Brain stimulation reveals critical auditory naming cortex

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One challenge in dominant temporal lobe epilepsy surgery is to remove sufficient epileptogenic tissue without compromising post-operative language functioning. Pre-resection electrical stimulation mapping enables identification of language areas that can be spared from resection, and also provides a unique opportunity to investigate brain–language relationships. Visual object naming is the gold standard for identifying 'essential' language cortex; however, sparing visual naming (VN) sites has not reliably prevented post-operative language decline. In addition to visual object naming, we included a more 'ecologically valid' auditory description naming task in our pre-resection cortical mapping protocol. Of the seven patients who had auditory naming (AN) sites removed, six declined post-operatively, whereas of the 12 patients who did not have AN sites removed, only 3 declined post-operatively (P = 0.02), suggesting an association between AN site removal and post-operative naming decline. Interestingly, although VN sites were preserved in all patients, AN site removal resulted in decline in both auditory and VN tasks. These findings not only have potentially critical clinical significance, but also argue for modality specificity, with considerable integration within the semantic system.

Keywords: language mapping; naming; cortical stimulation

Abbreviations: AN = auditory naming; ANT = auditory naming test; MTS = medial temporal sclerosis; RCI = reliable change index; TLE = temporal lobe epilepsy; TOT = tip-of-the-tongue; VN = visual naming; VNT = visual naming test

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Introduction

Unlike sensory or motor cortex where electrical stimulation elicits a sensation or observable motor response, stimulation of language cortex would appear inconsequential unless the individual were engaged in an observable language task. For decades, visual object naming has been the task of choice for identifying language cortex, and the observable effect of stimulation at positive naming sites is the patient's inability to name a pictured item during the period of stimulation (Ojemann, 1983). Visual naming (VN) sites are considered 'essential', as there is some evidence that removal of these sites (including those within 1 cm of the resection margin) results in post-operative naming decline (Haglund et al., 1994; Ojemann and Dodrill, 1981).

Despite initial reports that sparing VN sites from resection preserves post-operative language functioning, results of a relatively large multicentre investigation showed no difference in post-operative naming between patients who did and did not undergo pre-resection, visually based, cortical language mapping (Hermann et al., 1999). This finding is consistent with our experience that despite having had VN sites spared from resection many patients nonetheless complain of word finding difficulty post-operatively, and they demonstrate such difficulty in spontaneous speech and on expressive language tests. We have also qualitatively observed that temporal lobe epilepsy (TLE) patients rarely complain of difficulty in naming visual objects. Rather, they commonly describe word finding difficulties that occur in the context of everyday auditory–verbal discourse, both before and after surgery.

Given these observations, we explored the utility of an auditory-based naming task. In a previous work we found that auditory description naming (e.g. 'What a king wears on his head') was more sensitive than visual object naming to left
temporal damage (Hamberger and Seidel, 2003; Hamberger and Tamny, 1999), and that auditory but not VN correlated significantly with self-reported word finding difficulty in TLE patients (Hamberger and Seidel, 2003). Additionally, we found a modality based topographical distinction among positive sites in lateral temporal cortex in that stimulation at most anterior temporal sites disrupted auditory but not VN, whereas stimulation at most posterior temporal sites disrupted both visual and auditory naming (AN) (Hamberger et al., 2001). Malow et al. (1996) also reported a distinction between AN and VN sites, although the cortical distribution of the different naming sites was less clear, likely due to their small patient sample.

However, the identification of a particular type of naming site does not necessarily indicate that it is critical to exclude these sites from resection. For instance, the discovery of VN sites in the basal temporal region was a novel and interesting finding; however, subsequent study indicated these sites could be removed without causing post-operative language decline (Krauss et al., 1996). Therefore, they are typically removed when located within the region of a planned resection.

