups, was performed to investigate the effects of language dominance on material-specific memory in LTLE patients.

Two types of analyses were performed, one involving individual trial scores and the other involving aggregate measures of individual trial scores. The aggregate measures, referred to as Z scores, were obtained by converting raw scores of all relevant trial scores to Z scores (based on the entire study sample) and then averaging the z scores. The KAVLT Z score was derived from the seven learning and memory trials of the KAVLT (Trials 1 to V, delayed recall, and delayed recognition), and the KCFT Z score was derived from the two memory trials of the KCFT (immediate recall and delayed recall). The analyses of individual trial scores were performed to explore the possible source differences in the aggregate measures. The analyses of the aggregate measures were given primary importance for the following reasons. First, the aggregate measures were inherently more comprehensive than individual trial scores, allowing a more focused test of the research hypotheses. Second, the aggregate measures permitted a direct statistical comparison (i.e., paired t test) of verbal versus nonverbal memory scores within a group, whereas this was impossible for individual trial scores because of noncomparable units of measurement. Finally, the analyses of the aggregate measures involved fewer statistical tests than the analyses of individual trials scores. Thus, the former was less vulnerable to experimentwise Type I error than the latter.

The RKMT (Kim, 1999) yields scales for each KAVLT and KCFT trial, which provide normalized standard scores with a normative mean of 10 and a standard deviation of 3. Aggregate measures of these scaled scores were obtained by averaging the scaled scores of all relevant trials. All statistical analyses reported in this article were performed twice: directly on raw scores and Z scores, and on the scaled scores and aggregate scaled scores. The pattern of statistical significance was highly comparable with raw scores and with scaled scores. Thus, for simplicity of presentation, the following description of statistical results will be limited to the analyses of raw scores, unless otherwise noted.

Results

Demographic and Clinical Variables

Demographic and clinical characteristics of the sample are presented in Table 1, separately for the LHLD–LTLE, LHLD–RTLE, NLHLD–LTLE, and NLHLD–RTLE groups. Group differences were examined by F tests for continuous variables and by 2 × 2 Fisher exact tests for categorical variables. Statistical analyses revealed no significant differences between the LHLD–LTLE and LHLD–RTLE groups in terms of age, education, gender ratio,
handedness, onset age of recurrent seizures, duration of seizures, incidence of febrile convulsions, 1-year postsurgery outcome (percent Class I), memory quotient, full-scale IQ, and incidence of mesial temporal sclerosis ($p$s > .10). The LHLD–LTLE and NLHLD–LTLE groups were significantly different in two variables, handedness and onset age of recurrent seizures. The incidence of left-handedness was significantly higher in the NLHLD–LTLE group (Fisher’s exact test, $p = .009$). The onset age of recurrent seizures was significantly earlier in the NLHLD–LTLE group, $F(1, 46) = 12.47, p < .01$. These findings replicate the corresponding results of several prior studies (e.g., Rasmussen & Milner, 1977; Satz, Strauss, Wada, & Orsini, 1988).

Effects of Seizure Laterality

Means and standard deviations for KAVLT and KCFT performance of the sample are presented in Table 2, separately for the LHLD–LTLE, LHLD–RTLE, NLHLD–LTLE, and NLHLD–RTLE groups. Both raw and scaled scores are listed in Table 2. As stated before, the pattern of statistical significance was highly comparable with raw scores and with scaled scores. Thus, the following report of statistical results is limited to the analyses of raw scores.

The mean Z scores of the four groups are depicted in Figure 1. The Z scores of the LHLD–LTLE and LHLD–RTLE groups were analyzed using a $2 \times 2$ (Material × Seizure Laterality) ANOVA. The only significant effect in this ANOVA was a Material × Seizure Laterality interaction, $F(1, 62) = 15.03, p < .001$. A priori contrasts using paired $t$ tests indicated that the LHLD–LTLE group had a significantly better KCFT than KAVLT Z score, $t(23) = 3.38, p < .01$, one-tailed, whereas the LHLD–RTLE group had a significantly better KAVLT than KCFT Z score, $t(39) = 1.94, p < .05$, one-tailed (see Figure 1). Thus, the LHLD–LTLE group showed relative verbal memory deficit, whereas the LHLD–RTLE group showed relative nonverbal memory impairment.

