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A Comparison of Two FMRI Methods for Predicting Verbal Memory Decline After Left Temporal Lobectomy: Language Lateralization vs. Hippocampal Activation Asymmetry

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Abstract

Purpose—Language lateralization measured by preoperative fMRI was shown recently to be predictive of verbal memory outcome in patients undergoing left anterior temporal lobe (L-ATL) resection. The aim of this study was to determine whether language lateralization or hippocampal activation asymmetry is a better predictor of memory outcome in this setting.

Methods—Thirty L-ATL patients underwent preoperative language fMRI, preoperative hippocampal fMRI using a scene encoding task, and pre- and postoperative neuropsychological testing. A group of 37 right ATL surgery patients who underwent the same testing procedures was included for comparison.

Results—Verbal memory decline occurred in roughly half of the L-ATL patients. Preoperative language lateralization was correlated with postoperative verbal memory change. Hippocampal activation asymmetry was strongly related to side of seizure focus and to Wada memory asymmetry but was unrelated to verbal memory outcome.

Discussion—Preoperative hippocampal activation asymmetry elicited by a scene encoding task is not predictive of verbal memory outcome. Risk of verbal memory decline is likely to be related to lateralization of material-specific verbal memory networks, which are more closely correlated with language lateralization than with overall asymmetry of episodic memory processes.

Keywords

temporal lobectomy; fMRI; memory; hippocampus; language dominance

Introduction

Anterior temporal lobe (ATL) resection is an effective treatment for individuals with medically intractable epilepsy (Wiebe et al., 2001; Tellez-Zenteno et al., 2005). The undeniable benefit of this treatment must be balanced against the risk of memory decline, particularly in patients undergoing left ATL resection. Though the incidence of postoperative morbidity varies from study to study depending on the specific assessment methods used, approximately 30–60% of

patients undergoing left ATL resection show significant declines in verbal memory (Chelune et al., 1993; Helmstaedter & Elger, 1996; Martin et al., 1998; Sabsevitz et al., 2001; Lee et al., 2002; Stroup et al., 2003; Gleissner et al., 2004; Baxendale et al., 2006; Lineweaver et al., 2006; Binder et al., 2008). One principal goal of the preoperative evaluation in ATL surgery candidates is, therefore, to estimate the risk of verbal memory decline.

Functional magnetic resonance imaging (fMRI) is a safe, non-invasive brain mapping tool that may provide information about preoperative lateralization of memory networks. Several preliminary studies showed correlations between preoperative medial temporal lobe (MTL) activation and postoperative verbal memory decline (Richardson et al., 2004; Richardson et al., 2006; Frings et al., 2008; Powell et al., 2008). These studies focused on activation in the hippocampus and other MTL areas. In a recent study of 60 patients undergoing left ATL resection, we showed that postoperative verbal memory change was predicted by preoperative language-related activation measured throughout the cerebral hemispheres (Binder et al., 2008). In the present study we compare this language lateralization index with an fMRI method based on hippocampal activation asymmetry to determine which is a better predictor of postoperative verbal memory outcome.

Methods

Participants

Participants were 30 patients with intractable left temporal lobe epilepsy (L-ATL group), encountered consecutively at the Medical College of Wisconsin Comprehensive Epilepsy Program between 1995 and 2006, who met the following criteria: (a) left ATL resection, (b) preoperative fMRI language mapping performed, (c) preoperative fMRI hippocampal mapping performed; (d) preoperative and 6-month-postoperative neuropsychological evaluation performed, and (e) full scale IQ > 70. These patients are a subset from our previous study (Binder et al., 2008) who also underwent hippocampal fMRI mapping. One other L-ATL patient who otherwise met criteria was excluded because fMRI showed no significant activation in the hippocampus on either side. A control group of 37 consecutively encountered patients who had right ATL resection (R-ATL group) and preoperative hippocampal fMRI served as a comparison group.

All patients underwent a standard ATL resection removing the anterior 3 to 4 cm of the temporal lobe, including lateral (middle temporal gyrus, inferior temporal gyrus, polar superior temporal gyrus) and medial (fusiform gyrus, parahippocampus, amygdala, anterior hippocampus) structures. The posterior extent of resection was tailored using electrocorticography in all patients and intra- or extraoperative stimulation mapping of language cortex when the language-dominant temporal lobe was resected. The same epilepsy surgeon performed all operations. FMRI data were collected for research purposes only and were not available to the surgeon before or after surgery. Informed consent was obtained from all patients prior to fMRI using a protocol approved by the Institutional Review Board of the Medical College of Wisconsin.

