Reading skills after left anterior temporal lobe resection: an fMRI study

Uta Noppeney,1 Cathy J. Price,1 John S. Duncan2 and Matthias J. Koepp2

1Wellcome Department of Imaging Neuroscience and 2Department of Clinical and Experimental Epilepsy, Institute of Neurology, London, UK

Summary
Maintaining language functions after left hemisphere lesions has been associated with compensatory right hemisphere activation. It remains unclear whether recruitment of right hemisphere regions necessarily provides an effective mechanism to compensate for language deficits. To investigate the compensatory mechanisms that mediate good reading skills in patients after left anterior temporal lobe resection for mesial temporal lobe epilepsy (mTLE), we tested for the effect of their reading ability on the regional fMRI (functional MRI) signal elicited by sentence reading. Sixteen control subjects and 16 patients participated in the study. In the activation condition, they silently read nine-word sentences, and in the baseline condition they viewed nine-word sentences after all the letters were transformed into false fonts. Reading ability in controls and patients significantly (P < 0.05, corrected) predicted activations in a left hemisphere middle temporal region that was part of the normal sentence reading system. In addition, reading ability in patients, but not controls, significantly predicted activation in the right inferior frontal sulcus, right hippocampus and right inferior temporal sulcus. Right inferior frontal activation was only observed in the patients. In contrast, right hippocampal and inferior temporal activation was observed in all controls and in patients whose reading ability was within the normal range, indicating the importance of these regions for efficient encoding during normal sentence reading. We conclude that proficient reading skills following left anterior temporal lobe resection for mTLE rely on two mechanisms: (i) integrating regions from the normal system (i.e. the left middle temporal, right hippocampus and anterior superior temporal sulcus); and (ii) recruiting right hemisphere regions (i.e. the right inferior frontal sulcus) that are not activated in control subjects.

Keywords: sentence comprehension; functional MRI; left anterior temporal lobe resection; temporal lobe epilepsy

Abbreviations: fMRI = functional MRI; HCV = hippocampal volume; mTLE = mesial temporal lobe epilepsy

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Introduction
Contralateral, possibly homologous cortical areas are thought to compensate for language deficits after left hemisphere lesions (Wernicke, 1886; Kertesz, 1988; Weiller et al., 1995; Thulborn et al., 1999; Gold and Kertesz, 2000; Blasi et al., 2002). It remains controversial whether recruitment of right hemisphere regions necessarily provides an effective mechanism to compensate for language deficits. A necessary role for right hemisphere regions in language processing was initially proposed on the basis of patients with left hemisphere lesions who showed residual language impairment after additional transient (sodium amobarbital test, Kinsbourne, 1971) or permanent (e.g. stroke, Basso et al., 1989) right hemisphere lesions. Functional imaging studies that have investigated the effect of language abilities on regional brain activation have yielded conflicting results: while language recovery in patients with acute aphasia has been suggested to depend on restored activation in unaffected left hemisphere regions (Karbe et al., 1998; Heiss et al., 1999), chronic post-stroke aphasia (Weiller et al., 1995; Thulborn et al., 2000; Blasi et al., 2002) or slowly evolving brain lesions (Thiel et al., 2001) have been shown to benefit from inter-hemisphere reorganization. These discrepancies suggest that lesion location and extension as well as onset and time course of the pathological process determine in part which reorganization pattern is beneficial for language processing.

Functional imaging studies of language processing in chronic epilepsy patients with a left hemisphere focus have provided some evidence for a preoperative right hemispheric...
activation shift (Billingsley et al., 2001; Carpentier et al., 2001; Gaillard et al., 2002; Rutten et al., 2002; Adcock et al., 2003; Sabsevitz et al., 2003). However, these preoperative functional MRI (fMRI) studies are difficult to interpret because of residual responses in the left anterior temporal pole (Rutten et al., 2002) and influences of ictal or even post-/interictal epileptic activity, that may falsely lateralize language function to the right hemisphere (Gaillard et al., 1995; Bellgowan et al., 1998; Jayakar et al., 2002). Moreover, the majority of studies primarily used global brain activation lateralization indices as possible predictors of postoperative outcome of language functions. For instance, less lateralized fMRI activations on a preoperative semantic decision task were associated with less confrontation naming over, the majority of studies primarily used global brain activation lateralization indices as possible predictors of postoperative outcome of language functions. For instance, less lateralized fMRI activations on a preoperative semantic decision task were associated with less confrontation naming deficits postoperatively (Adcock et al., 2003). Although these results suggest that higher preoperative right hemisphere activation predicts good postoperative naming, they do not indicate which parts of the language system have been reorganized or whether the reorganization occurs within the normal language system.