With regard to AN sites, it is not yet known whether these sites should be preserved in order to prevent or minimize post-operative naming decline. However, two factors suggest that removal of AN sites might be detrimental to naming ability. First, greater sensitivity of AN than VN to left temporal lobe damage suggests that the integrity of these sites is important for normal naming function. Second, the resection of anterior temporal cortex, where AN sites are located in most patients, is often associated with naming decline. Thus, we hypothesized that patients who had had AN sites removed (including those with sites within 1 cm of the resection boundary) would decline on naming measures post-operatively, whereas patients who did not have AN sites removed would not exhibit post-operative naming decline.

In this study, we compared post-operative changes in naming performance between patients who did and did not have AN sites included in their resection. VN sites were spared in all patients, with at least a 1 cm margin from the resection boundary. All patients underwent extensive testing of naming before and ~1 year after the surgery. Significant changes in naming were defined using reliable change indices (Sawrie et al., 1996) calculated for each of the three naming measures.

Methods

Subjects

A total of 20 consecutive patients (13 women, 19 right handed) who underwent cortical language mapping before the surgery involving the left temporal region were included in this study. All patients were left hemisphere language dominant, as determined by intracarotid amobarbital testing. Seven had medial temporal sclerosis (MTS, defined as MRI evidence of abnormal signal and hippocampal atrophy), one had left temporal atrophy without MTS, two had left posterior temporal lobe tumour, one had a vascular malformation (sylvian fissure) and nine had no abnormality on MRI. In all the patients, the left temporal region was identified as the area of seizure onset by using intracranial EEG monitoring or a combination of MRI evidence of MTS or other lesions and scalp EEG/video recording. Twelve patients underwent language mapping extraoperatively via subdural electrodes, nine at Columbia University Medical Center (CUMC) and three at New York University Medical Center (NYU). Seven patients underwent intraoperative language mapping prior to resection at CUMC. One patient suffered a surgical complication (venous infarct) and is therefore excluded from data analyses. Demographic and clinical information on the remaining 19 patients were as follows: WAIS-III (Wechsler, 1997) full scale IQ (mean: 101.5, SD: 13.6, all >69), age at mapping (mean: 35.0, SD: 14.6) and age at seizure onset (mean: 17.5, SD: 10.2). This study was approved by Institutional Review Boards at both CUMC and NYU.

Pre- and post-operative testing

Three naming instruments were administered to all patients: the 60-item Boston Naming Test (BNT) (Kaplan et al., 1983), an Auditory Naming Test (ANT) and a Visual Naming Test (VNT), described in Hamberger and Seidel (2003). The BNT is a commonly used picture naming test, which requires examinees to name line drawn objects within 20 s of presentation. Normative data are provided for accuracy only (i.e. number correct). The ANT and VNT were normed on the same population and target items were equated for word frequency between tasks, and normative data indicate that the tests are comparable in their level of difficulty. The VNT differs from the BNT with respect to word frequency of the picture names. The BNT contains a number of relatively low frequency items (e.g. sphinx and protractor), whereas the VNT contains only familiar, mid to high frequency items.

On the ANT, examinees are required to name items orally described, and on the VNT they are required to name line drawn objects (all VNT items are distinct from those on the BNT). For both the ANT and VNT, instructions emphasize responding as rapidly as possible. Normative data are available for accuracy (i.e. number correct), response time and tip-of-the-tongue (TOT) responses (defined as the number of correct responses following phonemic cueing, or that occurred two or more seconds post-stimulus). Of these three response measures, we utilized TOT scores, as these were shown to be most sensitive to subjective word finding difficulty and were more reliably predictive of left temporal seizure onset (Hamberger and Seidel, 2003). Additionally, 1-year test–retest data collected from both healthy controls and non-surgical epilepsy patients indicated no significant practice effect on any ANT or VNT response measures. Further details and normative data on these tasks are presented in Hamberger and Seidel (2003). All patients were tested before surgery (mean = 4.9 months, SD = 4.2), and again at ~1 year post-operatively (mean interval from surgery = 14.2 months, SD = 5.6).