The LHLD–LTLE group had a significantly higher KCFT Z score relative to the LHLD–RTLE group, $F(1, 62) = 8.83, p < .01$. An examination of KCFT trial scores indicated that both immediate, $F(1, 62) = 10.38, p < .01$, and delay recall scores, $F(1, 62) = 6.67, p < .05$, were significantly higher for the LHLD–LTLE group. The LHLD–RTLE group showed a better KAVLT Z score than the LHLD–LTLE group, but this did not reach statistical significance, $F(1, 62) = 1.27, p > .20$. No KAVLT trial scores were significantly different between the two groups ($p$s > .05). Thus, the present sample of LHLD–LTLE and LHLD–RTLE patients showed a significant difference in nonverbal memory

Table 1

Demographic and Clinical Characteristics of the Sample

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>LHLD–LTLE ($n = 24$)</th>
<th>LHLD–RTLE ($n = 40$)</th>
<th>NLHLD–LTLE ($n = 24$)</th>
<th>NLHLD–RTLE ($n = 4$)</th>
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</thead>
<tbody>
<tr>
<td>Age (years)</td>
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<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
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<tr>
<td>Education (years)</td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
</tr>
<tr>
<td>Gender ($%$ male)</td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
</tr>
<tr>
<td>Handedness ($%$ right-handed)</td>
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<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
</tr>
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<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
</tr>
<tr>
<td>Duration of seizures (years)</td>
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<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
</tr>
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<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
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<td>1-year postsurgery outcome ($%$ Class I)</td>
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<td>$SD$</td>
<td>$M$</td>
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<tr>
<td>Gender (%) male</td>
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<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
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<tr>
<td>Education (years)</td>
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</table>
| Note: LHLD = left-hemisphere language dominance; LTLE = left temporal lobe epilepsy; RTLE = right temporal lobe epilepsy; NLHLD = non-left-hemisphere language dominance; MQ = memory quotient; RKMT = Rey–Kim Memory Test (Kim, 1999); FSIQ = full-scale IQ; K–WAIS = K–Wechsler Adult Intelligence Scale (Yeom, Park, Oh, Kim, & Lee, 1992); MTS = mesial temporal sclerosis.
capacity in the expected direction but no significant difference in verbal memory capacity.

Effects of Language Dominance

The Z scores of the LHLD–LTLE and NLHLD–LTLE groups were analyzed using a 2 × 2 (Material × Type of Language Dominance) ANOVA. The only significant effect in this ANOVA was a Material × Type of Language Dominance interaction, F(1, 46) = 6.84, p < .05. A priori contrasts using paired t tests indicated that the LHLD–LTLE group had a significantly better KCFT than KAVLT Z score, as described above. In contrast, the NLHLD–LTLE group showed no significant difference in the ability to learn verbal versus nonverbal material, t(23) = 1 (see Figure 1). Thus, the LHLD–LTLE group showed a relative verbal memory deficit, whereas the NLHLD–LTLE group showed relatively equal ability to learn verbal versus nonverbal material.

The NLHLD–LTLE group had a significantly better KAVLT Z score relative to the LHLD–LTLE group, F(1, 46) = 5.00, p < .05, indicating relatively spared verbal memory capacity. An examination of KAVLT trial scores showed a significantly higher performance by the NLHLD–LTLE group compared to the LHLD–LTLE group. An examination of KCFT trial scores showed a significantly higher performance by the NLHLD–LTLE group compared to the LHLD–LTLE group.

Table 2

<table>
<thead>
<tr>
<th>Measure</th>
<th>LHLD–LTLE (n = 24)</th>
<th>LHLD–RTLE (n = 40)</th>
<th>NLHLD–LTLE (n = 24)</th>
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<td>SD</td>
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<td>Trial I</td>
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<tr>
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<tr>
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<tr>
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<td>3.1</td>
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Note. LHLD = left-hemisphere language dominance; LTLE = left temporal lobe epilepsy; RTLE = right temporal lobe epilepsy; NLHLD = non-left-hemisphere language dominance; KAVLT = K-Auditory Verbal Learning Test; KCFT = K-Complex Figure Test.