Patient demographic information is summarized in Table 1. The L-ATL and R-ATL groups did not differ on age, sex, years of education, handedness, age at onset of epilepsy (defined as the age at onset of recurring seizures), epilepsy duration, or measures of intelligence (all *P* values > 0.1).

Neuropsychological Testing

Neuropsychological testing was performed before and 6 months following ATL surgery. Verbal episodic memory was assessed using the 6-trial Selective Reminding Test (SRT)

(Buschke & Fuld, 1974). The SRT includes several measures of word list learning as well as delayed recall and recognition tests. Pre- to post-operative change scores on each test were calculated by subtracting the preoperative score from the postoperative score. Positive values thus indicate improvement, whereas negative values indicate a decline in performance. Other memory tests given before and after surgery included the Logical Memory and Visual Reproduction subtests of the Wechsler Memory Scale (WMS-R or WMS-III) and the 7/24 Spatial Recall Test (Rao et al., 1984). We focus here on the Consistent Long-Term Recall (CLTR) and Delayed Recall measures of the SRT, which were among the most sensitive tests for detecting verbal memory decline in our prior study (Binder et al., 2008). CLTR indexes the rate at which a list of words is learned, whereas Delayed Recall indexes the ability to recall the list after a 30 minute delay.

Patients were nominally classified as either showing or not showing decline on each test, defined as a negative change score of 1.5 standard deviations or more from the mean change score in the R-ATL group. The resulting cut-off values are somewhat conservative and represent substantial declines, generally in the range of 40–60% relative to pre-operative raw scores.

Wada Testing

Wada memory data were available for 28 of the 30 L-ATL patients and all of the R-ATL patients. Wada language and memory testing followed procedures described previously (Loring et al., 1992; Binder et al., 1996; Binder et al., 2008). Immediately after recovery from the anesthetic, a 24-item object memory recognition test was administered. Eight target objects that had been presented in the visual field ipsilateral to the injection and named aloud by the examiner during the period of anesthesia and 16 novel foil objects were presented in a random order, and patients were required to indicate whether or not each object had been presented previously. A recognition memory score for each hemisphere, corrected for guessing, was calculated as the number of items correctly recognized minus half the number of false positive responses. These raw scores, which can range from 0 to 8, were divided by 8 to yield values ranging from 0 to 1. Wada memory asymmetry (WMA) was calculated by taking the difference between the recognition memory performances of the left hemisphere (inject right) and the right hemisphere (inject left), yielding values ranging from -1 (all memory capacity in the right hemisphere) to $+1$ (all memory capacity in the left hemisphere). In a previous study, this asymmetry measure correctly classified 89% of temporal lobe epilepsy patients as to side of seizure focus (Binder et al., 2008).

MRI Acquisition

Imaging was conducted on a 1.5 T GE Signa scanner. High-resolution, T1-weighted anatomical reference images of the entire brain were acquired with a spoiled-gradient-echo ("SPGR") sequence. Whole brain functional imaging used a T2*-weighted gradient-echo, echoplanar sequence with the following parameters: TE = 40 ms, TR = 3000 ms, field of view = 240 mm, pixel matrix = 64×64 , 19 sagittal slices, voxel size = $3.75 \times 3.75 \times 7$ mm.

fMRI Activation Tasks

Both fMRI protocols used a block design with alternation between two active task conditions. The language protocol contrasted a semantic decision task with a tone decision task. In the semantic decision task, patients heard animal names and decided whether each animal is "found in the United States" and "used by humans." In the tone decision task, patients heard brief trains of high and low tones and decided whether the train contained two high tones. These tasks, their rationale, and the typical patterns of activation and lateralization observed in normal participants were described previously (Binder et al., 1997; Frost et al., 1999; Springer et al., 1999; Szaflarski et al., 2002). The contrast between semantic decision and tone decision tasks

highlights speech perception and lexical-semantic processes engaged during the semantic decision task while controlling for early auditory, attention, executive, and motor response processes. This contrast produces reliable and strongly left-lateralized activation in areas previously implicated in language processing, including frontal, temporal, and parietal association cortices (Binder et al., 1997; Frost et al., 1999), and in the left hippocampus and surrounding medial temporal lobe (Binder et al., 1997; Bellgowan et al., 1998).