Cortical mapping

Electrodes

For the seven patients evaluated intraoperatively, a minimum of 12 and a maximum of 27 sites along the superior, middle and inferior temporal gyri and the posterior perisylvian cortex were stimulated using a carbon tipped bipolar stimulating electrode with 2 mm diameter ball contacts separated by 5 mm (Ojemann Cortical Stimulator, Radionics Inc.). The sites were chosen based on gyral/vascular anatomy and spaced <10 mm apart.
For the 12 patients who underwent extraoperative mapping, an eight by eight (i.e. 64 contact) grid array, with 5 mm diameter electrodes embedded in Silastic with centre to centre inter-electrode distances of 1 cm (Ad-Tech, Racine, Wisconsin), was positioned over the frontal-parietal-temporal region (trimmed as needed to conform to the covered area). The exposed cortical surface and grid position were documented by using digital photography and schematic diagrams. Subdural electrode positions were verified using skull X-rays, post-operatively. A minimum of 14 and a maximum of 46 sites were tested.

A greater number of sites were tested in the extraoperative group (mean = 29.1, SD = 9.0) than in the intraoperative group (mean = 19.0, SD = 4.7; Z = −2.63, P = 0.007); however, there were no significant differences in the number of auditory (Z = −1.60, P = 0.14) or VN sites (Z = −1.08, P = 0.34) identified between groups. (See below for explanation of statistical procedures).

Mapping procedures

Only items that patients successfully named at baseline were administered during cortical mapping (i.e. items associated with word retrieval errors at baseline could not be used to identify stimulation-related errors during mapping). For all patients, mapping was conducted while antiepileptic drug levels were in the therapeutic range, to minimize afterdischarges and seizure activity.

Extraoperative language mapping was conducted following video/EEG monitoring to identify the seizure onset zone. Testing was conducted during electrical stimulation applied to adjacent electrodes. When results were positive, each electrode was studied individually and referenced to a remote electrode in ‘silent cortex’. All available sites along the lateral temporal cortex as well as parietal sites in the perisylvian area were stimulated.

Patients who underwent intraoperative mapping were initially anesthetized with propofol. Language mapping began following craniotomy/dural opening, electrocorticography and stimulation to determine the threshold for afterdischarges. Several practice trials were conducted to ensure an adequate level of patient responsiveness. Stimulation sites were primarily in the vicinity of the anticipated resection, as determined by the presence of a lesion or intracranial EEG evidence of seizure onset. If no VN cortex was identified, additional perisylvian sites were tested with the goal of positively identifying the VN cortex (rather than relying on negative responses alone). Sites were tested with a bipolar stimulator (see above).

Stimulation mapping parameters followed well-established methods (Ojemann, 1983; 1991). For both intra- and extraoperative mapping at CUMC, a constant current stimulator (Ojemann Cortical Stimulator, Radionics Inc.) delivered a biphasic square waveform at a frequency of 60 Hz, with a 1 ms pulse duration and amperage ranging 3–15 mA during extraoperative mapping and 2–12 mA during intraoperative mapping. Mapping at NYU was conducted using a Grass Instruments S-12 Cortical Stimulator with a biphasic square waveform at a frequency 50 Hz with 0.3 ms pulse duration, with amperage ranging 3–15 mA. Afterdischarge levels were determined by increasing amperage until an afterdischarge was elicited, with an upper limit of 15 mA. Amperage for stimulation was set at 1 mA below the level that elicited an afterdischarge (or 15 mA), which was determined for each site individually. Results reported here are from trials during which no afterdischarges were elicited.