In the present study, we investigated the neuronal systems that mediate good reading performance in patients who had undergone left anterior temporal lobe resection for the treatment of mesial temporal lobe epilepsy (mTLE). Factors which usually affect studies in chronic epilepsy patients (i.e. interictal, ictal and post-ictal epileptic activity and the presence of usually more than two antiepileptic drugs given in high doses) were excluded by including only postoperative patients who had been seizure free for >2 years and were either on low doses of a single antiepileptic drug or on no antiepileptic drugs at all.

The neural systems that mediate good reading performance postoperatively were identified by including a composite reading ability score as a predictor in our general linear model. In this way, we were able to determine brain areas where activation increases with reading ability, i.e. areas where increased activation is associated with high reading ability. This performance correlational approach overcomes some of the limitations involved in the direct comparison of reading activation in different subject groups (e.g. the comparison of reading activation in pre versus postoperative patients or patients versus controls). For example, it capitalizes on the range of language abilities within the patient group rather than allowing performance differences to confound true differences between patients and controls or between patients pre- and postoperatively. Nevertheless, we also included a group of age- and gender-matched control subjects in order to dissociate compensatory mechanisms in the patients that occur within the normal reading system from those that occur in areas that are not observed in control subjects.

Thus, the present study aimed to characterize the neural systems underling successful behavioural compensation and high reading skills in postoperative patients.

In the activation conditions, the participants silently read sentences for meaning. In the baseline conditions, they attentively viewed false fonts. This low-level baseline allowed us to identify the entire sentence reading activation from visual attention and orthographic processing to semantic integration at the sentential level. We then assessed whether reading ability could predict activation in the regions engaged by sentence reading in patients.

### Subjects and methods

#### Subjects

Sixteen control subjects (five males; mean age 34 years; range 20–53) and 16 patients after left anterior temporal lobe resection (six males; mean age 36 years; range 29–53) participated in the fMRI study and the associated behavioural tests. Each of the patients had undergone surgical resection of the left anterior temporal lobe as a therapeutic procedure for refractory epilepsy (duration of epilepsy mean 22.1 years, range 7–46; age of onset, mean 7.6 years, range 1–20; length of postoperative period, mean 5.9 years; range 2–9; see Appendix for individual data). The duration and onset of epilepsy were highly correlated (correlation coefficient 0.67). Prior to surgery, all patients had a definite MRI diagnosis of unilateral left-sided hippocampal sclerosis according to accepted qualitative and quantitative MRI criteria with unilaterally reduced hippocampal volumes corrected for intracranial volume, abnormal hippocampal volume asymmetry indices and increased hippocampal T2 times (Woermann et al., 1998). In all patients, the MRI findings of hippocampal sclerosis were histologically verified in the excised mesial temporal structures (hippocampus, part of the amygdala and anterior 3 cm of lateral temporal neocortex). All patients were seizure free for at least 2 years (range 2–9) following surgery. At the time of fMRI scanning, patients were on monotherapy with carbamazepine (n = 9), sodium valproate (n = 1), topiramate (n = 1) or phenobarbitone (n = 1); the remaining four patients had stopped taking antiepileptic drugs. Out of a large epilepsy surgery programme spanning 1994–2000 with ~100 left anterior temporal lobe resections for mTLE, we were only able to recruit a total of 16 patients who would fit our inclusion criteria and were willing to participate: seizure freedom >2 years, significant reduction of antiepileptic drugs or free of antiepileptic drugs, able to tolerate an fMRI session and sufficient reading abilities (see Appendix for individual clinical data).