The hippocampal protocol contrasted a visual scene encoding task with a visual noise encoding task (Binder et al., 2005). In the scene encoding task, patients saw color photographs of natural scenes and decided whether each scene was indoor or outdoor. In the noise encoding task, patients saw spatially scrambled versions of the natural scenes and decided whether the left and right halves of each image were identical. These tasks, their rationale, and the typical patterns of activation observed in normal participants were described previously (Binder et al., 2005). Control participants show significantly better post-scan recognition of the scenes than of the scrambled scenes (Binder et al., 2005), reflecting the more effective activation of episodic memory encoding processes during the scene condition. The contrast between scene and noise encoding tasks highlights visual object recognition and episodic memory encoding processes engaged during the scene encoding task while controlling for early visual, attention, executive, and motor response processes. This contrast produces reliable, symmetric activation of the anterior hippocampus, posterior parahippocampus, and medial fusiform gyrus in healthy participants (Binder et al., 2005).

FMRI Data Analysis

Image processing and statistical analyses were conducted with AFNI (<http://afni.nimh.nih.gov/afni>). All analyses were performed at the individual subject level. Image alignment was used to reduce the effects of head movement. Task-related changes in MRI signal were identified using multiple regression. This method compares the time series of MRI signal values in each image voxel with an idealized hemodynamic response to the task alternation. The idealized response was modeled by convolving a gamma function with a time series of impulses representing each task trial. The regression model also included six movement vectors (computed during image registration) to further reduce any effects of head movement on estimation of the task response, and first- and second-order covariates to model any linear or quadratic baseline shifts.

Language lateralization was measured for three brain regions: frontal lobe, temporal lobe, and a lateral hemisphere region including frontal, temporal, and parietal lobes. The volumes defining these regions of interest (ROIs) were based on an average left hemisphere activation map from 80 healthy, right-handed participants (Frost et al., 1999; Szaflarski et al., 2002). Significantly activated voxels (uncorrected $p < .001$) in the left and right hemisphere were counted in each ROI for each patient. Laterality indexes (LI), reflecting the interhemispheric difference between voxel counts in left and right homologous ROIs, were calculated for each region using the formula: $LI = (L - R) / (L + R)$ (Binder et al., 1996; Springer et al., 1999; Sabsevitz et al., 2003). LIs can range from -1 (all active voxels in the right hemisphere) to $+1$ (all active voxels in the left hemisphere).

For the hippocampal fMRI protocol, hippocampus LIs were computed for three regions: anterior hippocampus, posterior hippocampus, and whole (anterior + posterior) hippocampus. These ROIs were created by manually tracing the hippocampus in 32 healthy participants (Binder et al., 2005). These tracings were aligned in stereotaxic space and averaged to create values for the probability of overlap at each voxel. Voxels included in the hippocampus ROIs were those with at least 90% overlap across the individual tracings. The anterior and posterior ROIs were delineated by a coronal plane through the posterior edge of the interpeduncular

cistern. Given the small size of these ROIs, an uncorrected threshold of $p < .05$ was used to define activated voxels for the LI computations.

Results

Pre- and Post-Operative Memory Performance

Table 2 shows the average pre-operative, post-operative, and pre-post change scores for each ATL group on the two verbal memory measures. The percentage of patients who declined is shown for each test. The L-ATL group showed significant decline in verbal memory, whereas the R-ATL group significantly improved. Roughly half of the L-ATL patients declined on each measure. See Binder et al. (2008) for more details on verbal and nonverbal memory outcome in the larger sample from which this subgroup was taken.

Language LI as a Predictor of Memory Outcome

Table 3 shows correlations between verbal memory change scores and the fMRI language LIs calculated over lateral hemisphere, frontal, and temporal regions. Change scores on CLTR, the list learning measure, were significantly correlated with preoperative language lateralization in the lateral hemisphere and frontal lobe ROIs. Change scores on Delayed Recall showed strong trends for correlation with language lateralization in these ROIs. These correlations reached significance in the larger patient sample studied previously (Binder et al., 2008).