A minimum of two trials, each of visual and AN, were conducted at each site. If results were ambiguous or the patient was temporarily inattentive, additional trials were administered. For visual naming, patients were shown line drawings of common items (e.g. bench and helicopter), and for auditory naming, patients heard oral descriptions of concrete items (e.g. ‘The yellow part of an egg’). For visual naming, patients began with the phrase ‘This is a’, whereas for auditory naming, patients were instructed to name the target item. To reduce differences in duration of cortical stimulation across tasks, the auditory stimuli were limited to those that contained a maximum of eight words and could be presented clearly within 4 s. Additionally, the requirement for patients during VN to articulate the carrier phrase (i.e. ‘This is a’) before naming the pictured object further balanced the stimulus processing and stimulation duration times among tasks. For each task, electrical stimulation began immediately before the presentation of pictures or auditory descriptions and lasted for a maximum of 10 s, but terminated immediately upon the patient’s production of a correct response. For both tasks, patients were instructed to respond as rapidly as possible. Sites were considered critical for task performance if the patient could not name target items during stimulation, but provided correct responses upon cessation of stimulation. When one of the two trials was performed inaccurately, another two trials were administered. Sites were considered critical for task performance only when at least 75% of responses were inaccurate.

Removal versus sparing of naming sites

As VN is considered the ‘gold standard’ for identification of essential naming areas all VN sites were spared from resection, with a margin of at least 1 cm from the resection boundary. As it has not as yet been determined whether AN sites are critical as well these sites were not considered with regard to resection boundaries. Consequently, AN sites detected within the margins of planned resections were removed, and resection boundaries were not adjusted for AN sites falling within 1 cm of the margin.

Statistical analyses

Three performance measures were used to assess pre- and post-operative naming: TOT scores from the ANT and VNT, and the BNT total score (i.e. number correct). As the objective of this study was to establish whether change occurred on an individual basis, the performance data were analysed using methods relevant to individual change (i.e. rather than group analyses). Reliable change indices (RCIs) (Jacobson and Truax, 1991; Sawrie et al., 1996) were used to determine whether the difference between pre- and post-operative naming scores were considered ‘meaningful’ (i.e. greater than normal variability due to measurement error and potential practice effects). RCIs for performance measures on the ANT and VNT were calculated using test–retest data (1-year interval) from non-surgical epilepsy patients (reported in Hamberger and Seidel, 2003). The RCI for the ANT–TOT measure is four items and for the VNT–TOT measure is three items. The RCI for the BNT (five items) is reported in Sawrie et al. (1996). For each patient, RCIs were used to classify each of the three measures as having improved, declined or remained the same. Fisher’s exact test was used to determine whether the presence or absence of naming decline was related to sparing versus removal of AN sites. Group comparisons of demographic and other patient related data were conducted using the non-parametric Mann–Whitney U-test when the sample size was <10. All tests were two-tailed.
Results
Of the 19 patients studied, at least one positive naming site was identified in 16 patients. Of the three patients in whom no naming sites were found, one had a temporal lobe tumour, one had a vascular malformation and one had no identifiable lesion; two were mapped extraoperatively and one was mapped intraoperatively. Among the 16 patients in whom naming sites were identified, seven patients had both distinct auditory and VN sites, four exhibited sites at which stimulation disrupted only auditory naming and five exhibited sites at which stimulation disrupted VN (most VN sites were also positive for auditory naming).

Sites at which stimulation impaired VN (either exclusively, or with impaired auditory naming) were spared from resection in all patients, whereas AN sites were not considered with respect to resection boundaries. Out of the 19 patients, 7 patients had AN sites removed and 12 patients had no AN sites removed (i.e. all AN sites were at least 1 cm from the resection edge).

Post-operative naming
Pre- and post-operative change scores for each patient were calculated for the three naming measures. Table 1 shows RCI based results and Table 2 shows relevant clinical data for each patient on each measure, with patients grouped according to whether AN sites were or were not removed. Of the 12 patients in whom no AN sites were removed, only 3 showed naming decline on any measure. On the other hand, six out of seven patients in whom AN sites were removed showed naming decline, four on at least two measures. Interestingly, despite the fact that VN sites were spared in all cases, removal of AN sites was associated with decline on VN measures in all six of these patients.

The direction of change across measures was consistent within a given patient, i.e. patients exhibited either decline or improvement on all measures indicating change in performance. Therefore, patients were readily classified as having improved, declined or showed no change. Fisher’s exact test assessing naming outcome as a function of AN site removal was significant (P = 0.02, Table 3), suggesting an association between AN site resection and post-operative naming decline. Also of note, Fisher’s exact test indicated no significant difference in seizure outcome (assessed at the time of post-operative testing) between groups (P = 1.0).