Figure 1. Mean Z scores for two types of material in left temporal lobe epileptic patients with left-hemisphere language dominance (LHLD–LTLE; n = 24), right temporal lobe epileptic patients with left-hemisphere language dominance (LHLD–RTLE; n = 40), left temporal lobe epileptic patients with non-left-hemisphere language dominance (NLHLD–LTLE; n = 24), and right temporal lobe epileptic patients with non-left-hemisphere language dominance (NLHLD–RTLE; n = 4). Error bars represent the standard error of the mean. KAVLT = K-Auditory Verbal Learning Test; KCFT = K-Complex Figure Test.
LHLD group in two trial scores: Trial IV, \( F(1, 46) = 5.61, p < .05 \), and Trial V, \( F(1, 46) = 4.45, p < .05 \). The NLHLD–LTLE group had a lower KCFT Z score relative to the LHLD–LTLE group, but this was not statistically significant, \( F(1, 46) < 1 \). An examination of KCFT trial scores revealed no significant difference between the NLHLD–LTLE and LHLD–LTLE groups. Thus, the NLHLD–LTLE group showed a significantly higher verbal memory capacity compared with the LHLD–LTLE group, but the two groups were similar in nonverbal memory capacity.

**Effects of Etiology**

The present study involved both patients with evidence of mesial temporal sclerosis (MTS\(^+\); \( n = 60 \)) and patients without evidence of mesial temporal sclerosis (MTS\(^-\); \( n = 28 \)). These two groups of patients were analyzed separately to investigate possible confounding because of inclusion of patients with different pathologic substrates. First, the effects of seizure laterality on material-specific memory were examined separately for LHLD–MTS\(^+\) (\( n = 39 \)) and LHLD–MTS\(^-\) patients (\( n = 22 \)). For LHLD–MTS\(^+\) patients, the Z scores were analyzed using a 2 × 2 (Material × Type of Language Dominance) ANOVA. The only significant effect in this ANOVA was a Material × Seizure Laterality interaction, \( F(1, 37) = 8.64, p < .01 \). As may be seen in Figure 2, this interaction reflected a significantly higher KCF (K-Auditory Verbal Learning Test) score for LTLE patients, \( t(12) = 2.83, p < .01 \), one-tailed, and a trend toward higher KAVLT than KCFT Z score for RTLE patients, \( t(25) = 1.28, p = .10 \), one-tailed. An analogous ANOVA for LHLD–MTS\(^-\) patients also yielded a significant Material × Seizure Laterality interaction, \( F(1, 20) = 5.56, p < .05 \). This interaction reflected a significantly higher KCFT than KAVLT Z score for LTLE patients, \( t(10) = 1.86, p < .05 \), one-tailed, and a trend toward higher KAVLT than KCFT Z score for RTLE patients, \( t(10) = 1.45, p = .09 \), one-tailed (see Figure 2). Thus, LHLD–MTS\(^+\) and LHLD–MTS\(^-\) patients were similar in the effects of seizure laterality on material-specific memory performance.

Second, the effects of language dominance on material-specific memory were examined separately for LTLE–MTS\(^+\) (\( n = 31 \)) and LTLE–MTS\(^-\) patients (\( n = 16 \)). For LTLE–MTS\(^+\) patients, the Z scores were analyzed using a 2 × 2 (Material × Type of Language Dominance) ANOVA. In this ANOVA, the Material × Type of Language Dominance interaction was significant, \( F(1, 29) = 4.83, p < .05 \), and no other effects reached statistical significance. As may be seen in Figure 3, this interaction reflected a significantly higher KCFT than KAVLT Z score for LHLD patients, as described above, but no significant difference between KCFT versus KAVLT Z score for NLHLD patients, \( t(17) < 1 \). For LTLE–MTS\(^-\) patients, the Material × Type of Language Dominance interaction failed to reach statistical significance. However, separate analyses for each language dominance group revealed a significantly higher KCFT than KAVLT Z score for LHLD patients, as described above, but no significant difference between KCFT versus KAVLT Z score for NLHLD patients, \( t(4) < 1 \) (see Figure 3). Thus, LTLE–MTS\(^+\) and LTLE–MTS\(^-\) patients were similar in the effects of language dominance on material-specific memory performance.

