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Anatomic dissociation of auditory and visual naming in the lateral temporal cortex

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Article abstract—*Background and Objective:* Visual object naming traditionally has been used to identify cortical areas essential for naming (i.e., word retrieval), and investigators have found critical naming sites in the middle and posterior temporal region in most patients. Based on clinical observation, empirical findings, and the pathophysiology of temporal lobe epilepsy, the authors hypothesized that naming sites identified from auditory cues might also be relevant, and that within the temporal region, these sites would be anatomically distinct and located anterior to naming sites based on visual cues. *Methods:* Twenty patients requiring resective surgery involving the left (language dominant) temporal lobe underwent pre-resection language mapping using direct cortical stimulation. Visual and auditory naming were tested at lateral temporal sites extending from 1 cm from the anterior tip to the parietal operculum. *Results:* Auditory naming was consistently disrupted by stimulation in the anterior temporal lobe, whereas both auditory and visual naming were impaired by stimulation in the posterior temporal region. *Conclusions:* This pattern may explain why word finding difficulties sometimes arise or worsen following surgical procedures in which the anterior temporal region is resected without language mapping, or when resection is based on mapping that identifies language cortex exclusively using visual tasks. These results suggest that utilization of auditory based naming tasks might improve pre-resection identification of essential language cortex during direct stimulation cortical mapping, as well as noninvasive localization of dysfunction during presurgical cognitive testing.

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Stimulation-based cortical language mapping is often necessary in patients with intractable epilepsy who are candidates for surgical resection within the language dominant hemisphere. Lateral cortical sites at which electrical stimulation impedes language are considered essential for normal language function and, therefore, are not included in the resection in order to preserve language postoperatively. Although there is some variability in the particular tasks employed during language mapping (e.g., naming, counting, reading),[1] most investigators rely primarily on visual object naming.[2-5] This consists of asking patients to name pictured items (e.g., bell, escalator) during a brief electrical stimulus.[2] The rationale for this approach is that visual object naming is impaired in virtually all aphasic syndromes and, therefore, preservation of cortex necessary for object naming should reduce the probability of postoperative aphasia.[6] Results from investigations using object naming tasks have been used to create "maps" illustrating the cortical distribution of "essential" language areas.[3,7] Although there is considerable

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variability in the precise localization of these areas among individual patients, across individuals, language sites tend to cluster in the perisylvian region, especially in the middle and posterior portion of the temporal lobe.[4] Although naming sites have been identified in the anterior temporal region in a small percentage of patients,[8,9] in general, visual naming areas are not usually found near the temporal pole. Thus, many epilepsy surgery programs perform "standard" anteromesial temporal resections for medial temporal lobe epilepsy (TLE) without undue concern for postoperative aphasia.[10] This consists of an en bloc removal of the anterior 3 to 3.5 cm of the inferior and middle temporal gyri and adjacent fusiform gyrus, and a radical removal of the medial structures (including the hippocampus and parahippocampal gyrus and the majority of the uncus/amygdala) without cortical language mapping.[11]

Although visual naming is impaired in cases of frank aphasia, we and others (Strauss, personal communication, 1998; Trennery, personal communication, 1999) have observed that patients with left (i.e., language dominant) TLE (LTLE) rarely complain of difficulty naming concrete objects. Conversely, they commonly describe more subtle naming difficulties that occur in the context of everyday auditory–verbal discourse, both before and after surgery. In an empirical study in which a heterogeneous group of left and right TLE patients were administered both auditory and visual naming tasks that were equated for difficulty, we found that auditory naming was significantly more sensitive to the word finding deficits in LTLE patients than visual object naming.[12] In light of this finding, it might be important to identify cortical areas involved in auditory as well as visual naming.

In contemplating the cortical areas involved in auditory naming, we considered the following: 1) the anterior and medial temporal regions are most often involved in TLE, both ictally and interictally,[11,13,14] 2) auditory naming is disproportionately impaired in LTLE patients,[12] and 3) auditory cortex is anterior to visual cortex. We therefore hypothesized that auditory naming is supported by the anterior temporal region, whereas visual naming is supported by the posterior temporal region. Accordingly, auditory but not visual naming would be disrupted by electrical stimulation at anterior sites, whereas visual but not auditory naming would be disrupted by electrical stimulation at posterior sites.