Hippocampal Functional Asymmetry as a Predictor of Memory Outcome

Validity of the hippocampal fMRI measures was assessed by comparing hippocampal LIs in the left and right ATL groups and by correlating the hippocampal LIs with memory asymmetry scores on the Wada test. As shown in Figure 1, all three hippocampal fMRI LIs differed between the left and right ATL groups. The anterior LI was the most strongly related to seizure focus (L-ATL: mean(sd) = $-.283(.620)$; R-ATL: mean(sd) = $.175(.622)$; $p = .004$). The posterior hippocampus LI differed only marginally between groups (L-ATL: mean(sd) = $.120(.652)$; R-ATL: mean(sd) = $.390(.553)$; $p = .071$). The whole hippocampus LI differed between the groups (L-ATL: mean(sd) = $-.049(.520)$; R-ATL: mean(sd) = $.270(.541)$; $p = .017$) but not as much as the anterior LI.

Similarly, the anterior hippocampus LI ($r = .307$, $p = .009$) and whole hippocampus LI ($r = .310$, $p = .007$) were significantly correlated with Wada memory asymmetry across all patients. The posterior hippocampus LI was only weakly correlated with Wada memory asymmetry ($r = .225$, $p = .061$). These validation measures demonstrate that the fMRI hippocampal LIs, particularly the anterior and whole hippocampus LIs, are sensitive to structural and functional asymmetries in the MTL memory system related to chronic temporal lobe epilepsy.

In contrast to the language LIs, none of the three hippocampal LIs was significantly correlated with either of the verbal memory change scores. Correlation values ranged from $-.134$ (posterior hippocampus LI vs. Delayed Recall change) to $.149$ (anterior hippocampus LI vs. Delayed Recall change); none of these approached statistical significance. Correlation between the anterior hippocampus LI and CLTR change was nil ($r = -.040$). Figure 2 illustrates the significant relationship between CLTR outcome and language LI and the lack of correlation between CLTR outcome and anterior hippocampus LI.

Several previous studies reported significant relationships between unilateral left hippocampal activation and verbal memory outcome (Richardson et al., 2006; Powell et al., 2008). In one of these studies (Richardson et al., 2006), change scores were negatively correlated with activation in both left and right hippocampus, suggesting that unilateral activation on the side of surgery may be a more reliable predictor of outcome than activation asymmetry. We found

no statistically significant correlations between unilateral activation in any of the hippocampal ROIs (mean beta coefficient averaged across voxels in the ROI) and verbal memory change on either of the outcome measures. Correlation values ranged from $-.158$ (posterior left hippocampus activation vs. CLTR change) to $-.099$ (anterior left hippocampus activation vs. CLTR change); none of these correlations approached statistical significance.

Discussion

Recent studies have explored the possibility of using preoperative fMRI to predict episodic memory impairment after ATL resection. Given the prominent role played by the hippocampus and other MTL structures in episodic memory, most of this research has focused on preoperative activation in MTL structures. In the first study to examine verbal memory outcome, Richardson and colleagues identified a focus in the anterior hippocampus where asymmetry of activation on fMRI predicted verbal memory outcome on a standardized word list learning test after left ATL resection (Richardson et al., 2004). Greater activation in this region on the left side relative to the right side predicted greater decline. Subsequent studies by the same authors showed correlations between verbal memory change and preoperative activation in either the left hippocampus (Powell et al., 2008) or both the left and right hippocampus (Richardson et al., 2006). Frings et al. showed a weak correlation (1-tailed $p = .077$) between postoperative verbal memory change and preoperative fMRI activation asymmetry in the hippocampus (Frings et al., 2008). While encouraging, these studies used very small sample sizes (7–12 left ATL surgery patients) and should therefore be viewed as preliminary. Moreover, the results were not entirely consistent across studies, with two reporting activation asymmetry as a significant predictor (Richardson et al., 2004; Frings et al., 2008) and two reporting unilateral activation on the left side as the main predictor (Richardson et al., 2006; Powell et al., 2008). In the studies by Richardson and colleagues, the exact location of the hippocampal ROI that best predicts outcome has also varied from study to study. Finally, a study by Rabin et al. failed to find any relationship between preoperative MTL activation (or activation asymmetry) and postoperative verbal memory outcome (Rabin et al., 2004).