![Figure 2](image-url)  
**Figure 2.** Mean Z scores as a function of material (KAVLT, KCFT) and seizure laterality (LTLE, RTLE). Left-hemisphere language dominant patients with evidence of mesial temporal sclerosis (LHLD–MTS\(^+\); \( n = 39 \)) are depicted in the left panel, and left-hemisphere language dominant patients without evidence of mesial temporal sclerosis (LHLD–MTS\(^-\); \( n = 22 \)) are depicted in the right panel. Error bars represent the standard error of the mean. KAVLT = K-Auditory Verbal Learning Test; KCFT = K-Complex Figure Test; LTLE = left temporal lobe epilepsy; RTLE = right temporal lobe epilepsy.
Discussion

The present study investigated material-specific memory in TLE patients, with reference to the effects of seizure laterality and language dominance. The examination of seizure laterality effects was restricted to the LHLD–LTLE and LHLD–RTLE groups. The Seizure Laterality Group × Material interaction was highly significant, indicating differential patterns of material-specific memory for the LHLD–LTLE and LHLD–RTLE groups. The LHLD–LTLE group showed significantly higher nonverbal than verbal memory capacity, whereas the LHLD–RTLE group showed significantly better ability to learn verbal than nonverbal material. The LHLD–LTLE group had significantly higher nonverbal memory capacity relative to the LHLD–RTLE group. The LHLD–RTLE group was superior to the LHLD–LTLE group in verbal memory performance, but this difference was not statistically significant. Thus, the LHLD–LTLE group showed relative verbal memory deficit, whereas the LHLD–RTLE group showed relative nonverbal memory impairment. These results indicate that LTLE may interfere more with verbal than nonverbal memory capacity, whereas RTLE may interfere more with nonverbal than verbal memory capacity.

The examination of language-dominance effects was restricted to the LHLD–LTLE and NLHLD–LTLE groups. The Language Dominance Group × Material interaction was significant, indicating differential patterns of material-specific memory for the LHLD–LTLE and NLHLD–LTLE groups. The LHLD–LTLE group showed higher capacity to learn nonverbal than verbal material, whereas the NLHLD–LTLE group showed no significant difference in the capacity to learn verbal versus nonverbal material. Moreover, the NLHLD–LTLE group was significantly superior to the LHLD–LTLE group in verbal memory performance, indicating relatively spared verbal memory capacity. Thus, the NLHLD–LTLE group did not show relative verbal memory deficit, which was evident in the LHLD–LTLE group. Separate analyses for MTS+ and MTS− patients were also performed to investigate possible confounding because of inclusion of patients with different pathologic substrates. The results indicated that effects of both seizure laterality and language dominance on material-specific memory performance are highly comparable for MTS+ versus MTS− patients. Thus, the present results are not easily attributed to a heterogeneous patient sample.

A plausible hypothesis for relative sparing of verbal memory function in the NLHLD–LTLE group is interhemispheric reorganization of verbal memory function. According to this hypothesis, certain early left-hemisphere injury associated with LTLE may cause interhemispheric transfer of verbal memory as well as general language functions to the right hemisphere, which in turn causes relative sparing of the functions. An alternative hypothesis may be intrahemispheric as opposed to interhemispheric reorganization of verbal memory function. Although the intrahemispheric reorganization hypothesis is not entirely implausible (Seidenberg et al., 1997), available evidence from other studies is more consistent with the interhemispheric reorganization hypothesis. An IAP study reported by Helmstaedter et al. (1994) indicates that in LTLE patients with RHLD the right hemisphere is superior to the left hemisphere in verbal memory processing (see also Glosser et al., 1995; Kim & Yi, 1997). Rausch et al. (1991) reported that LTLE patients with RHLD do not show verbal memory decline following
left temporal lobectomy, suggesting that verbal memory in these patients is supported primarily by the right hemisphere. However, the present study involved LTLE patients with NLHLD, which is a distinctly different population from LTLE patients with RHLD. Thus, future research will need to address possible differences in interhemispheric reorganization of verbal memory function in LTLE patients with RHLD versus bilateral language dominance.

