

Premotor Cortex Activation during Observation and Naming of Familiar Tools

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Positron emission tomography was used to investigate whether observation of real objects (tools of common use) activates premotor areas in the absence of any overt motor demand. Silent naming of the presented tools and silent naming of their use were also studied. Right-handed normal subjects were employed. Tool observation strongly activated the left dorsal premotor cortex. In contrast, silent tool naming activated Broca's area without additional activity in the dorsal premotor cortex. Silent tool-use naming, in addition to activating Broca's area, increased the activity in the left dorsal premotor cortex and recruited the left ventral premotor cortex and the left supplementary motor area. These data indicate that, even in the absence of any subsequent movement, the left premotor cortex processes objects that, like tools, have a motor valence. This dorsal premotor activation, which further augments when the subject names the tool use, should reflect the neural activity related to motor schemata for object use. The presence of an activation of both dorsal premotor cortex and ventral premotor cortex during tool-use naming suggests a role for these two areas in understanding object semantics. © 1997

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INTRODUCTION

When graspable objects are presented to an individual, two separate analyses of their characteristics are carried out simultaneously in the brain. One, mediated by the "ventral visual stream" (Ungerleider and Mishkin, 1982) enables the individual to categorize objects according to their pictorial and semantic properties; the other, mediated by the "dorsal visual stream,"

describes the objects in terms of their motor affordances (Jeannerod *et al.*, 1995; Milner and Goodale, 1995).

In the monkey, affordances of objects for grasping are coded in a specific sector of the parietal lobe, area AIP (Sakata and Taira, 1994; Taira *et al.*, 1990). From this area information is transferred to a sector of ventral premotor cortex (F5), which in turn is connected with the precentral motor cortex (Matelli *et al.*, 1994). In F5 neurons discharge during the execution of grasping movements. Many of them also discharge when the monkey looks at specific objects in the absence of any subsequent motor activity (Murata *et al.*, 1997; Rizzolatti *et al.*, 1988). Thus, in the monkey, each time a graspable object is presented, the premotor cortex is activated regardless of whether the monkey is going to grasp it or not.

The main aim of the present experiment was to investigate whether the presentation of a graspable object would activate the premotor cortex in humans, as in monkeys, and, if this was the case, where this activation would be located. For this purpose normal subjects were presented with real, 3-D objects (tools of common use) and instructed to observe them. We used positron emission tomography (PET) to map frontal cortical regions active during object observation.

A possible role for frontal lobe in tools analysis was previously investigated by Perani *et al.* (1995). These authors presented normal subjects with drawings of tools or animals, in a task requiring a same/different judgment. They found that during tools discrimination there was a frontal lobe activation located in area 45. No premotor activation, however, was present. This latter (negative) result may indicate a real lack of a premotor activation in response to tool presentation. Alternatively, it may be that no premotor activation occurred because the use of two-dimensional stimuli and the discriminative request of the task decreased the motor valence of the objects and induced a merely semantic analysis of their features.

Activation of posterior frontal lobe areas, including ventral area 6, were found by Martin *et al.* (1996) in a

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task in which subjects were required to name tools silently. The result of this experiment is very intriguing. Its interpretation, however, is not straightforward. It may be that the observed activation was due to a "pragmatic" processing of the presented objects, leading to an automatic (not intentional) activation of the premotor areas, but it may equally be that the observed activation was related to their naming. In order to differentiate between these two possibilities we introduced two further conditions in our experiment: silent naming of tools and silent naming of their use. The comparison between object observation and tool-related verbal tasks should clarify to what extent ventral premotor area activation depends on naming.

MATERIALS AND METHODS

Eight (four male, four female) right-handed young adult subjects (mean age 23 years) participated in the study after informed consent was obtained in accordance with the Human Subjects Review Board of our institution. All were normal by medical interview. All were right-handed as determined with a standardized inventory (Oldfield, 1971). PET was used to measure changes in regional blood flow (rCBF) during the performance of four different behavioral tasks. Subjects lay supine in the PET scanner with their heads immobilized with a foam head restraint (Smithers Corp., Akron, OH). A curtain was arranged so that the subject's visual scene was limited to a 26° view of a vertically oriented board within reach of the subject. This view was intermittently blocked with a cardboard screen. During each interruption a new target was attached to the board by the examiner for the subject to view. For the object viewing task, a familiar, manipulatable tool was shown every 4 s. Typical objects included scissors, hammer, spanner, comb, etc. Subjects were instructed to look at the object on the board. This task was compared to a fractal viewing condition, in which subjects were instructed to look at complex color fractals (without a three-dimensional geometric form) presented at the same rate of every 4 s. Two additional tasks were performed to further assess the verbal aspects of this task. In both of these tasks the objects were presented as described in the object viewing task. In the object naming task the subjects were instructed to silently name each of the tools as they were presented (e.g., "razor"). In the object use task, the subjects were instructed to silently say to themselves the use of an object (e.g., "to shave"). All conditions were repeated twice in counterbalanced order. Subjects practiced the tasks for 5 min prior to each PET scan.

Images of rCBF were acquired using a modified autoradiographic method every 10 min (Herscovitch *et al.*, 1983). For each scan, a bolus of 35 mCi of H₂¹⁵O was injected intravenously commensurate with the start of

scanning and the behavioral task. A 90-s scan was acquired and reconstructed using calculated attenuation correction, with boundaries derived from each emission scan sinogram. Arterial blood samples were not obtained. Images of radioactive counts were used to estimate rCBF as described previously (Mazziotta *et al.*, 1985).