Qualitatively, naming changes (i.e. declines) were generally characterized by slower response time and greater reliance on cueing, rather than complete inability to name items named preoperatively. Mean change scores (and ranges) were as follows (for clarity, negative values denote decline, positive values denote improvement): ‘AN not removed’ group: ANT-TOT: +3.2 (–5 to +11), VNT-TOT: +0.7 (–2 to +4) and BNT: –1.6 (–8 to +3); ‘AN removed’ group: ANT-TOT: –3.1 (–10 to +3), VNT-TOT: –4.4 (–11 to 0) and BNT: –6.4 (–15 to 0). Mann-Whitney U test comparing the two groups was significant only for ANT-TOT change scores (Z = –2.5, P = 0.01).

Exploring the possible influence of other relevant variables on post-operative naming, Mann-Whitney U tests comparing patients who had AN sites spared with those who had AN sites removed showed no significant differences in age of seizure onset (‘not removed’ mean = 16.1, SD = 9.8, ‘removed’ mean = 17.6, SD = 10.0; Z = –0.38, P = 0.71), age at the time of surgery (‘not removed’ mean = 31.0, SD = 13.0, ‘removed’ mean = 41.8, SD = 15.0; Z = –1.35, P = 0.19), full scale IQ (‘not removed’ mean = 100.5, SD = 13.6, ‘removed’ mean = 92.3, SD = 15.8; Z = –0.38, P = 0.71) or in preoperative naming performance on any of the three naming measures (ANT-TOT: ‘not removed’ mean = 9.4, SD = 6.0, ‘removed’ mean = 10.7, SD = 5.8; Z = –1.19, P = 0.26; VNT-TOT: ‘not removed’ mean = 5.3, SD = 5.7, ‘removed’ mean = 4.1, SD = 2.7; Z = –0.38, P = 0.71; BNT: ‘not removed’ mean = 48.1, SD = 9.5, ‘removed’ mean = 47.8, SD = 8.5; Z = –1.19, P = 0.66).

As patients with MTS tend to show milder post-operative decline relative to patients without MTS (Bell and Davies, 1998; Davies et al., 1998), we explored the possibility that the lack of naming decline in the ‘not removed’ group was related to the presence of MTS, and that the naming decline in the ‘removed’ group was attributable to the absence of MTS. Fisher’s exact test assessing the proportion of MTS and non-MTS patients between groups was not significant (P = 0.65), suggesting that the post-operative naming results are not a function of the presence/absence of MTS.
We also explored the potential influence of hippocampal removal and post-operative naming decline. Thirteen patients underwent hippocampal resection, with eight exhibiting naming decline and five showing no decline. Of the six patients in whom the hippocampus was spared, one declined, whereas five exhibited no decline. Fisher’s exact test assessing the relation between hippocampal removal and post-operative naming was not significant (P = 0.14).

Greater post-operative naming decline has been associated with smaller distances between VN sites and the resection margin (Haglund et al., 1994). However, a t-test comparing these distances between patients who did (n = 9) and did not show naming decline (n = 10) was not significant (P = 0.421).

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It has also been demonstrated that later age of seizure onset is associated with greater post-operative naming decline (Bell and Davies, 1998; Hermann et al., 1994). However, age of onset did not differ significantly between patients who declined (mean = 16.6, SD = 9.4) and those who did not (mean = 16.7, SD = 10.4; t = 1.04, P = 0.31).