In this study, we tested auditory and visual naming in 20 patients who underwent cortical language mapping before left temporal lobe surgery, and compared the topographic distributions of sites at which stimulation interrupted auditory versus visual naming.

Methods. *Subjects.* Twenty consecutive right-handed patients (12 women) who underwent cortical language mapping before surgery involving the left temporal region were included in this study. All patients were left hemisphere language dominant, as determined by intracarotid amobarbital testing. Six had medial temporal sclerosis (MTS; defined as MRI evidence of abnormal signal and hippocampal atrophy), four had temporal lobe tumors (two in posterior, inferior temporal region, one in the posterior superior temporal gyrus, and one in the anterior, middle to inferior temporal region), two had vascular malformations (one deep within the sylvian fissure and insular cortex, one in the sylvian fissure), and eight had no abnormality on MRI. Of the eight patients with normal MRI, four had medial onset, and four had neocortical onset (one involving the anterior 3.5 cm of the middle and inferior temporal gyrus, and anterior 2.5 cm of the superior temporal gyrus, one involving the anterior 4 cm of the inferior temporal gyrus, and two involving the anterior 4.5 cm of the middle and inferior temporal gyri). In all patients, the left temporal region was identified as the area of seizure onset by intracranial EEG monitoring or a combination of MRI evidence of MTS and scalp EEG/video recording. Twelve patients underwent language mapping extraoperatively via subdural electrodes, five at Columbia Presbyterian Medical Center (CPMC) and seven at New York University Medical Center (NYU). Eight patients underwent intraoperative language mapping before resection at CPMC. Demographic and clinical information were as follows: Wechsler Adult Intelligence Scale–Revised[15] Full-Scale IQ (mean: 96.4, SD: 13.1, all > 69), age at mapping (mean: 37.9, SD: 13.8), age at seizure onset (mean: 22.2, SD: 14.3), years of education completed (mean: 14.7, SD: 3.7). There were no differences between CPMC and NYU patients on any of these variables (Mann–Whitney test, all $p > 0.05$).

Electrodes. For the eight patients evaluated intraoperatively, 12 (min) to 19 (max) sites along the superior, middle, and inferior temporal gyri and the posterior perisylvian cortex were stimulated using a bipolar stimulator with 2 mm diameter ball contacts separated by 5 mm (Ojemann Cortical Stimulator, Radionics Inc., Burlington, MA). The sites were chosen based on gyral/vascular anatomy and spaced less than 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 center to center interelectrode distances of 1 cm (Ad-Tech, Racine, WI), was positioned over the frontal-parietal-temporal region (trimmed as needed to conform to the covered area). The exposed cortical surface and grid position was documented by digital photography and schematic diagrams. A similar approach documented the stimulation sites for the intraoperatively mapped patients. Subdural electrode positions were verified by skull X-rays, postoperatively. Thirteen (min) to 34 (max) sites were tested.

Mapping procedures. All auditory and visual naming stimuli were administered to patients within 1 to 4 months before surgery. Auditory and visual items, selected from previously published stimuli,[12] were equated for word frequency, and were similar in difficulty level (i.e., similar mean scores for 100 healthy controls: visual: 99.2% correct, auditory: 98.3% correct). Only items that patients successfully completed 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 (AED) 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, referenced to a remote electrode in "silent cortex." All available sites along 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 visual naming cortex was identified, additional perisylvian sites were tested with the goal of positively identifying the visual naming cortex (rather than relying on negative responses alone). Sites were tested with a bipolar stimulator (see above).

Stimulation mapping followed well established methods.[2,4] For both intra- and extraoperative mapping at CPMC, a constant current stimulator (Ojemann Cortical Stimulator, Radionics Inc.) delivered a biphasic square waveform at a frequency of 60 Hz with a 2 msec pulse duration and amperage ranging from 3 to 15 mA during extraoperative mapping and 1 to 6 mA during intraoperative mapping. Mapping at NYU was conducted using a Grass Instruments S-212 cortical stimulator (Winston, MA) with a biphasic square waveform at frequency 50 Hz with a 0.3 msec pulse duration, with amperage ranging from 3 to 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 0.5 to 1 mA below that which 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.