One difficulty in using hippocampal activation as a prognostic marker is the relatively small size of this structure, which contains only around a hundred fMRI voxels even when scanning at relatively high resolution. Compared to the entire cerebral hemisphere, which contains many thousands of voxels, measuring activation in the hippocampus thus depends on a much smaller sample size and is consequently more susceptible to random noise, subject motion, and measurement error arising from imperfect identification of hippocampal boundaries. Loss of MRI signal due to macroscopic field inhomogeneity ("signal dropout") often affects the amygdala and occasionally the anterior hippocampus (Constable et al., 2000; Fransson et al., 2001; Morawetz et al., 2008) and represents another technical difficulty for fMRI of the hippocampus. For these reasons, we explored the use of language lateralization as a prognostic marker for verbal memory outcome. The obvious advantage of such an approach is that the ROI over which lateralization is measured can be much larger, potentially offering a more stable and reliable measurement. In addition to this technical advantage, however, there are theoretical reasons to consider language lateralization as a prognostic marker. Evidence suggests that verbal and nonverbal information is encoded in somewhat distinct episodic memory networks, and that these typically have different patterns of hemispheric lateralization (Glosser et al., 1995; Kelley et al., 1998; Chiaravalloti & Glosser, 2001; Golby et al., 2001; Reber et al., 2002; Powell et al., 2005). Furthermore, it seems likely that this specialization for verbal or nonverbal material is not a property of the MTL itself, but is rather a function of the type of information received by the MTL from the ipsilateral hemisphere. If this model is correct, then the MTL in the language-dominant hemisphere is likely to be more critical for supporting verbal episodic memory, and language lateralization should be correlated with verbal memory lateralization.

Analysis of the current patient subgroup is consistent with our previous larger study (Binder et al., 2008) in showing a correlation between verbal memory change and preoperative language LI. Effect sizes were similar in the two analyses, though the correlations with Delayed Recall outcome did not reach standard significance levels in the subgroup analysis due to the smaller sample size. In the previous study, both fMRI language LI ($r = -.432, p < .001$) and Wada language asymmetry ($r = -.398, p < .01$) were significant predictors of verbal memory change, lending strong support to the hypothesis that verbal memory lateralization is correlated with language lateralization. In contrast, a material-nonspecific Wada memory asymmetry score (recognition of visually-encoded real objects) was only weakly related to verbal memory outcome ($r = -.331, p < .05$).

In contrast to the correlations with language LI, we found no evidence of a correlation between verbal memory outcome and preoperative hippocampal activation. There were no significant correlations with either activation asymmetry or unilateral activation in the left hippocampus. These null findings held for ROIs targeting the anterior hippocampus, posterior hippocampus, and whole hippocampus.

Notably, these null results cannot be explained by poor data quality or lack of functional activation. All patients in the study had significantly activated voxels detected in the hippocampus. More importantly, the hippocampal LIs, especially the anterior hippocampus LI, showed clear evidence of functional lateralization away from the side of the seizure focus, as expected in chronic temporal lobe epilepsy. Finally, the anterior and whole hippocampus LIs were significantly correlated with Wada memory asymmetry. Thus, this fMRI protocol based on a visual scene encoding task detected hippocampal functional asymmetry preoperatively, but failed to predict postoperative memory outcome.

We believe this apparent paradox can be explained by activation of both verbal and nonverbal episodic memory networks during the scene encoding task. The resulting activation reflects overall asymmetry of the (verbal + nonverbal) episodic memory system and is therefore a good indicator of lateralized MTL damage. However, because the activation represents a mix of verbal and nonverbal encoding processes, it is not a specific indicator of *verbal* memory lateralization and thus cannot accurately predict verbal memory outcome. In some patients, for example, overall episodic memory is relatively lateralized to the right side while verbal memory remains exclusively on the left, resulting in unexpected verbal memory decline despite preoperative lateralization of activation to the right (Figure 2). In contrast, language lateralization is predictive of verbal memory outcome because it is closely tied to lateralization of verbal episodic memory processes.

According to this model, predicting verbal memory outcome requires an fMRI contrast that distinguishes verbal from nonverbal memory processes. The work by Richardson and colleagues, cited above, has followed this approach (Richardson et al., 2004; Richardson et al., 2006; Powell et al., 2008). Their patients performed a semantic decision task (e.g., "Is it living or nonliving?") on a series of words during fMRI and were later given a recognition test including the same words. Activation related specifically to verbal encoding was identified by contrasting the subsequently recognized (and therefore successfully encoded) words against words that were not subsequently recognized. The authors then searched for voxels in the MTL where activation or activation asymmetry was correlated with verbal memory change across the patient sample. A limitation of this approach is the initial uncertainty about the locations of these correlated voxels, which have varied somewhat from study to study. In order for the test to be useful in a newly encountered individual, some way of identifying these critical voxels *a priori* would seem to be necessary.

