Functional Activation during an Auditory Comprehension Task in Patients with Temporal Lobe Lesions

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Functional magnetic resonance imaging (fMRI) was used to map regional brain activation during an auditory comprehension task in two normal controls and two patients with left temporal lobe lesions. Activity in the superior temporal and angular gyrus regions was detected in all normal subjects. In the patients, the spatial distribution of activation ipsilateral to the lesions differed from the pattern observed in contralateral cortex or in control subjects. These studies highlight the potential of fMRI for mapping abnormal functional anatomy in the human brain.

INTRODUCTION

Recently, functional magnetic resonance imaging (fMRI) methods sensitive to blood oxygenation or blood flow have demonstrated regional changes in signal when the subject is stimulated with primary sensorimotor or cognitive tasks (Bandettini et al., 1992; Frahm et al., 1992; Kwong et al., 1992; Ogawa et al., 1992). We present the results of fMRI examinations obtained from two right-handed patients with left temporal lobe lesions, an arteriovenous malformation (AVM) and a glioma, during the performance of an auditory comprehension task. fMRI was performed prior to resection of the lesions as part of routine MRI evaluations. These results are compared with fMRI examinations of two normal subjects using the identical activation protocol.

CASE REPORTS

Case 1

A 39-year-old right-handed male with hypertension was well until 10 days prior to the fMRI study, when he experienced a generalized seizure. Neuroimaging evaluation revealed an AVM, without hemorrhage, involving the posterior aspects of the left middle and superior temporal gyri (Fig. 1, left). The AVM was obliterated 2 months later. He had mild difficulties with naming and repetition during the immediate postoperative period, but these improved to baseline over the next several days.

Case 2

A 50-year-old right-handed male presented with a 2-week history of impaired concentration and reading comprehension and an acute episode of confusion and aphasia thought to be due to a seizure. Neuroimaging evaluation revealed a hemorrhagic heterogeneous mass in the left posterior temporal lobe (Fig. 1, right). This mass was resected 4 days after the fMRI study and histopathology revealed a high-grade pleomorphic xanthoastrocytoma. During the immediate postoperative period he had difficulties in naming and word finding, but these improved to baseline over several days.

METHODS

MRI examination was carried out on a 1.5-T SIGNA scanner (G.E. Medical Systems) equipped with a prototype fast gradient system for echo-planar imaging. The standard RF head coil was used with foam padding to comfortably restrict head motion. Sagittal T1-weighted images were obtained in every subject. Axial T2-weighted images were obtained from both patients. All subjects gave their informed consent for the fMRI study.

fMRI acquisitions were limited to a total of 256 scans each due to software restrictions. Four axial slices through the temporal lobes were chosen for fMRI examination from the sagittal images and 60 gradient echo echo-planar images were obtained in these four slices using TR 2 s, TE 50 ms. A resolution of 64 × 64 in a 24-cm field of view was used. Case 2 and the normal subjects were examined with 5-mm-thick slices separated by 5-mm gaps. Case 1 was examined with 8-mm slices separated by 4-mm gaps. Each patient under-
went two runs consisting of 40 s of rest, 40 s of cognitive challenge, and 40 s of rest. The cognitive challenge was a semantic task requiring the subject to listen to a series of object names presented once per second and to give a positive response, a slight motion of the left foot, for exemplars of the category “vegetables.” The stimulus set contained equal numbers of targets and foils, and these two subsets were matched on all relevant criteria such as word length and frequency of occurrence. Passive listening to words has been shown to produce activation in superior temporal gyrus (Petersen et al., 1988; Wise et al., 1991; Binder et al., 1994), in the same location as the two pathological lesions studied here. The additional semantic distinction used in the present study served to verify the patients’ attentiveness to the stimuli and has been shown to add to angular gyrus and frontal lobe activation relative to passive listening (Grossman et al., 1995a; Binder et al., 1995).

Activation maps were calculated using the correlation coefficient, or \(r\) value, between the stimulus and the image signal intensity using a boxcar function as previously described by Bandettini et al. (1993). In

**FIG. 1.** T2-weighted MR images of pathologic cases. In case 1 (left), the AVM nidus is depicted as a focal region of signal void in the left posterior–superior temporal lobe. In case 2 (right), a heterogeneous mass lesion with edema is situated in the left posterior temporal lobe and shows considerable mass effect.

**FIG. 2.** Signal intensity change in a region of interest in the right temporal lobe of case 1 plotted vs time. The auditory comprehension task began at 40 s and ceased at 80 s (indicated by bar).