One weak aspect of the present data is failure to find a significant difference in verbal memory capacity between the LHLD–LTLE and LHLD–RTLE groups. However, the group means were in the predicted direction and related within-groups material-specific effects reached statistical significance. Thus, the lack of statistical significance is best attributed to insufficient statistical power in combination with small magnitude of the effect. Lateralized material-specific effects could be demonstrated in either between- or within-groups comparisons. The within-groups comparison (i.e., comparison of verbal versus nonverbal memory performance within a group) is conceptually at least as important as the between-groups comparison. Moreover, the within-groups comparison should reach statistical significance more efficiently than the between-groups comparison, reflecting its higher statistical power. Nevertheless, prior studies of material-specific memory in TLE patients have relied more on the between- than the within-groups comparisons. The low use of the within-groups comparisons may reflect the fact that they require equal units of measurement across memory tasks, which may be difficult to fulfill unless standardized tasks are used. The present use of aggregate Z scores provides one means that can circumvent this difficulty.

The present study shows that the NLHLD–LTLE group, despite left mesiotemporal dysfunction, does not show relative verbal memory deficit. Thus, inclusion of NLHLD–LTLE patients may have contributed to certain prior failures to find a significant difference in material-specific memory between LTLE and RTLE patients. Consistent with this view, a number of prior studies (Cohen, 1992; Delaney et al., 1980; Ellis et al., 1991; Giovagnoli & Avanzini, 1999; Giovagnoli et al., 1995; LaDavas et al., 1979; Lendt et al., 1999; Mugas, Ehlers, Walton, & McCutchen, 1985; Piguet et al., 1994) failed to control variations in type of language dominance. Even when a study controlled type of language dominance, the study sample may have included some patients with NLHLD. This is suggested by wide differences in the reported incidence of LHLD in the TLE population across epilepsy centers, ranging from 60% to 90% (Chelune et al., 1998; Dinner, 1991; Loring et al., 1990; Zatorre, 1989). These vastly different estimates suggest nontrivially differential criteria for defining LHLD (or NLHLD) among the centers, as noted by many authors (Benbadis et al., 1995; Kurthen et al., 1994; Snyder, Novelly, & Harris, 1990). The present study adopted a conservative criterion for LHLD, because it was thought to be critical for proper testing of the research hypotheses. The significant differences between the LHLD–LTLE and NLHLD–LTLE groups in the present study suggest the utility of conservatively defining LHLD.

In conclusion, the present study shows that both seizure laterality and language dominance have significant effects on material-specific memory in TLE patients. The effects of seizure laterality indicate that LTLE may interfere more with verbal than nonverbal memory capacity, whereas RTLE may interfere more with nonverbal than verbal memory capacity. The effects of language dominance indicate that selective verbal or nonverbal memory deficits that are dependent on side of seizure onset are apparent in patients with LHLD but not in patients with NLHLD. However, the difference in verbal versus nonverbal memory capacity was of relatively small magnitude even in patients with LHLD. Thus, the lateralizing value of material-specific memory performance would be, at best, of modest degree. Limitations of the present study include the use of one particular type of verbal and nonverbal memory tasks. Moreover, the two memory tasks were not matched in procedures. Thus, the external validity of the present findings needs to be investigated using other types of verbal and nonverbal memory tasks. In addition, there are several other possible ways of classifying hemispheric language dominance on the basis of the IAP than the one adopted in the present study. For example, the NLHLD group may be further divided into those with RHLD versus bilateral language dominance. Thus, the effects of language dominance on material-specific memory need to be further explored using other classification criteria.

References


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