Differential lateralization of memory discrimination and response bias in temporal lobe epilepsy patients

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Abstract
Recognition memory for words and designs was assessed in epilepsy patients who underwent unilateral anterior temporal lobectomy. Memory was assessed during the intracarotid amobarbital test (IAT) performed prior to surgery and also following surgery. Memory discrimination and response bias lateralized differently. Memory discrimination, or memory accuracy, lateralized as a function of the type of material used in memory testing. Left temporal lobe lesions resulted in more impaired discrimination of verbal materials; right temporal lobe lesions resulted in more impaired discrimination of visuospatial materials. Response bias, the decision rule adopted in situations of uncertainty, was more liberal following left temporal lobe lesions for both verbal and visuospatial materials. Findings suggest that the two cerebral hemispheres are differentially specialized for encoding different types of information in long term memory, and that this impacts on decision strategies in situations of memory uncertainty. (JINS, 1998, 4, 502–511.)

Keywords: Temporal lobectomy, Intracarotid amobarbital test (IAT), Verbal memory, Visuospatial memory

INTRODUCTION
Much of the evidence for the multifactorial nature of memory comes from studies of patients with different types of brain damage who demonstrate dissociations between different aspects of memory, such as explicit versus implicit memory, encoding/consolidation versus retrieval, and working versus long-term memory (Squire & Butters, 1993).

One distinction in the study of memory concerns specialization of the two cerebral hemispheres for processing different types of information for long-term memory. Support for the distinction between verbal and visuospatial memory processing comes from studies of patients with intractable epilepsy who have undergone unilateral resection of mesial temporal lobe structures believed to be critical for the acquisition of new information into long-term memory. In patients with left hemisphere language dominance, impaired verbal memory has been reported following left temporal lobectomy (Blakemore & Falconer, 1967; Hermann et al., 1995; Milner, 1958, 1974; Ojemann & Dodrill, 1985), while impaired nonverbal visuospatial memory has been reported following right temporal lobectomy (Jones-Gotman, 1986; Kimura, 1963; Milner, 1968). Differential lateralization of material-specific memory functions has also been demonstrated in studies that have used the intracarotid amobarbital test (IAT) to produce a transient pharmacologically reversible lesion (Milner et al., 1962). Following amobarbital injection to either the epileptic or nonepileptic hemisphere, left-sided lesions have resulted in selectively impaired memory for verbal information, and right sided lesions have resulted in selectively impaired memory for nonverbal visuospatial information (Christianson et al., 1990; Glosser et al., 1995; Perrine et al., 1993). The differential specialization of the two hemispheres for processing verbal...
and visuospatial materials for memory has been related to the cerebral lateralization of basic language and perceptual functions. Comparing patients with left hemisphere language dominance and those with bilateral or right hemisphere specialization for language processing, Glosser et al. (1995) observed that neural structures specialized for verbal memory processing were distributed in parallel with the neural systems devoted to language processing, and visuospatial memory processing was subserved by neural structures that appeared to be in close proximity to systems specialized for certain visuospatial perceptual functions. It was suggested that this neural organization reflects the fact that memory processing depends critically on results of the initial perceptual analysis of different kinds of information. For individuals with left hemisphere language dominance, verbal memory accuracy is enhanced for linguistic information processed in the left hemisphere, and memory accuracy is enhanced for visuospatial information processed in the right hemisphere.

The neuropsychological distinction that has been discussed thus far deals with hemispheric differences in the accuracy of memory recall or recognition for different kinds of materials. A somewhat different distinction that has been made in the study of memory is that between memory discrimination and response bias (Corwin, 1994; Snodgrass & Corwin, 1988). Memory discrimination refers to the accuracy of memory and reflects the familiarity or strength of representations of previously presented information. Under Two-High Threshold Theory (Snodgrass & Corwin, 1988), discrimination is computed as a function of the proportion of targets correctly accepted (hit rate) minus the proportion of falsely accepted distractors (false alarm rate) on recognition memory testing. Discrimination scores can range from −1.0 to +1.0, though in practice the actual range is 0 to +1.0, where a higher score indicates greater accuracy. Response bias, on the other hand, refers to the strategy that is adopted in conditions of uncertainty (i.e., when discrimination is less than optimal) to decide whether an item was or was not previously presented. When accurate information is not immediately available in memory, the individual may adopt a more liberal (“yea saying”) response bias or a more conservative (“nay saying”) response bias. Response bias is computed as the ratio of false positive responses (false alarm rate) to the proportion of incorrect discrimination responses. Response bias can range from 0 to 1. A neutral value of .5 reflects 50% “yes” guesses and 50% “no” guesses when uncertain. A response bias score greater than .5 indicates a more liberal response bias, and values lower than .5 indicate a more conservative bias.