All participants were right-handed English native speakers (except for one left-handed English native patient). Written informed consent was obtained in all cases according to the Declaration of Helsinki. The approvals of the Joint Ethics Committee of The Institute of Neurology and The National Hospital for Neurology and Neurosurgery were obtained.

#### Behavioural testing (before scanning)

All subjects were assessed for their reading age (Schornell test) and verbal IQ (National Adult Reading Test; NART). Their reading fluency was assessed by measuring the passage time (mean = 30 s, SD = 8) and the number of errors (accuracy) for a standardized text paragraph. These reading tests (NART, reading age, reading fluency and reading accuracy) were selected out of a large preoperative routine neuropsychological test programme, so as to match preoperative reading ability. In addition, the digit span was measured to provide insight into subjects’ attention span and ensure that they were able to attend during the experiment.

Before the actual scanning, subjects were given a training session where they read similar nine-word sentences in the same rapid visual presentation mode as in the scanner. To ensure that subjects were
able to read sentences, they were asked to read them out aloud and to explain their semantic content.

**Experimental design**

In the activation condition, subjects silently read nine-word sentences for meaning. Altogether they read 240 novel sentences covering a range of different syntactic structures and semantic content. No explicit task was required during scanning in order to avoid inducing additional executive processes (see below for evaluation of sentence comprehension and recognition). In the baseline condition, subjects attentively viewed nine-word sentences after all the letters were transformed into false fonts. This baseline controlled for visual input, but not lexical, semantic or syntactic content. The paradigm therefore maximized our chances of seeing reading-related activation at any level of the reading system. Blocks of six sentences were interleaved with blocks of five false font sentences. The order of conditions was counterbalanced across sessions and subjects.

Sentences and false fonts were presented one word at a time at a fixed rate [word duration 300 ms, word stimulus onset asynchrony 350 ms, sentence word stimulus onset asynchrony 4350 ms; block length for (i) six sentences, 26.1 s; (ii) five false font sentences, 21.7 s]. This serial presentation mode was used to control for visual input and eye movements, and to equate the reading pace of control subjects and patients. Continuous eye monitoring was performed to ensure that subjects were attending to the stimuli.

**Behavioural testing (after scanning)**

**Recognition memory test**

To ensure that subjects had processed the sentences during the fMRI experiment, they were given a surprise recognition test. In other words, subjects were informed about the recognition test only after scanning in order not to confound the activation results by intentional encoding components. All 240 of the ‘old’ sentences that subjects had read in the scanner were re-presented together with 240 ‘new’ sentences. The test required subjects to indicate by a two-choice key press (i) whether or not they had read the sentence in the experiment (old/new judgement); and (ii) whether or not they were confident about their decision (confidence judgement). Subjects were only asked to be as accurate as possible; reaction time was not emphasized. Two patients and one control subject did not perform all parts of the recognition memory test; one control subject and one patient did not participate.

**Word by word sentence reading and comprehension test**

Using the rapid visual presentation mode, subjects read 52 novel sentences. Thirty of these sentences were followed by a question that reformulated the preceding sentence. The questions were presented as a whole on the screen. Subjects had to indicate their answer by a two-choice key press. The sentences and questions covered a range of different syntactic structures related to different degrees of comprehension difficulty (see Appendix for example sentences).

**Reading ability measure**

Five behavioural measures were acquired from patients and controls: (i) reading fluency; (ii) reading accuracy; (iii) reading age; (iv) sentence comprehension; and (v) verbal IQ. As these performance scores were highly correlated with one another (pairwise correlations ≥0.5), we were not able to dissociate their effects on brain activation. To obtain a single reading measure, the five performance scores for control subjects and patients were therefore entered into a factor analysis (as implemented in SPSS; missing values were replaced by the group mean; see Table 1 for group means and Appendix for individual data). This factor analysis yielded only one main (i.e. eigenvalue >1) component that explained 63.7% of the variance in the data. The subject-specific scores for this first factor thus represent reading ability and were used as predictors in the subsequent fMRI analysis.