**Table 2** Clinical information for patients with and without AN site removal

<table>
<thead>
<tr>
<th>Group</th>
<th>Patient no</th>
<th>Onset age/surgery age (years)</th>
<th>Lateral (L) vs. medial (M) onset</th>
<th>Lesion/pathology</th>
<th>Resection data</th>
<th>Seizure outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>AN site not removed</td>
<td>2</td>
<td>34/53</td>
<td>L</td>
<td>Heterotopia</td>
<td>Neocortical resection&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>Ib</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>34/36</td>
<td>L</td>
<td>Cavernous Malformation&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Lesionectomy&lt;sup&gt;b&lt;/sup&gt;</td>
<td>IIa</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>16/26</td>
<td>M</td>
<td>MTS</td>
<td>AMTR</td>
<td>Ila</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>14/14</td>
<td>L</td>
<td>Ganglioma&lt;sup&gt;d&lt;/sup&gt;</td>
<td>Lesionectomy&lt;sup&gt;a&lt;/sup&gt;</td>
<td>lc</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>3/44</td>
<td>M</td>
<td>MTS</td>
<td>AMTR</td>
<td>la</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>22/29</td>
<td>M</td>
<td>Normal AMTR</td>
<td>AMTR</td>
<td>la</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>15/20</td>
<td>L</td>
<td>MTS</td>
<td>AMTR</td>
<td>la</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>6/50</td>
<td>M</td>
<td>Cavernous Malformation&lt;sup*e&lt;/sup&gt;</td>
<td>Lesionectomy&lt;sup*e&lt;/sup&gt;</td>
<td>la</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>9/16</td>
<td>L</td>
<td>Normal AMTR</td>
<td>AMTR</td>
<td>la</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>19/27</td>
<td>M</td>
<td>Normal AMTR</td>
<td>AMTR</td>
<td>la</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>10/22</td>
<td>M</td>
<td>MTS</td>
<td>AMTR</td>
<td>la</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>12/41</td>
<td>M</td>
<td>Normal AMTR</td>
<td>AMTR</td>
<td>Illb</td>
</tr>
<tr>
<td>AN site removed</td>
<td>1</td>
<td>17/66</td>
<td>M</td>
<td>MTS</td>
<td>AMTR</td>
<td>lc</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5/48</td>
<td>M</td>
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<td></td>
<td>6</td>
<td>23/45</td>
<td>M</td>
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<td></td>
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<td>AMTR</td>
<td>la</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>31/51</td>
<td>L</td>
<td>Normal Neocortical resection&lt;sup&gt;*g&lt;/sup&gt;</td>
<td>Neocortical resection&lt;sup&gt;*g&lt;/sup&gt;</td>
<td>llb</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>26/30</td>
<td>M</td>
<td>MTS</td>
<td>Modified AMTR&lt;sup&gt;h&lt;/sup&gt;</td>
<td>la</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>5/18</td>
<td>M</td>
<td>Normal Neocortical resection&lt;sup&gt;i&lt;/sup&gt;</td>
<td>Neocortical resection&lt;sup&gt;i&lt;/sup&gt;</td>
<td>llb</td>
</tr>
</tbody>
</table>

Lesionectomies location and size: two gyri posterior to sensory cortex. Seizure outcome based on Engel’s classification system (Engel et al., 1993) (I = seizure free). AMTR = resection of ≤3.5 cm medial temporal gyrus (MTG), ≤4 cm inferior temporal gyrus (ITG), radical hippocampal resection, plus excision of uncus, amygdala and parahippocampal gyrus. Hippocampus spared. Resection data: ≤4.5 cm MTG and 4.5 cm ITG. Sylvian fissure 4.2 × 2 × 1 cm, posterior superior temporal lobe, 1.5 × 1.5 × 1 cm, 3 cm diameter lesion in inferior parietal lobule. AMTR included 2.0 cm STG and 2 cm hippocampus, ITG 1.5–5 cm from anterior tip. AMTR with 5 cm MTG and ITG, 2.5 cm superior temporal gyrus, 3.5 cm MTG, and 3.5 cm ITG.

**Table 3** Post-operative naming as a function of AN site removal

<table>
<thead>
<tr>
<th></th>
<th>No decline</th>
<th>Decline</th>
</tr>
</thead>
<tbody>
<tr>
<td>AN not removed</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>AN removed</td>
<td>1</td>
<td>6</td>
</tr>
</tbody>
</table>

Number of patients who did and did not decline.