Studies with memory impaired neurological and psychiatric patients have demonstrated that discrimination and response bias may be dissociable. Snodgrass and Corwin (1988) and Brandt et al. (1992) found that Huntington’s disease (HD) patients and Alzheimer’s disease (AD) patients showed poor discrimination for words and pictures, and both patient groups evidenced a liberal response bias. In contrast, amnesic patients, who showed discrimination that was poorer than the HD patients (Butters et al., 1985), displayed normal response bias (Snodgrass & Corwin, 1988). A dissociation between discrimination and response bias has also been described in studies of recognition memory comparing depressed and manic patients to normals (Corwin et al., 1990). Despite equal levels of discrimination on a word recognition test, depressives and manics demonstrated differing patterns of response bias. Depressives tended to respond in a conservative manner, whereas manics were inclined to respond more liberally. Finally, Gainotti and Marra (1994) found that response bias best differentiated between AD patients and those with the dementia of depression. AD patients adopted a very liberal response bias, whereas depressed patients with equally severe cognitive impairments adopted a conservative response bias. When considered together, the results of these various studies indicate that etiologically distinct populations of memory-disordered patients may be separated not only by level of memory accuracy (discrimination), but also by the pattern of response bias.

Studies of humans, nonhuman primates, and rodents have identified mesial temporal lobe structures to be critical for encoding and consolidation of information into long-term memory (Squire, 1992). The medial temporal lobe system, therefore, constitutes one of the primary neural substrates for the cognitive processes involved in memory accuracy or discrimination. In contrast to the considerable knowledge about the neural specialization our memory discrimination, much less is known about the neural bases for response bias and about the cognitive processes involved in decision making during recognition memory testing.

Various neuropsychological accounts of the mechanisms underlying response bias have been proposed, but none has received universal support. One account suggests that response bias may be mediated by differential regulation of central noradrenergic and cholinergic mechanisms (Corwin et al., 1990). States marked by relative adrenergic excess (i.e., hypomanic mood disorders and AD) are marked by liberal response bias. Relative cholinergic excess, on the other hand, yields conservative response bias. In general, depressed mood states are associated with more conserva-

In the studies reported here we examined epilepsy patients with well-localized temporal lobe lesions to explore the neuropsychological bases of memory discrimination and response bias for different types of material. Specifically, we focused on lateralized differences in memory discrimination and response bias for verbal and visuospatial materials.
EXPERIMENT 1

The intracarotid amobarbital test (IAT) is often performed in patients with medically refractory seizures prior to temporal lobectomy to assess lateralized differences in language and memory processing (Branch et al., 1964; Milner et al., 1962). This procedure creates a reversible lesion that makes it possible to test the capacities of an individual hemisphere in relative isolation from the other. The IAT disrupts function in the anterior two-thirds of the injected cerebral hemisphere (Gotman et al., 1992; Jeffery et al., 1991). It impairs functioning of mesial temporal lobe structures, as well as frontal, temporal, and parietal cortical regions perfused by the middle and anterior cerebral arteries. Since each patient undergoes two injections, one in the presumed epileptogenic hemisphere and one in the non-epileptogenic hemisphere, the IAT provides an opportunity to evaluate functioning within healthy as well as diseased cerebral structures. Administration of a recognition memory test during IAT yields information about the relative strength of memories for different types of material encoded in the two hemispheres (discrimination) and also about ways in which memory encoding in the two hemispheres might impact on decisions about material in memory (response bias).