**FIG. 3.** Activation maps of auditory function in the temporal lobes of a normal subject, and the two pathological cases superimposed on sagittal T1-weighted images. (Top) In the normal subject activation is centered bilaterally in the superior temporal and angular gyrus regions. (Middle) In case 1, the AVM nidus is depicted as a focal region of signal void in the left posterior–superior temporal lobe. The center of functional activation ipsilateral to the AVM demonstrates a more posterosuperior location compared to the contralateral side or to controls. (Bottom) In case 2, a heterogeneous mass lesion with edema is situated in the left posterior temporal lobe and shows considerable mass effect. Activation ipsilateral to the glioma occurs at the posterior boundaries of the mass lesion.
plane translational motion correction was carried out using a least-squares approach. Anatomical localization of activated brain regions was obtained by visual comparison of high resolution axial slices with the Damasio standard MRI templates (Damasio and Damasio, 1989). To better display the spatial distribution of the temporal lobe signal, the correlation maps were rebinned to simulate 3-mm-thick sagittal slices through the temporal lobes. Gaps in the sagittal reconstructions due to noncontiguous axial slices were filled using interpolation. Maps of the r value were overlaid in color on black and white T1-weighted sagittal images with a threshold applied such that only r values in excess of the threshold were shown. The threshold r value, shown in dark red, corresponded to a Bonferroni corrected P < 0.003 based on the significance calculations described in Bandettini et al. (1993). Higher r values, shown in bright red to yellow, were of much greater significance.

RESULTS AND DISCUSSION

Normal subjects and patients were able to perform the task without difficulty. For all subjects, the pattern of task-specific activation was reproducibly observed in each run. Region of interest analysis confirmed that the activation appeared to follow the task and recovered to baseline in an appropriate manner (Fig. 2). Analysis of the images revealed bilateral, confluent activation in the region of the superior temporal gyrus (Brodmann's area 22) extending partially into the angular gyrus (Brodmann's area 39) in control subjects (Fig. 3, top). This pattern was also observed in the unaffected hemispheres of both patients (Fig. 3, middle and bottom right). In case 1, the center of activation in the left hemisphere was located superior and posterior to the corresponding activation in the normal hemisphere (Fig. 3, middle left). In case 2, the center of activation was located primarily at the superior borders of the tumor (Fig. 3, bottom left). In both patients activation of Brodmann's area 22 was very weak. Activation occurred predominantly in the supramarginal gyrus (Brodmann's area 40) in both cases with extension to angular gyrus. In case 1, activity extended even to Brodmann's area 7. This pattern of activity was not observed in any of the normal subjects in our study nor in other MRI studies of passive listening to words or semantic judgment (Binder et al., 1994, 1995; Grossman et al., 1995a), confirming the pathologic cause of the abnormal functional anatomy. Bilateral dorsolateral frontal lobe activation was also more prominent in patients than in control subjects, though the limited slice coverage obtained precludes definitive determination of this finding.

The pattern of activation in temporal and parietal cortex observed in the present study in normal subjects and the unaffected hemispheres of the patients is consistent with the findings of other investigators using PET scanning during auditory tasks (Petersen et al., 1988; Wise et al., 1991) and fMRI scanning during passive listening to words, pseudowords, white noise, and sentences (Binder et al., 1994). In the present study, the pathologic cases showed substantial auditory activation on the affected side as well, but in abnormal locations. The lack of functional deficit in the presence of lesions in the regions subserving auditory comprehension suggested the possibility of alternate locations for this function. fMRI was able to demonstrate this location noninvasively with sensitivity and anatomic detail. While task-specific signal intensity changes observed in fMRI are thought to arise primarily from venous structures (Menon et al., 1993), there is no reason to believe that the presence of pathological lesions would have specifically affected the proximity of these venous structures to activated cortex, resulting in erroneous localization of function.

The spatial distribution of the activation pattern also differed in the two pathological cases, suggesting the possibility of different mechanisms of relocation. In the tumor case, mass effect may have displaced the functioning tissue due to rapid growth, resulting in a circumferential pattern of activation along the tumor rim. In contrast, AVMs do not typically produce mass effect in the absence of hemorrhage, and would not be expected to cause acute displacement of brain tissue. Rather, the superiorly displaced activation observed in the AVM case may be an example of reorganization of function (Grossman et al., 1995b) in the presence of a more chronic lesion. Further investigation of additional cases with fMRI or PET (Grafton et al., 1994; Leblanc et al., 1992) is needed to elucidate these mechanisms, for example to determine whether the distribution of the activation correlates with the growth rate of the lesion or with brain maturity at the onset of the lesion.

These studies highlight the potential of fMRI for mapping abnormal functional anatomy in the human brain. fMRI studies may be obtained less invasively and less expensively than PET studies, which have already begun to be applied to the investigation of recovery of function in human patients (Di et al., 1992; Weiller et al., 1992; Engelen et al., 1995). This approach should allow mechanisms of recovery of function to be better elucidated in patients with focal lesions of the central nervous system. Once these mechanisms are better understood, fMRI may become a useful prognostic tool for treatment planning which can be combined with standard anatomical MRI studies.

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