At least two trials each of visual and auditory naming 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, helicopter), and for auditory naming, patients heard oral descriptions of concrete items (e.g., "What a king wears on his head"). For visual naming, patients began with the phrase, "It is a" to enable differentiation between speech arrest and anomia, 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 seconds. Additionally, the requirement for patients during visual naming 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 presentation of pictures or auditory descriptions, and lasted for a maximum of 10 seconds, but terminated immediately upon the patient's production of a correct response. For both tasks, patients were instructed to respond as quickly 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 two trials was performed inaccurately, another two trials were administered. Sites were considered critical for task performance only when responses to both of these two trials were incorrect. Sites at which this further testing resulted in 50% accuracy were not considered critical for task performance.

Analyses of naming areas. For each patient, the location of electrode sites was determined by intraoperative digitized photographs and schematic drawings, and supplemented by postoperative skull X-rays. Naming sites from each patient were plotted on a schematic of the temporal lobe region and coded to indicate whether auditory, visual, or both auditory and visual naming were disrupted by stimulation. In keeping with conventions of other investigators,[16] and considering the posterior boundary of standard resections at most epilepsy surgery programs, we defined the anterior temporal region as $\leq$4 cm from the temporal pole, and the posterior temporal region as $>$4 cm from the temporal pole. The topographic distribution of auditory and visual naming sites was analyzed via Fisher's exact test.

Results. Results of mapping revealed three types of positive naming sites: 1) sites at which stimulation impaired auditory but not visual naming ("auditory-only"), 2) sites at which stimulation impaired both auditory and visual naming ("dual sites"), and 3) sites at which stimulation impaired visual but not auditory naming ("visual-only"). Of the 20 patients who underwent mapping, at least one type of naming site was identified in 18 patients. Of the two patients in whom no naming sites were found, one had a temporal lobe tumor and one had a vascular malformation; both were mapped intraoperatively. The number of sites tested per patient ranged from 12 to 34 (mean: 20.5, SD: 6.1). The mean number of sites tested per patient was 16.1 (SD = 2.8) in the intraoperative group, and 23.4 (SD = 6.0) in the extraoperative group. This difference ($t^{18} = 3.18$, $p < 0.01$) likely reflected greater time constraints and more rapid patient fatigue associated with awake surgery. Nonetheless, results of Fisher's exact test to determine whether the likelihood of finding auditory sites was influenced by intra- versus extraoperative mapping were not significant.

Of the 18 patients in whom naming sites were found, 15 exhibited auditory-only sites, three exhibited visual-only sites, and 11 exhibited both auditory-only and dual (or visual-only) sites. In patients in whom naming sites were identified, the number of naming sites (auditory-only, visual-only, or dual) identified within an individual patient ranged from one to eight per patient (auditory-only sites: one to four per patient, visual-only sites: one per patient, dual sites: one to five per patient).

The figure shows the distribution of naming sites as a function of stimulus modality across patients. As predicted, stimulation at sites along the anterior surface of the temporal lobe disrupted auditory but not visual naming. In contrast to our hypothesis, however, stimulation of most sites in the posterior region disrupted both auditory

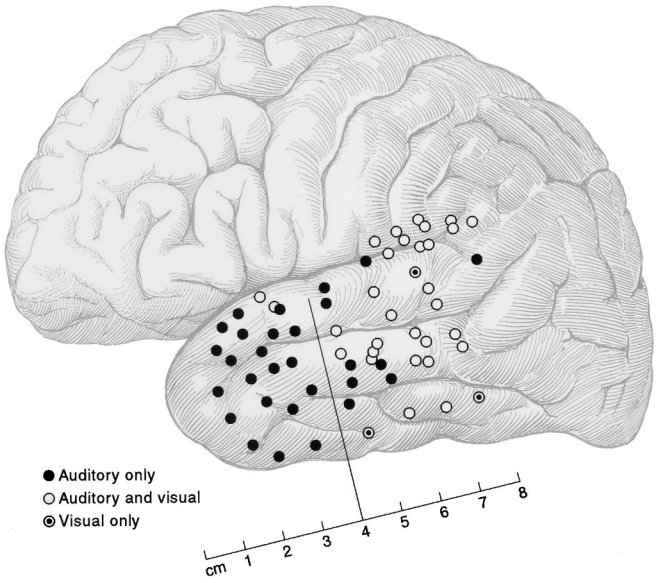

Figure. Topographic distribution of naming sites across patients indicating whether auditory, visual, or both auditory and visual naming were disrupted during stimulation.

and visual naming. At only three sites did stimulation disrupt visual but not auditory naming. Results of Fisher's exact test assessing the anterior/posterior distinction (i.e., anterior/auditory-only versus posterior/dual or visual-only) was significant ($p < 0.001$).