Methods

Research participants

Participants were 80 patients with intractable partial epilepsy who were candidates for resective surgery at the time of study. All were determined to have a unilateral epileptogenic focus and subsequently underwent unilateral anterior temporal lobectomy. Prior to surgery the epileptogenic temporal lobe was localized using non-invasive scalp/sphenoidal video-EEG monitoring, MRI, and thiopental studies and positron emission tomography in selected patients (Sperling & O’Connor, 1989; Sperling et al., 1992). Intracranial EEG monitoring was used when noninvasive testing could not locate the epileptogenic focus. There were 50 patients who underwent right anterior temporal lobectomy (RTL), and 30 underwent left anterior temporal lobectomy (LTL). There were no significant differences between patients with left and right seizure foci in terms of sex, handedness, education, presurgical FSIQ, age at onset of regular seizures, and age at surgery (Table 1). The group was homogeneous with regard to the pathology underlying the epilepsy, though the majority (approximately 70%) had mesial temporal sclerosis based on the general population of temporal lobectomy patients treated at the Comprehensive Epilepsy Center at The Graduate Hospital. Only patients determined to have exclusive left hemisphere dominance for language functions on the intracarotid amobarbital test (IAT) were included in the study.

Intracarotid amobarbital test (IAT) procedure

The IAT was performed according to a standard protocol (Glosser et al., 1995; Saykin et al., 1991; Sperling et al., 1994). A catheter was placed into an internal carotid artery via a transfemoral approach, and an angiogram was performed to delineate the vascular anatomy. Subsequently, 100 to 125 mg of sodium amobarbital (diluted in 5 cc saline) was injected by hand over a 5-s period to produce a contralateral hemiplegia. Both hemispheres were studied on the same day. The side ipsilateral to the suspected epileptogenic temporal lobe was injected first, and the same dose was always used for the two hemispheres. The interval between injections was approximately 45 to 50 min.

Approximately 90 s postinjection, after language testing was complete, the memory encoding phase was initiated. Nine-to-be-remembered targets were presented: three common objects for naming, three low imagery words for oral reading, and three abstract line drawings for visual inspection. The presentation sequence was identical for all patients (i.e., objects, words, designs).

Recognition memory testing began after the neurological examination and EEG had returned to baseline, approximately 10 min after amobarbital injection. The nine targets were presented with 18 foils (six objects, six words, six designs) in a standard quasi-random order for yes/no recognition.

Two alternate forms with similar stimuli were used to test memory in each hemisphere. Test forms were randomized over side of injection and side of epileptogenic focus across all participants.

Measures

Calculations of memory discrimination and response bias followed Two-High Threshold Theory (Snodgrass & Corwin, 1988). This method has been shown to yield measures that are statistically independent from each other. The discrimination measure (Pr) was calculated using the hit rate (HR = true positives/number of targets) minus the false alarm rate or the proportion of incorrectly chosen distractors (FAR = number of false positives/number of distractors). Pr represents the proportion of the time that

<p>| Table 1. Characteristics of right temporal lobectomy (RTL) and left temporal lobectomy (LTL) patients who were evaluated on the intracarotid amobarbital test |
|---------------------------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>RTL (N = 50)</th>
<th>LTL (N = 30)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at surgery [M, (SD)]</td>
<td>33.2 (9.9)</td>
<td>30.8 (8.3)</td>
</tr>
<tr>
<td>Age at seizure onset [M, (SD)]</td>
<td>13.4 (9.1)</td>
<td>11.3 (8.2)</td>
</tr>
<tr>
<td>Percent male</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>Percent right handed</td>
<td>84%</td>
<td>93%</td>
</tr>
<tr>
<td>Education [M, (SD)]</td>
<td>13.4 (2.2)</td>
<td>13.6 (2.1)</td>
</tr>
<tr>
<td>FSIQ [M, (SD)]</td>
<td>96.3 (15.1)</td>
<td>91.7 (15.7)</td>
</tr>
</tbody>
</table>

1 As suggested by Snodgrass and Corwin (1988), the hit rate was calculated as (True Positives + 0.5)/(Number of Targets + 1.0), and the false alarm rate was calculated as (Number of False Positives + 0.5)/(Number of Distractors + 1.0), to avoid the problem of division by zero in the computation of Br when Pr = 1.
participants are in one of two states: certain that a presented item belongs to the group of targets or certain that it belongs to the group of distractors.

The measure of response bias, \( Br \), is calculated as \( Br = \frac{FAR}{(1 - Pr)} \). The numerator is the proportion of “yes” responses to distractors. The denominator is the proportion of incorrect responses. Therefore, \( Br \) reflects the proportion of items on which participants say “yes” when uncertain.

\( Pr \) and \( Br \) measures were computed separately for words and designs. Scores for object recognition were not considered in most of the analyses reported below because of ceiling effects in memory discrimination for these items (overall accuracy was 96% using the intact left hemisphere and 93% using the intact right hemisphere). Bias is not observable and cannot be measured when discrimination is at or near perfect levels.