**fMRI**

A 2 T Siemens Vision system was used to acquire both T1 anatomical volume images and T2*-weighted axial echoplanar images with blood oxygenation level-dependent (BOLD) contrast [gradient echo, Cartesian k-space sampling, echo time (TE) = 40 ms, repetition time (TR) = 2.9 s, slices acquired sequentially in the descending direction, 64 × 64 matrix, 3 × 3 × 3 mm³ voxels spatial resolution, 1.2 mm interslice gap, 1.8 mm slice thickness, 38 slices covering nearly the whole brain]. To avoid Nyquist ghost artefacts, a generalized reconstruction algorithm was used for data processing (Josephs et al., 2000). There were two sessions with a total of 350 volume images per session. The first six volumes were discarded to allow for T1 equilibration effects.

**Data analysis**

The data were analysed with statistical parametric mapping (using SPM99 software from the Wellcome Department of Imaging Neuroscience, London; http://www.fil.ion.ucl.ac.uk/spm). Scans from each subject were realigned using the first as a reference, spatially normalized (Friston et al., 1995) into standard space (Talairach and Tournoux, 1988), resampled to 3 × 3 × 3 mm³ voxels and spatially smoothed with a Gaussian kernel of 8 mm full width at half-maximum (FWHM). The time series in each voxel was highpass filtered to 1/100 Hz. The fMRI experiment was modelled in an event-related fashion with regressors entered into the design matrix after convolving each event-related stick function with a canonical haemodynamic response function and its first temporal derivative. Each stick function encoded the onset of a single sentence. Other covariates of no interest were the realignment parameters (to account for motion artefacts).

Condition-specific effects for each subject were estimated according to the general linear model (Friston et al., 1995). The contrast image (sentence reading relative to baseline) for each subject was

### Table 1 Behavioural data

<table>
<thead>
<tr>
<th></th>
<th>Controls</th>
<th>Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading age</td>
<td>17.7 (1.8) n = 15</td>
<td>16.4 (2.4)</td>
</tr>
<tr>
<td>Sentence comprehe</td>
<td>0.8 (0.07) n = 14</td>
<td>0.8 (0.1)</td>
</tr>
<tr>
<td>(proportion correct)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NART</td>
<td>112.7 (9.1) n = 15</td>
<td>105.8 (10.4)</td>
</tr>
<tr>
<td>Reading fluency (s)</td>
<td>33.9 (4.9)</td>
<td>37.4 (12.0)</td>
</tr>
<tr>
<td>Reading accuracy (no. of errors)</td>
<td>0.6 (0.9)</td>
<td>0.8 (1.5)</td>
</tr>
<tr>
<td>Digit span (scaled)</td>
<td>12.0 (3.3)</td>
<td>11.3 (3.6)</td>
</tr>
</tbody>
</table>

Values are across-volunteer means (SD).
then entered into a second level analysis of variance (ANOVA), which modelled the group effect (i.e. control subjects or patients) on the contrast of interest. The mean corrected reading scores were entered as covariates separately for control subjects and patients. The mean corrected duration of epilepsy was entered as a covariate for the patients. Inferences were made at the second level to emulate a random effects analysis and enable inferences at the population level (Friston et al., 1999). Given that our design was balanced, this two-stage procedure is mathematically identical to a random/mixed effects analysis.

At the second level, we tested for the following.

Sentence effects in control subjects
Sentences > baseline in control subjects.

Sentence effects in patients
Sentences > baseline in patients.

Sentence effects that increased with reading ability for both patients and controls
Sentence-evoked activations that increased with reading ability in both patients and controls were identified with a conjunction of (i) positive correlation with reading ability in patients; (ii) positive correlation with reading ability in controls; (iii) the sentence effect in patients (contrast 1); and (iv) the sentence effect in controls (contrast 2).

Sentence effects that increased with reading ability for patients
Sentence-evoked activations that increased with reading ability only in patients were identified with a conjunction of (i) a positive correlation with reading ability in patients; and (ii) the sentence effect in patients (i.e. contrast 2). Furthermore, we only report regions that also showed a significant interaction (i.e. correlation with reading ability in controls > correlation with reading ability in patients) at 0.01 uncorrected.

Sentence effects that increased with reading ability for controls
Sentence-evoked activations that increased with reading ability only in controls were identified with a conjunction of (i) a positive correlation with reading ability in controls; and (ii) the sentence effect in controls (contrast 2).