Of the 11 patients who demonstrated both auditory and visual naming sites (i.e., auditory-only plus visual-only or dual sites), auditory sites were anterior to visual only and dual sites in all but three patients. Each of these patients, however, demonstrated several positive sites, and most sites were consistent with the anterior/posterior pattern. Specifically, in Patient 13, of five naming sites identified, the three posterior sites were dual sites and two of three anterior sites were auditory-only sites. In Patient 3, five of six posterior sites were dual sites, and two of two anterior sites were auditory. In Patient 15, two of four posterior sites were dual sites, and one was a visual-only site.

Naming sites as a function of pathology. Although subgroups of patients based on brain pathology were too small for statistical analysis, there were no apparent differences in presence or distribution of naming sites as a function of pathology. Of the five MTS patients, two exhibited auditory-only sites, whereas the other three patients had both auditory-only and dual sites. Of the nine non-MTS patients, two exhibited only a single auditory-only naming site, whereas the remaining seven exhibited auditory-only and dual sites (one had a visual-only site as well). Of the four tumor patients, three exhibited auditory-only and dual sites, and in one patient, no naming sites were found. Of the two vascular patients, a dual site and a visual-only site were identified in one, and no sites were found in the other. The far posterior temporal auditory-only site was elicited in a single patient with a tumor in the inferior posterior temporal region.

Discussion. Utilization of both auditory and visual naming tasks during cortical mapping revealed a modality related distribution of naming sites across the lateral temporal region. As anticipated, stimulation at most anterior temporal sites (≤4 cm from temporal pole) disrupted auditory naming, but did not impede visual naming. Although we hypothesized that posterior temporal stimulation would impair visual naming exclusively, stimulation disrupted both visual and auditory naming at most sites in this region. In patients in whom both auditory and dual (i.e., auditory and visual) sites were identified, auditory sites were anterior to dual sites in most, with only three patients deviating from this pattern. Even in these three patients, however, most positive sites conformed to this general pattern. In one patient, however, an auditory naming site was identified in the far posterior temporal region, suggesting that in some patients, auditory naming areas may not be limited to the anterior temporal region.

Identification of an anterior temporal auditory naming area carries both theoretical and clinical implications and may explain, at least in part, several previously reported phenomena. As naming has traditionally been mapped with visual stimuli, which will not detect auditory naming sites, the topographic pattern revealed in this study might explain why some investigators have claimed that "naming" is represented in the posterior portion of the temporal lobe.[3,16] It might also explain why many patients who undergo "standard" anterior resections often experience increased word finding difficulty postsurgically.[17-20] The dissociation of auditory and visual naming sites might also explain why some patients experience word finding decline after surgery, despite having been mapped with visual naming tasks before resection.[5,8] Interestingly, results of a recent multicenter study demonstrated no postsurgical naming differences between patients who were mapped with visual naming compared to those who had standard resections without language mapping, suggesting no benefit of preresection mapping.[5] It may be that mapping with visual stimuli enabled identification of cortex essential for picture naming; however, auditory naming sites remained unidentified, and may have been removed in some patients. If so, utilization of auditory naming during preresection mapping could potentially assist in preserving word retrieval postsurgically.

Although the current findings support the notion that poorer visual compared to auditory naming is consistent with posterior temporal pathology, it could be argued that anterior temporal pathology might not impede auditory naming as auditory as well as visual naming sites were found in the posterior temporal region. Although this certainly is possible, we believe that under normal circumstances—i.e., everyday auditory–verbal discourse—the anterior temporal region is most critical for auditory-based word retrieval. Conceivably, the most parsimonious explanation for impaired auditory naming during posterior temporal stimulation is that the auditory descriptions, which were visually descriptive, and

target items, which were all concrete, highly imageable items, frequently elicited visual processing. In fact, some patients reported that they "couldn't help but *picture* the items being described." Thus, visual association areas were probably recruited during the auditory task due to the nature of the stimuli in this contrived situation. Yet, this is less likely to occur in the context of everyday conversation, which typically has a more auditory/conceptual basis.