**Results**

A repeated measures analysis of variance (ANOVA) of recognition memory scores corrected for guessing (Glosser et al., 1995) was performed with side of epileptic focus (right, left) as the between-group factor and test form (A, B) and material (words, designs) as the within-group factors. There was no significant main effect of test form, and test form did not interact with any other variables. In all subsequent analyses, therefore, data were collapsed over the two test forms.

**Memory discrimination**

A 2 (side of epileptic focus) × 2 (side of injection) × 2 (material) mixed ANOVA of memory discrimination (\( Pr \)) scores yielded a significant main effect of side of injection \([F(1,78) = 98.11, p < .001]\), a significant interactions between Side of Epileptic Focus × Side of Injection \([F(1,78) = 13.351, p < .001]\), as well as a significant three-way interaction \([F(1,78) = 36.78, p < .001]\). The largest effect, of course, was the finding that memory discrimination was better following injection of the presumed epileptic hemisphere when patients were relying primarily on the neurologically less affected hemisphere. Overall discrimination accuracy, based on the composite recognition memory score for objects, words and designs, was significantly higher in RTL \([t(49) = 13.62, p < .001]\) and LTL \([t(29) = 4.85, p < .001]\) groups when patients were relying on the neurologically more healthy hemisphere compared to the epileptic hemisphere. This well-recognized advantage of the nonepileptic hemisphere for memory processing (Loring et al., 1993; Perrine et al., 1995) was not the primary interest of this investigation. Therefore, to better understand and decompose the interaction between side of epileptic focus and side of injection and material, pertinent to the discussion herein, separate ANOVAs were conducted on scores obtained when patients were using the nonepileptic and the epileptic hemisphere.

Lateralized differences in memory discrimination were assessed first for information encoded following injection of the presumed epileptic hemisphere: that is, when patients were relying primarily on the neurologically less affected hemisphere (Table 2). A 2 (side of epileptic focus) × 2 (material) mixed ANOVA comparing \( Pr \) scores yielded a significant main effect of hemisphere \([F(1,78) = 3.9, p < .05]\) and a significant Side of Focus × Material interaction \([F(1,78) = 20.3, p < .001]\). Planned comparisons showed that following right hemisphere injection memory discrimination for words was significantly better than that for designs \((p < .002)\), and that following left hemisphere injection discrimination for designs was significantly better than for words \((p < .003)\).

A similarly lateralized pattern of material specific memory discrimination was found for performances following injection of the presumed nonepileptogenic hemisphere, when patients were relying mostly on the epileptogenic hemisphere. A two-way ANOVA of \( Pr \) scores again showed a significant main effect of hemispheric side of epileptic focus \([F(1,78) = 7.55, p < .01]\) and a significant Side of Focus × Material interaction \([F(1,78) = 12.96, p < .001]\). As above, the planned comparisons revealed a significant \( Pr \) advantage for words compared to designs following right injec-

| Table 2. Mean (standard deviation) material specific recognition memory scores on the intracarotid amobarbital test for patients undergoing right temporal lobectomy (RTL) and left temporal lobectomy (LTL) |
|------------------------|-------------------|-------------------|------------------|-------------------|
|                        | Injection of the epileptic hemisphere | Injection of the nonepileptic hemisphere |
|                        | RTL Right hemisphere injection | LTL Left hemisphere injection | RTL Left hemisphere injection | LTL Right hemisphere injection |
| Discrimination scores \( (Pr) \) | | | | |
| Words                  | .813 (.24) | .517 (.36) | .130 (.24) | .483 (.32) |
| Designs                | .640 (.34) | .717 (.26) | .323 (.40) | .289 (.41) |
| Response bias scores \( (Br) \) | | | | |
| Words                  | .455 (.32) | .498 (.39) | .394 (.25) | .394 (.40) |
| Designs                | .448 (.37) | .620 (.35) | .402 (.35) | .288 (.30) |
tion \((p < .0001)\) and an advantage for designs compared to words following left injection \((p < .05)\). Consistent with our expectations, when patients are relying primarily on the neurologically more affected hemisphere, overall memory discrimination is poorer following injection of the presumed nonepileptogenic hemisphere. Within the epileptogenic hemispheres, however, the relative advantage is still maintained for verbal memory processing in the left hemisphere and for visuospatial memory processing in the right hemisphere.