Discussion

Although most neurosurgical teams rely primarily on VN for stimulation-based cortical language mapping, recent findings and clinical observations raise questions regarding the efficacy of this approach. Specifically, sparing VN sites from resection does not appear to consistently protect left TLE patients from post-operative naming decline (Hermann et al., 1999). Given this observation, together with recent findings regarding the use of AN in TLE patients, we hypothesized that post-operative naming decline in left TLE patients might also be related to the removal of AN sites. In the current study, VN sites were spared in all patients, whereas AN sites were removed if they were located within the margins of planned resections. Using RCIs to define ‘meaningful’ post-operative change, we found that patients who had AN sites removed tended to decline on objective naming measures, whereas patients who did not have AN sites included in their resection tended to perform similarly or in some cases, improve on naming measures post-operatively. Interestingly, despite the fact that VN sites were spared in all patients, patients who had
AN sites removed declined not only on AN measures, but on VN measures as well.

Historically, stimulation mapping with VN has been considered the gold standard for identification of critical language areas, and therefore, has been used almost exclusively to guide temporal lobe resections. In fact, because it has repeatedly been demonstrated that ‘naming’ sites (i.e. VN sites) are rarely found in the anterior temporal region (Davies et al., 1994; Ojemann, 1983, 1991), most surgical programmes perform ‘standard’ anteriomedial temporal lobe resections without cortical language mapping. Thus, it has been puzzling why stimulation mapping (with visual naming) does not more consistently prevent post-operative naming decline, and why some patients who undergo ‘standard’ resections show post-operative naming decline. The current findings suggest that resection of AN sites, either undetected during mapping due to the exclusive use of visual naming or inadvertently included in standard resections, might contribute to this decline. The finding that VN declined in some patients as well is consistent with reports that post-operative decline is sometimes observed on VN tasks, despite exclusion of VN sites from resection (Hermann et al., 1999).

Identifying predictors of post-operative naming decline has been the subject of numerous investigations. Stafniak et al. (1990) and Saykin et al. (1995) reported greater naming decline in TLE patients with no early risk factor, suggesting that an early insult provides protection against decline by eliciting cortical reorganization of function. Langfitt and Rausch (1996) found that older age at surgery was associated with naming decline. Davies et al. (1998) reported an association between status of the preoperative hippocampus (i.e. presence or absence of MTS) and naming decline, with less decline associated with the presence of MTS. More recently, Sabsevitz et al. (2003) found that a greater degree of left hemisphere language lateralization determined by IMRI predicted post-operative naming decline in left TLE patients. Taken together, results from these studies suggest that the aetiology of post-operative naming decline is likely multidetermined; the current findings suggest that resection of AN sites plays a role in this regard. We are aware of only one other study in which auditory description naming was used during cortical mapping and tested both pre- and post-operatively. Of four patients, Malow et al. (1996) found one patient with significant naming decline, and one with mild to moderate decline; however, it was not specified which patients had AN sites resected. Thus, it is difficult to compare these results with our findings.

Reduced VN performance following resection of auditory but not VN sites raises intriguing questions regarding structure–function relationships underlying language processing in the temporal region. Although the stimulation-based findings suggest at least some degree of modality specificity within the ‘semantic/naming system’, the post-operative decline in both naming modalities supports the notion of an amodal semantic system, or at least a considerable degree of integration between modality based subsystems. In accordance with the current findings Bookheimer et al. (1998) reported FET based activation during auditory description naming (‘responsive naming’) in primary and secondary visual brain regions (in addition to expected primary and secondary auditory cortex), similar to that observed when language stimuli entered via the visual modality. These results were interpreted to reflect a distributed semantic system in which sensory-specific semantic modules are mutually interactive.