On a related note, that auditory naming was disrupted with posterior temporal stimulation in some patients raises the question as to why the anterior temporal region failed to support word retrieval during the auditory naming task independently. One possibility is that the anterior and posterior regions support different, yet equally essential, components of auditory-based word retrieval. However, in keeping with the explanation noted above, visual association cortex was probably essential when patients utilized strategies that relied primarily on visual imagery. Although concrete nouns were selected intentionally with the goal of developing comparable tasks, this may have contributed to the partial overlap of auditory and visual naming sites.

Another possibility to consider is that compared to visual naming, auditory naming may require participation of a wider distribution of cortical areas. Although visual and auditory tasks were equated for word frequency, which is known to affect facility of word retrieval,[21] and healthy controls performed similarly on the two tasks, the auditory task may have required more elaborate processing.

Comparisons with other studies. To our knowledge, there is one other published study (although smaller scale) in which the topography of stimulation based auditory and visual naming sites was compared.[22] These investigators mapped auditory and visual naming in six left hemisphere language dominant LTLE patients, six to 12 sites per patient, and found poorer auditory naming than visual naming during stimulation in the anterior and posterior lateral region. It was unclear if, and to what extent, the region within the first 4 cm of the temporal pole was tested; however, the figures shown suggest that coverage was less extensive in the anterior region. Consequently, it is difficult to compare these findings with ours, yet the differential performance as a function of topography and modality is consistent with our results. A study comparing results of PET activation and cortical stimulation showed some evidence of greater posterior activation during visual naming compared to that observed during auditory naming.[23] With cortical stimulation, however, several regions in the lateral temporal lobe were identified where stimulation produced errors in auditory but not visual naming, and auditory errors were elicited at lower thresholds than visual naming errors. More detailed information regarding the precise location of these sites was not provided, as the purpose of the study was to compare results of the two techniques rather than the topography generated by testing in different modalities. Another study comparing PET images generated during auditory naming[25] with PET images obtained during visual naming from a different study (i.e., using different subjects)[26] showed activation in primary and secondary visual brain regions, similar to the activation generated by visual images. Similar to the current study, the visual nature of the target stimuli, as well as the imagery created by descriptions themselves (e.g., "tall pink bird"), very likely elicited visual processing. Despite problems with task comparability, it might be necessary to eliminate or at least reduce the confound of visual processing during imaging and stimulation studies to determine whether visual association areas are, in fact, essential for auditory naming.

Several investigators have reported disruptions in expressive and receptive language processing during stimulation of the basal temporal area.[16,26] In a PET study comparing activation patterns in LTLE patients and healthy controls, however, the left anterior fusiform activation observed in controls was absent among patients.[27] It is unknown, at this point, how our findings regarding lateral temporal cortex might relate to this region. In light of these observations, it might be of interest to pursue mapping using both disruptive (e.g., stimulation) and activation (e.g., PET, fMRI) techniques.

The heterogeneity of the patient sample and the small number of patients in various subgroups limited our ability to explore potential relationships between particular topographic patterns and the nature or location of pathology. Among the patients studied, however, no such trends were apparent. In fact, most patients, regardless of the nature or location of pathology, demonstrated auditory naming sites that were anterior to visual or dual naming sites. The consistent pattern observed across patients suggests it might generalize across pathologic conditions. Nonetheless, there may be significant differences in the cortical representation of auditory and visual naming as a function of age at onset, location, and nature of pathology, and we are pursuing further studies to address these questions.

As is often the case with patient populations, generalization of findings to the normal population must be made cautiously. Other investigators have noted that an epileptogenic lesion or abnormal brain activity could potentially alter the cortical distribution of cognitive functions.[8,9,28] The fact that most patients in this study developed seizures during adulthood might control for this to some extent, although a larger study in which age at onset or age at first risk could be examined systematically would better address this issue. Additionally, functional MRI or other imaging techniques using healthy volunteers, although less precise with respect to spatial resolution than stimulation based mapping, could be used to more directly study the distribution of naming areas in normal individuals.

The modality related distribution of naming sites found in the current study is interesting theoreti-

cally and may have important clinical applications as well. From a heuristic perspective, localization of a modality specific naming region potentially enhances our understanding of how the temporal lobe mediates semantic and lexical processing. At the same time, results of this study raise questions regarding the clinical significance of auditory naming sites in lateral temporal cortex. Extensive investigations, involving rigorous pre- and postsurgical testing, accounting for the location of auditory naming sites relative to the boundaries of the resection as well as patient variables (i.e., age at onset, nature and location of pathology) are in progress in our laboratory.

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