**Response bias**

Analyses of response bias measures showed a somewhat different pattern of results. A 2 (side of epileptic focus) \(\times\) 2 (side of injection) \(\times\) 2 (material) mixed ANOVA of memory response bias \((Br)\) scores yielded a significant main effect of side of injection \([F(1,78) = 20.11, p < .001]\). As for memory discrimination, there was a difference in response bias following injection of the nonepileptogenic hemisphere compared to injection of the epileptogenic hemisphere. Irrespective of lateralization of the epileptogenic focus, side of IAT injection, and type of material, the composite recognition memory score for objects, words, and designs demonstrated a more conservative response bias when patients were relying primarily on the epileptogenic hemisphere compared to the more healthy hemisphere within both the RTL \([t(49) = 3.21, p < .01]\) and LTL \([t(29) = 2.75, p < .01]\) groups. In addition to the main effect of side of injection, a significant three-way interaction emerged between Side of Epileptic Focus \(\times\) Side of Injection \(\times\) Material \([F(1,78) = 36.78, p < .001]\). This interaction was decomposed in separate ANOVAs of scores obtained when patients were using the nonepileptic and the epileptic hemisphere.

Lateralized differences in \(Br\) were first examined for information encoded following injection of the epileptic side, when patients were relying primarily on the neurologically less affected hemisphere (Table 2). A 2 (hemisphere) \(\times\) 2 (material) mixed ANOVA comparing \(Br\) scores revealed a trend for more liberal response bias using the right compared to the left hemisphere \([F(1,78) = 3.08, p < .08]\), but there were no other significant main effects or interactions.

Lateralized material specific differences in \(Br\) were examined next for performance obtained following injection of the nonepileptic hemisphere, when patients were relying mostly on the neurologically affected hemisphere (Table 2). An ANOVA revealed no significant main effects, but there was a significant Hemisphere \(\times\) Material interaction \([F(1,78) = 16.1, p < .001]\). Planned paired \(t\) tests showed that following injection of the nonepileptic left hemisphere \(Br\) was more liberal for designs than for words \((p < .001)\). There were no differences in response bias for words and designs following injection of the nonepileptic right hemisphere. Combining these results with aforementioned analyses of response bias when information was encoded using the nonepileptic hemisphere, it appears that response bias tends to be more liberal when information is encoded for memory using the right cerebral hemisphere, and this effect may be larger when memory is tested for nonverbal visuospatial as compared to verbal material.

**Discussion**

Discrimination and response bias in recognition memory were found to lateralize differently following IAT injection. For memory discrimination there was an advantage for verbal material, as compared to visuospatial material, when memory encoding relied primarily on the left hemisphere, and there was an advantage for visuospatial material when relying on the right hemisphere. This material-specific lateralization for memory accuracy was apparent when using both nonepileptogenic and epileptogenic structures. Results are consistent with previous studies that have demonstrated material specific impairments in memory following unilateral mesial temporal lobe lesions.

Response bias, by contrast, tended to be more liberal when participants were tested for recognition of information that was encoded using the right cerebral hemisphere compared to the left, and this was most apparent in recognition memory testing for visuospatial information encoded using the right hemisphere. Earlier we introduced three proposed neuropsychological accounts of the mechanisms underlying response bias.

One of these accounts suggests that response bias is related to the affective state of the individual at the time of memory encoding or retrieval (Corwin et al., 1990). Our finding of an apparent bias to respond in a more liberal fashion when recognition memory testing takes place after left hemisphere injection is not easily explained by this account. Although we did not examine our patients’ mood directly during the IAT, several past studies have indicated that emotional states tend to be elevated following pharmacological inactivation or structural lesions of the right hemisphere and depressed following inactivation or lesion of the left hemisphere (Gainotti, 1972; Lee et al., 1990, 1993; Terzian, 1964). By this account, response bias should have been more liberal during or following right hemisphere IAT injection. In fact, the observed lateralization pattern for \(Br\) was exactly opposite to this prediction. Response bias tended to be more liberal following left IAT injection. Therefore, it seems unlikely that the lateralization of response bias documented in this study was related to different emotional states.