That stimulation impeded only AN, whereas resection of the same area resulted in both auditory and VN decline (in some cases) is a curious finding; the rationale for stimulation-based mapping is that the application of electrical current produces a temporary lesion that mimics the effect of resecting that circumscribed region. It is possible that cortical regions immediately adjacent to AN sites are critically involved in more general, ‘amodal’ naming processes, such as access and retrieval of semantic information or phonological subprocesses that are critical for word retrieval regardless of the modality of the cue. Alternatively, it is possible that stimulation produced a more limited localized response, whereas resection resulted in more extensive damage to neuronal/cognitive processes underlying word retrieval.

Another interesting aspect of our results is the variability among patients in the particular measures that showed decline. This might reflect inter-patient variability regarding the specific subprocesses of naming that were affected by the resection. For instance, some patients may have become more dependent on phonological cues or may have had a reduction in naming efficiency, resulting in poorer TOT scores on the ANT and VNT. On the other hand, patients who declined on the BNT (with no decline in TOT scores) may have suffered deterioration in the access or representation of low frequency item names. Bell et al. (2000) reported an ‘age of acquisition’ effect, in that patients exhibited greater difficulty naming BNT item names that were acquired later in life (i.e. mostly, lower frequency words) following left temporal lobe resection.

**Functional significance**

By objective measures, patients who underwent AN site resection showed statistically significant declines in naming performance. Nevertheless, it remains unknown whether these changes are ‘clinically’ meaningful. That is, do patients experience a subjective difference in word finding ability, and are these changes associated with decrements in social or occupational functioning? The answer to this question is critical, in so far as it might influence surgical decisions to remove or spare AN sites identified. As noted, it has not yet been definitively determined whether sparing AN sites would influence seizure outcome. Additionally, if it is determined that patients do in fact experience a functional decline in word finding, it is possible that the benefits of good seizure outcome might outweigh the cost of word finding decline. Such decisions would depend on the extent of expected decline, the functional demands on the patient and tolerance level of the
individual with respect to both word finding difficulty and residual seizure activity. At any rate, it will be important to determine whether, and to what extent, decline on objective measures might be associated with subjective or functional decline. This information would assist both the patient and the treatment team in surgical decisions. Studies addressing these issues are currently underway in our laboratory.

Limitations
The ability to generalize the current findings is limited primarily due to lack of random group assignment. Given that the two groups were created retrospectively, i.e. after it was determined whether AN sites were removed, it is feasible that factors other than removal vs. sparing of AN sites might account for the post-operative naming differences. For instance, most of the patients in the 'not removed' group had no AN sites identified. This could reflect a different topographic distribution of AN sites or a complete absence of AN sites in these patients, with either of these potentially accounting for the post-operative naming differences between groups. Mainly, it is unknown how these patients would have fared with respect to both post-operative naming and seizure outcome had AN sites been identified, and had the resection been modified in order to spare these sites from resection. Nevertheless, the consistency in naming decline in patients who did have AN sites removed suggests that the integrity of AN sites is important for normal naming function.

Conclusion
The original rationale for using VN in cortical language mapping was based on the observation that visual object naming is impaired in virtually all aphasic syndromes; thus, it was reasoned that preservation of cortex necessary for object naming would reduce the probability of post-operative aphasia (Ojemann et al., 1989). However, decades of experience with TLE surgery has demonstrated that post-operative aphasia is extremely rare; rather, the primary concern with respect to post-operative language function following temporal lobe resection is essentially limited to word finding decline (Davies et al., 1998; Saykin et al., 1995). In light of this knowledge, it might be reasonable to reconsider traditional practices and focus our efforts toward reducing post-operative naming decline. The current results suggest that incorporation of auditory description naming in stimulation mapping protocols might assist in reducing post-operative naming deficits following temporal lobe surgery.

Form a heuristic perspective, the current results emphasize that the language disturbances observed during cortical stimulation and after surgery are highly contingent on the particular tasks employed. The dissociation of auditory and VN during stimulation, and their ‘re-association’ observed in the form of post-operative decline likely represent pieces of the puzzle regarding amodal versus integrative processing in object naming. Future stimulation studies utilizing tasks designed to specifically address these issues hold promise for a deeper and more comprehensive understanding of temporal lobe mediation of language.

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References
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