The language activation protocol used in the current study also uses a semantic decision task that engages verbal episodic memory encoding. Although the contrast does not focus on successful vs. unsuccessful encoding, the comparison between a semantic word task and a sensory tone task constitutes a "depth of processing" manipulation that is known to modulate verbal episodic memory encoding processes (Craik & Lockhart, 1972; Otten et al., 2001; Bartha et al., 2003). Thus, the critical difference between our approach and the one adopted by Richardson and colleagues is the region of interest over which activation is analyzed. Given the assumption that lateralization of verbal episodic memory processes is tightly coupled to language lateralization, using the larger language network to compute a lateralization index provides a more stable measurement than a small hippocampal ROI and obviates the need to find the set of hippocampus voxels that are predictive of outcome.

In summary, this study shows that preoperative hippocampal activation asymmetry elicited by a scene encoding task is not predictive of verbal memory outcome. Risk of verbal memory decline is likely to be related to lateralization of material-specific verbal memory networks, which are more closely correlated with language lateralization than with overall episodic memory asymmetry.

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Figure 1. Mean preoperative hippocampal fMRI laterality indexes in left and right ATL surgery groups. The three graphs depict LIs for the anterior, posterior, and whole hippocampus. Error bars represent standard error.

Figure 2.

Scatterplots showing correlation between change on the CLTR verbal memory test and fMRI language LI (left) and the lack of correlation between CLTR change and hippocampal LI (right) in 30 left ATL surgery patients. In the graph at right, note several patients in the lower left corner who experienced large declines (negative change scores) on the CLTR test despite preoperative hippocampal activation lateralized strongly to the right.

Table 1

Patient data.

	Left ATL	Right ATL
	Mean (SD)	Mean (SD)
n	30	37
Age at Surgery, y	38.0 (10.8)	39.5 (11.4)
Sex, F/M	16/14	19/18
Education, y	13.1 (1.9)	13.9 (3.0)
Handedness, R/L/A	22/7/1	30/4/3
Age at Epilepsy Onset, y	18.4 (11.2)	15.5 (11.6)
Epilepsy Duration, y	19.7 (13.5)	24.2 (14.4)
Full Scale IQ	93.3 (13.0)	94.5 (12.2)
Verbal IQ	92.2 (11.5)	95.0 (13.2)
Performance IQ	96.6 (14.6)	94.9 (12.5)

F = female, M = male, R = right-handed, L = left-handed, A = ambidextrous, y = years

Table 2

Verbal memory test scores.

		Left ATL	Right ATL	L vs. R
		Mean (SD)	Mean (SD)	<i>p</i>
CLTR	Pre-op	27.2 (14.5)	30.8 (14.3)	n.s.
	Post-op	14.9 (11.5)	40.8 (13.8)	<0.0001
	Change	-12.3 (17.2) [§]	10.0 (14.6) [§]	<0.0001
	Number (%) Declining	16 (53%)	2 (5%)	
Delayed Recall	Pre-op	6.03 (2.82)	6.82 (2.94)	n.s.
	Post-op	2.90 (2.50)	8.11 (2.76)	<0.0001
	Change	-3.13 (3.13) [¶]	1.36 (2.85) [*]	<0.0001
	Number (%) Declining	17 (57%)	2 (6%)	

CLTR = consistent long-term recall score from the Selective Reminding Test.

CLTR data based on 30 left and 37 right ATL patients.

Delayed Recall data based on 30 left and 33 right ATL patients.

Change scores significantly different from zero:

^{*}
 $p < 0.01$,[§]
 $p < .001$,[¶]
 $p < .0001$

Table 3

Correlations between fMRI language LIs and verbal memory change scores in left ATL resection patients.

	CLTR		Delayed Recall	
	R	p	R	p
FMRI Lateral LI	−.392	.020	−.313	.077
FMRI Frontal LI	−.413	.013	−.322	.067
FMRI Temporal LI	−.227	n.s.	−.290	n.s.