Another explanation has posited that lateralized differences in response bias reflect a general tendency to respond in a more liberal fashion when memory discrimination or memory strength is impaired (Loring et al., 1989). Taking into account the specialization of the two cerebral hemispheres for memory discrimination of different kinds of material, this account predicts that response bias would be more liberal for verbal material when encoded following left-sided injection and more liberal for visuospatial material when encoded following right injection. In fact, in our study...
response bias was found to be most liberal for visuospatial materials encoded following left hemisphere injection. Overall we found that memory discrimination was relatively impaired and response bias was relatively more conservative when patients were relying primarily on the neurologically affected hemisphere. Perhaps because patients realized that their memory accuracy was relatively compromised, they adopted a more cautious response style during inactivation of the nonepileptic hemisphere. Thus, when side of epileptic focus and type of material are taken into account together with side of injection, the hypothesis that liberal response bias is a function of weakened memory strength was not supported.

With regard to the notion that response bias reflects some aspect of disturbed executive control functioning, several investigators have predicted that right frontal lobe lesions are related to a greater tendency to false recognition (Carran et al., 1997; Rapscak et al., 1994; Schacter et al., 1996). Since the IAT disrupts functioning in both frontal and temporal lobe structures, we expected a more liberal response bias following right as compared to left-sided injection. Again, our results were contrary to this prediction.

Before considering other explanations of our data, we sought to confirm the finding of an apparent association between liberalization of response bias and inactivation of the left, language dominant, cerebral hemisphere in a second experiment.

EXPERIMENT 2

Three concerns may be raised with regard to the results of Experiment 1. First, as discussed above, the IAT tends to inactivate a relatively large area of brain, which includes structures believed to be specialized for memory processing, but it also affects additional frontal, temporal, and parietal cortical regions. The IAT is quite useful for ascertaining lateralization of cognitive functions, but it is difficult to draw firm conclusions about the intrahemispheric localization of cognitive deficits based on IAT data. Second, the time-limited nature of the lesions produced by the IAT places a restriction on the amount of testing that can be accomplished during the procedure. Interpretations are based on relatively small samples of behavior. Third, because IAT recognition memory testing takes place after both hemispheres have returned to baseline neurological functioning, questions may be raised about the role of lateralized neural structures in strategies during actual memory recognition. Lateralized mesial temporal lobe structures are known to be inactive during memory encoding that usually takes place during the maximal effect of the amobarbital, but typically memory recognition is tested after the central effects of amobarbital have worn off. To address these issues, we examined lateralization of memory discrimination and response bias for verbal and visuospatial materials in a new group of patients with chronic lateralized lesions in the temporal lobes.

Methods

Research participants

Participants were epilepsy patients who had already undergone unilateral anterior temporal lobectomy. These patients were different from those who participated in the previous study, but they shared many of the same characteristics. Patients were examined at a mean of 35 weeks post-surgery. There were 40 right temporal lobectomy (RTL) patients and 34 left temporal lobectomy (LTL) patients. All had demonstrated left hemisphere language dominance during the IAT prior to surgery.

The two groups did not differ in terms of mean age at testing, mean number of weeks since surgery, mean years of education, sex, and handedness (Table 3). Full Scale IQ, however, was significantly lower in the LTL group, which is a finding reported in several other studies of this patient population (Glosser et al., 1997; Selwa et al., 1994; Straus et al., 1996). For the 51 patients who had been followed for at least 1 year post-surgery, there was no difference in the percent that were completely seizure free in the RTL (60%) and LTL (66%) groups, indicating that, except for side of resection, the two groups were relatively comparable in terms of their neurological status after temporal lobectomy.

Procedure

Each patient was administered the California Verbal Learning Test (CVLT) using standard administration procedures (Delis et al., 1987) and the Biber Figure Learning Test–Extended (BFLT–E), which is a modification of a memory test using visuospatial stimuli (Glosser et al., 1989). Both tasks involve five presentations of a supraspan set of stimuli for free recall (words or designs), administration of an interference task in which a new set of memory stimuli is presented, immediate or short delayed free recall of the original stimulus set, long delayed (20–30 min) free recall, and yes/no recognition memory testing for the original stimulus set. For the recognition memory test on the CVLT the 16 target nouns are presented in interspersed fashion with 28 distractor nouns, and on the BFLT–E the 15 target designs are interspersed with 30 related distractor designs con-

Table 3. Characteristics of right temporal lobectomy (RTL) and left temporal lobectomy (LTL) patients who were evaluated following surgery