**Results**

**Behavioural data**

Sixteen control subjects and 16 patients after left anterior temporal lobe resection were included in this study. The summary performance scores (group mean ± SD) of control subjects and patients are presented in Table 1 for the following behavioural parameters: (i) sentence comprehension skills (=word by word sentence reading and comprehension test, see Subjects and methods); (ii) NART-IQ; (iii) reading accuracy; (iv) reading age; (v) reading fluency; (iv) working memory span; and (i) sentence recognition score (see below). The individual performance scores are presented in the Appendix.

The composite reading scores derived from the factor analysis were not significantly different across groups (P > 0.05; patients, mean = 3.2, SD = 0.6; controls, mean = 3.2, SD = 0.6).

**Recognition memory test**

After the fMRI experiment, subjects performed a surprise sentence recognition test (see Subjects and methods, Table 2). Accuracy of confident and non-confident recognition (Snodgrass and Corwin, 1988) was indexed by the discrimination measure Pr (probability hit – probability false alarm). The discrimination rates were significantly greater than zero for both controls [Pr = 0.48, t(13) = 7.2] and patients [Pr = 0.39, t(12) = 7.2, P < 0.001, two-tailed] and they were not significantly different across groups [t(25) = 1.0, P > 0.05]. Summing over the sure/not sure decision, controls categorized 76% of the new sentences as new, and 74% of the old sentences as old, while patients categorized 72% of new sentences as new and 67% of old sentences as old.

<table>
<thead>
<tr>
<th>Word type</th>
<th>Recognition judgement (proportion of responses)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sure old</td>
</tr>
<tr>
<td>Old</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0.57 (0.18)</td>
</tr>
<tr>
<td>P</td>
<td>0.56 (0.20)</td>
</tr>
<tr>
<td>New</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0.09 (0.12)</td>
</tr>
<tr>
<td>P</td>
<td>0.16 (0.15)</td>
</tr>
</tbody>
</table>

Values are across-volunteer means (SD); C = control subjects; P = patients.

**Table 2 Recognition performance for new and old sentences that were read during the fMRI study**

![Fig. 1](http://brain.oxfordjournals.org/) Sentence activations for control subjects (red) and patients (green) are rendered on a normalized brain. Height threshold: P < 0.05 corrected. Extent threshold: >3 voxels.
In control subjects, reading sentences activated the left inferior frontal, middle temporal/superior temporal sulcus and fusiform gyri, the left precentral sulcus, bilateral temporal poles and right parahippocampal gyrus. In addition, activation was noted in the left occipital cortex (ramus descendens) and right cerebellum.

**Fig. 2** Left: effect of reading ability (i) common to control subjects and patients (row 1); and (ii) in patients (rows 2–4) on coronal slices of a structural image created by averaging the normalized images from 16 patients. Height threshold: $P < 0.001$ uncorrected. Middle: parameter estimates for (1) sentence reading relative to baseline for patients (2) sentence reading relative to baseline for controls (3) correlation with reading ability for patients and (4) correlation with reading ability for controls. The parameter estimates reflect the contributions of each of these explanatory variables to the experimental variance. Right: scatter plots depict the correlation between individuals' regional fMRI signal and reading ability (open circles, control subjects; filled circles, patients). The ordinate represents the fMRI signal and the abscissa represents reading ability.

**Functional imaging data**

**Sentence effects in control subjects**

In control subjects, reading sentences activated the left inferior frontal, middle temporal/superior temporal sulcus and fusiform gyri, the left precentral sulcus, bilateral temporal poles and right parahippocampal gyrus. In addition, activation was noted in the left occipital cortex (ramus descendens) and right cerebellum.
Table 3  Activation affected by reading ability

<table>
<thead>
<tr>
<th>Coordinates</th>
<th>Z-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>y</td>
</tr>
<tr>
<td>In patients and controls Left middle temporal gyrus/superior temporal sulcus</td>
<td>−63</td>
</tr>
<tr>
<td>In patients only Right inferior frontal sulcus</td>
<td>45</td>
</tr>
<tr>
<td>Right hippocampus</td>
<td>24</td>
</tr>
<tr>
<td>Right inferior temporal sulcus</td>
<td>48</td>
</tr>
</tbody>
</table>