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>RTL (N = 40)</th>
<th>LTL (N = 34)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at surgery [M, (SD)]</td>
<td>35.7 (11.0)</td>
<td>31.8 (7.3)</td>
</tr>
<tr>
<td>Age at seizure onset</td>
<td>14.2 (10.2)</td>
<td>11.0 (9.5)</td>
</tr>
<tr>
<td>Weeks post surgery [M, (SD)]</td>
<td>34.6 (35.5)</td>
<td>36.8 (33.6)</td>
</tr>
<tr>
<td>Percent male</td>
<td>52%</td>
<td>59%</td>
</tr>
<tr>
<td>Percent right handed</td>
<td>86%</td>
<td>88%</td>
</tr>
<tr>
<td>Education [M, (SD)]</td>
<td>13.3 (2.1)</td>
<td>13.2 (1.8)</td>
</tr>
<tr>
<td>FSISQ [M, (SD)]</td>
<td>97.3 (14.8)</td>
<td>93.1 (11.2)</td>
</tr>
</tbody>
</table>
structured using the same principles as the targets. Measures of discrimination and response bias were calculated for each task separately using Two-High Threshold Theory formula.

**Results**

In a 2 (group) × 2 (material) ANOVA of Pr scores (Table 4), there were no significant main effects, but there was a significant Group × Material interaction \[ F(1,72) = 10.68, p < .01 \]. On the CVLT Pr scores were significantly lower for LTL compared to RTL patients \( t(72) = 2.26, p < .05 \), whereas on the BFLT–E Pr scores were significantly lower for RTL compared to LTL patients \( t(72) = 2.10, p < .05 \).

A 2 (group) × 2 (material) ANOVA of Br scores (Table 4) indicated a different pattern of results. Only the main effect for group was significant \( F(1,72) = 9.31, p < .01 \). Thus, on both the CVLT \( t(72) = 2.55, p < .05 \) and BFLT–E \( t(72) = 2.62, p < .05 \), LTL patients (who may be assumed to have been relying more on the intact right hemisphere) showed significantly more liberal response bias compared to RTL patients.

**GENERAL DISCUSSION**

In two different studies of recognition memory for words and designs, one using a model of normal hemispheric dominance and the second using a lesion model, we found that memory discrimination and response bias were lateralized differently in left hemisphere language dominant patients with temporal lobe lesions. Lateralization of memory strength (discrimination) was a function of the type of material used in the recognition memory test. Lesions within the left hemisphere, specifically within the left mesial temporal lobe, resulted in impaired discrimination for verbal materials (words); right temporal lobe lesions were associated with impaired discrimination for visuospatial materials (designs). Similarly, when using the neurologically nonaffected left hemisphere during the IAT, patients showed better memory discrimination for words than designs; when using the nonepileptic right hemisphere, patients showed better memory discrimination for designs than for words. Response bias, on the other hand, was not consistently related to the type of material used in the recognition memory test. Instead we found that, compared to right temporal lobe surgical lesions, left temporal lobe lesions resulted in more liberal response bias on both verbal and visuospatial memory tests. More liberal response bias was also demonstrated on the IAT when patients were using the right, non-language-dominant hemisphere, together, all of these results are consistent with the proposal that discrimination and response bias represent dissociable aspects of memory performance and are mediated by different neurological systems. Both discrimination and response bias must be considered in evaluating memory functioning in clinical populations.

Our finding of lateralized hemispheric differences in memory accuracy for verbal and visuospatial materials replicates numerous previous studies and does not require a new explanation. Our findings with regard to response bias, however, are not easily explained by any existing accounts of the false recognition effect. Several groups of investigators have reported an increased tendency to make false positive errors on tests of verbal recognition memory in patients with left temporal lobe lesions (Bortz et al., 1995; Loring et al., 1989; Rausch, 1981; Seidenberg et al., 1993; Troster et al., 1989) and more false positive errors on nonverbal memory tasks in patients with right temporal lobe lesions (Kimura, 1963). Unfortunately, analyses of data from previous studies have not controlled systematically for the known correlation between measures of hit rate and false alarm. To our knowledge there has been no previous systematic investigation of response bias on tests of both verbal and visuospatial materials in a single population of patients. When we tested recognition memory for verbal and visuospatial materials in the same patient population and applied a formula that derives measures of response bias that are independent of memory accuracy, we found that left temporal lobe lesions were associated with more liberal response bias for both types of information. The finding that response bias was independent of the adequacy of memory discrimination for different kinds of material is incompatible with previous explanations that have attributed a liberal response bias to inefficient encoding of information. As reviewed above, the pattern of our results is also inconsistent with the explanation that a liberal response bias or the tendency to make false positive errors on recognition memory testing is a function of elevated mood, weakened memory strength, or a disturbance in executive processes for memory retrieval and decision making. All of these factors have been shown to affect response bias, but none of these variables seems to account adequately for the findings in the two studies reported above.

We propose an alternative hypothesis to explain the apparent adoption of a more liberal response bias when making decisions about information that was encoded for memory when relying primarily on the right cerebral hemisphere and a more conservative response bias when making decisions about information encoded in the left, language-dominant hemisphere. It will be recalled that a liberal re-

**Table 4.** Scores on word (CVLT) and design (BFLT–E) recognition memory tests following right temporal lobectomy (RTL) and left temporal lobectomy (LTL)

<table>
<thead>
<tr>
<th>Recognition memory test</th>
<th>RTL</th>
<th>LTL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( M (SD) )</td>
<td>( M (SD) )</td>
</tr>
<tr>
<td><strong>Discrimination scores (Pr)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Words (CVLT)</td>
<td>.820 (.15)</td>
<td>.739 (.17)</td>
</tr>
<tr>
<td>Designs (BFLT–E)</td>
<td>.711 (.22)</td>
<td>.854 (.38)</td>
</tr>
<tr>
<td><strong>Response bias scores (Br)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Words (CVLT)</td>
<td>.373 (.25)</td>
<td>.521 (.26)</td>
</tr>
<tr>
<td>Designs (BFLT–E)</td>
<td>.347 (.25)</td>
<td>.473 (.23)</td>
</tr>
</tbody>
</table>
Response bias was found in testing recognition memory for information that was encoded during left hemisphere IAT injection, but the bias to make false positive responses occurred after return to the baseline neurological state, when both hemispheres were presumably functional. Thus, it is not likely that the observed bias in recognition memory was due to hemispheric inactivation at the time of retrieval or decision making about the information in memory. Rather, the bias more likely reflects the way in which the information was encoded initially in long term memory. That is, lateralization in response bias may reflect hemispheric differences in strategies for memory encoding and representation.

Information processing in the left hemisphere is believed to be more analytic and sequential, whereas information processing using the right hemisphere is more global and simultaneous (Gazzaniga, 1989; Goldberg, 1990; Goldberg & Costa, 1981). In general, the notion of “modularity” is associated with the left hemisphere, wherein information is believed to be represented in terms of nonoverlapping discrete units. However, it has been suggested that information is represented in the right cerebral hemisphere in a more distributed, overlapping fashion (Satz et al., 1990; Semmes, 1968). In a situation of uncertainty, as when a perfect match does not occur between an item presented in a recognition memory test and information in memory, it seems more likely that a new (distractor) item will be rejected if it varies some small amount from the highly detailed representations encoded by the left hemisphere (conservative response bias). On the other hand, if the new item is compared to a distributed representation (McClelland & Rumelhart, 1986) encoded by the right hemisphere, it is more likely to be accepted as a possible target even if only a partial match is achieved (liberal response bias). The system that actually makes decisions about the information in memory need not be lateralized. If memory retrieval and decision making are dependent on functioning within the frontal lobes, as many have suggested (Damasio & Anderson, 1993; Schacter et al., 1996), it is still possible that this system will produce different decision outcomes depending on whether the memory representations that are being evaluated were encoded discretely by the left (language dominant) or more globally by the right hemisphere.

The hypothesized contribution of hemispheric differences in information processing and representation to apparent variation in response bias is compatible with notions that affective, executive, and contextual factors all contribute to making decisions in situations of memory uncertainty. Because we only compared right and left temporal lobe epilepsy patients and we only varied dimensions of hemispheric side of temporal lobe lesion and type of learning material, we cannot estimate the possible effects of other factors on response bias. We suggest that in future studies temporal lobe epilepsy patients be compared to other brain-damaged populations, as well as to healthy controls, under a theoretical approach that yields independent estimates of accuracy and bias (see Snodgrass & Corwin, 1988) in order to ascertain how hemispheric processing differences may interact with other variables to determine the strategy adopted when making decisions in situations of memory uncertainty.

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