Discussion

The current study investigated the neural systems that mediate the maintenance of reading functions in patients after left anterior temporal lobe resection. In the patients, reading ability significantly predicted activation in left temporal regions that form part of the normal sentence comprehension system and a right frontal region that was not activated for sentence reading in control subjects. Moreover, the patients showed an effect of reading ability in the right hippocampus and the right superior temporal sulcus, indicating their importance for efficient encoding during language processing following left temporal lobe resection.

Three distinct types of activation patterns could be distinguished in the regions that contributed to successful maintenance of sentence comprehension.

First, sentence activation in a left middle temporal area was present and increasing with reading ability in the patients. Thus, high reading ability in postoperative patients is also mediated via recruitment of a right hemisphere region that is not activated in the control subjects. Possibly, the right prefrontal region might be engaged in working memory processes or particular syntactic operations like its homotope left hemisphere region in control subjects (Just et al., 1996; Caplan et al., 1998, 1999). It might also function as an articulatory control system. Clearly, future studies are needed to characterize the functional role of this area following left temporal lobe resection.

Secondly, sentence activation in the right prefrontal region was only present and increasing with reading ability in the patients. Thus, high reading ability in postoperative patients is also mediated via recruitment of a right hemisphere region that is not activated in the control subjects. Possibly, the right prefrontal region might be engaged in working memory processes or particular syntactic operations like its homotope left hemisphere region in control subjects (Just et al., 1996; Caplan et al., 1998, 1999). It might also function as an articulatory control system. Clearly, future studies are needed to characterize the functional role of this area following left temporal lobe resection.

Thirdly, the right hippocampus and superior temporal sulcus showed an effect of reading ability only in the patient group and were activated relative to baseline only in the control subjects and in the patients whose reading ability was within the normal range. An activation pattern of this sort might simply reflect differences in task performance between patients with high and low reading skills. For instance, given the hippocampal role in incidental encoding, subjects with high reading skills might be more engaged in encoding the sentences. Alternatively, our results suggest that proficient reading skills in the absence of the left anterior hippocampus rely on the intactness of the right hippocampus. Consequently, reading ability might be reduced in those patients who have additional neuronal dysfunction in the right hippocampus not evident on MRI. Most autopsy studies of hippocampal sclerosis from patients with long-standing TLE have revealed that the degree of hippocampal cell loss is usually asymmetrical, but present, to some degree, on both sides in the majority of patients (Babb and Brown, 1987). As many as 25% of patients with unilateral hippocampal sclerosis had symmetrical damage associated with endfolium sclerosis often noted in the...
contralateral hippocampus (Margeron and Corsellis, 1966). Endfolium sclerosis is difficult to detect using MRI (Van Paesschen et al., 1995). We have excluded severe hippocampal sclerosis of the contralateral hippocampus by T2 and HCV measures, but lesser degrees (e.g. endfolium sclerosis) may be present and not found on MRI. We previously reported evidence for contralateral benzodiazepine receptor abnormalities in about one-third of patients in whom high resolution MRI only revealed unilateral hippocampal sclerosis (Koepp et al., 1997). Our current fMRI findings might reflect the functional correlate of these subtle structural abnormalities leading to functional disturbances despite seizure freedom.

Taken collectively, our results suggest that effective language maintenance in postoperative patients depends on two mechanisms: (i) integrating regions from the normal system (i.e. the left middle temporal, right hippocampus and anterior superior temporal sulcus); and (ii) recruiting right hemisphere regions (right prefrontal area) that are not activated in control subjects.

While our study emphasizes the importance of right hemispheric activations for language maintenance after left anterior temporal lobe resection, it cannot determine whether these plastic changes occurred pre- or postoperatively. Thus, inter-hemisphere reorganization has been emphasized previously by fMRI studies that demonstrated a right hemisphere shift of language-related activation as indexed by decreased lateralization indices in about a quarter of preoperative patients with mTLE relative to control subjects (Billingsley et al., 2001; Carpentier et al., 2001; Gaillard et al., 2002; Rutten et al., 2002; Adcock et al., 2003). However, some of these studies directly compared language activation between control subjects and patients with lower reading abilities, so that activations reflecting compensatory mechanisms could not be dissociated from task performance confounds. In our study, the association of high reading ability after left temporal lobectomy with right hemisphere activation identifies inter-hemisphere reorganization as an important neural mechanism for behavioural language compensation in mTLE patients after left temporal lobectomy.

Moreover, by selecting only patients in whom the epileptogenic area had been completely removed as indicated by postoperative seizure freedom, the current study allows us to eliminate the effect of ongoing epileptic activity on language reorganization. There is some evidence that metabolism and blood flow are uncoupled during the interictal state (Breier et al., 1997) in patients with localization-related epilepsies (Gaillard et al., 1995). It is conceivable that frequent seizure activity can cause severe focal uncoupling that compromised the BOLD effect, leading to false activation and language lateralization (Jayakar et al., 2002). Furthermore, atypical, right-sided or bilateral speech representation in left mTLE recently has been associated with higher spiking frequency, suggesting that the epileptic activity itself, i.e. interictal discharges and seizure spread, may influence speech reorganization (Janszky et al., 2003).

In conclusion, the activation results in patients after successful anterior temporal lobe resection demonstrate that left and right hemisphere regions are involved in effective language maintenance. These findings will inform future longitudinal fMRI studies that examine patients before and after anterior temporal lobe resection and thus provide further insights into the causal factors and time course of the functional reorganization in patients with long-standing mTLE.

Acknowledgements

We wish to thank P. Thompson and S. Baxendale for supervising the routine neuropsychological testing, and the radiographers at the Functional Imaging Laboratory for their assistance in collecting the data. U.N. and C.P. were supported by the Wellcome Trust, and M.K. by the National Society for Epilepsy.

References


Appendix

**Example sentences of the word by word sentence comprehension test**

The poet joined the culture club for career reasons.

The poet became a member of the club to further his career?

The ill horse was given medicine by the doctor.

The horse received medical treatment?

After shooting the old policeman, the criminal ran away.

The policeman shot the criminal?

As the scientist won an award, friends congratulated him.

The colleagues congratulated the scientist for his award?

The explosion injured six workers during their lunch break.

Six labourers were injured in the explosion?

The foreign minister apologized for not attending the conference.

The minister turned up at the meeting?

The plumber removed the dirt in the water pipe.

The water pipe was cleaned by the workman?

The dutiful sexton lit the candles in the chapel.

The chapel was illuminated by candles?


Woermann FG, Barker GJ, Birnie KD, Meencke HJ, Duncan JS. Regional changes in hippocampal T2 relaxation and volume: a quantitative magnetic resonance imaging study of hippocampal sclerosis. J Neurol Neurosurg Psychiatry 1998; 65: 656–64.
### Individual Behavioural Data

<table>
<thead>
<tr>
<th>No.</th>
<th>Sentence comprehension (proportion correct)</th>
<th>Reading age</th>
<th>NART</th>
<th>Fluency (no. of errors)</th>
<th>Accuracy</th>
<th>Digit span scaled</th>
<th>Recognition discrimination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.9</td>
<td>18.1</td>
<td>114</td>
<td>25</td>
<td>0</td>
<td>12</td>
<td>0.27</td>
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<tr>
<td>2</td>
<td>0.53</td>
<td>16</td>
<td>102</td>
<td>49</td>
<td>0</td>
<td>7</td>
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</tr>
<tr>
<td>3</td>
<td>0.67</td>
<td>18.1</td>
<td>115</td>
<td>30</td>
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<td>0.9</td>
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<td>6</td>
<td>0.63</td>
<td>13.2</td>
<td>98</td>
<td>70</td>
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</tr>
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<td>7</td>
<td>0.73</td>
<td>16</td>
<td>111</td>
<td>35</td>
<td>0</td>
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<td>0.7</td>
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<td>95</td>
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### Patient Behavioural Data Pre- and Postoperatively

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33 ± 10 (normal range) 84–100 (normal range)