PET images of rCBF were acquired with the Siemens 953/A tomograph. The device collects 31 contiguous planes covering a 105-mm field of view. The nominal axial resolution is 4.3 mm at full width half maximum (FWHM) and the trans-axial resolution is 5.5 mm FWHM as measured with a line source.

Image processing was performed on a SUN SPARC 20 workstation. This processing was accomplished with spatial normalization, global blood flow normalization, and statistical analysis. Spatial normalization used a within-subject alignment of PET scans using the AIR 2.0 automated image registration algorithm (Woods *et al.*, 1992, 1998a). A mean image of the registered and resliced images was coregistered to a population-based PET cerebral blood flow reference atlas centered in Talairach coordinates using an affine transformation with 12 degrees of freedom (Grafton *et al.*, 1994; Talairach and Tournoux, 1988; Woods *et al.*, 1998b). Once the PET scans were coregistered, images were smoothed to a final isotropic resolution of 18 mm full width half maximum (as verified with a line source). The smoothed images were normalized to one another using proportionate scaling calculated from the global activity of each scan. After stereotactic coregistration, a mask defining a more limited search volume was generated using the following criteria: (1) for each pixel location in the image there must be data available from all 64 PET scans; (2) a threshold was manually defined that reduced the volume to only gray matter, excluding deep white matter and ventricles; (3) a volume of interest of the frontal lobes was manually drawn on a high-resolution T-1 weighted magnetic resonance image scan aligned in the Talairach coordinate space. The postcentral sulcus was used as the posterior border of the volume.

A two-way analysis of variance (ANOVA) with repeated measures and planned comparisons of means across task conditions based on the general linear model of multivariate analysis was used to identify significant task effects (Neter *et al.*, 1990; Woods *et al.*, 1996). The effects in this approach were task, repetition, and subject. A *t*-map image for each contrast between tasks was calculated on a pixel by pixel basis (*df* = 48) and a threshold was set for *t* = 2.9426 (*Z* = 2.576), *P* < 0.005. Distinct sites on the *t*-map above this were localized and maximal *t* and *p* values and mean rCBF values were tabulated. For the given search volume (20,000 pixels) and absolute threshold (*P* < 0.005), only activation sites of at least 500 contigu-

TABLE 1
Location and Significance of Frontal Lobe Task Differences

Region	Talairach coordinates (mm)			Object versus Fractal	Naming versus Fractal	Naming versus Object	Use versus Fractal	Use versus Object	Use versus Name
	x	y	z						
Left medial frontal gyrus (6)	-3	3	63		3.724				
Left medial frontal gyrus (6)	-6	3	48				5.242	4.847	
Left dorsal precentral sulcus (6) dorsal premotor cortex	-39	-6	51	3.954	4.759		5.862	4.414	3.793
Left inferior precentral sulcus (6/44) ventral premotor cortex	-48	-2	29				4.736	5.448	5.346
Left inferior frontal sulcus (Trans. 45/46)	-32	44	17	3.218	3.839		3.977		
Left inferior frontal gyrus (46)	-35	44	11		4.092				
Left frontal operculum (44)	-38	17	17		4.437	4.598	5.862	5.862	
Right superior frontal gyrus (9)	23	47	30			3.517			
Right anterior cingulate (32)	17	26	27		4.230	4.185			

Note. Locations are relative to the anterior commissure (Talairach and Tourneaux, 1988). Significance was determined by two-way ANOVA with repeated measures and planned comparison of task means, with a threshold of $P < 0.005$ and a cluster size of >500 to account for multiple comparisons. Peak t values at each location are shown. Corresponding Brodmann's areas, as defined in Talairach and Tourneaux (1988) and Rajkowska and Goldman-Rakic (1995), are given in parentheses. Trans., transitional area.

ous pixels were tabulated. Using these criteria, the likelihood of a false-positive activation after correcting for multiple comparisons was less than 5% (Friston *et al.*, 1994). The resultant t -maps were superimposed on a reference atlas composed of an MRI from a normal subject centered in Talairach coordinates. To improve the description of response localization with respect to surface brain anatomy the t images of rCBF significance were rendered in three-dimensional perspective on the surface of the MRI reference atlas using the display software AVS (Advanced Visualization Systems, Waltham, MA).

RESULTS

In the present article we concentrate on frontal lobe activations associated with object presentation and the naming tasks (see Table 1). Other activations will not be dealt with here, as our a priori hypothesis focused on potential changes of brain activity in frontal motor areas.

Passive object viewing, object naming, and object-use naming all produced an activation of the left precentral sulcus, i.e., a sector of premotor cortex (Brodmann's area 6) at the level of the posterior middle frontal gyrus, as shown in Fig. 1A. There was no difference between object viewing and object naming at this site. In contrast, object-use naming increased the strength of this activation.

All conditions requiring internal verbalization activated a site extending from the inferior frontal gyrus to the frontal operculum, i.e., Broca's area (Brodmann's area 44), regardless of whether the naming concerned objects or their use, as shown in Fig. 1C. This was true whether observation of fractals or observation of objects was the control condition. The contrast "object-use naming vs object naming" was not significant in Broca's area.

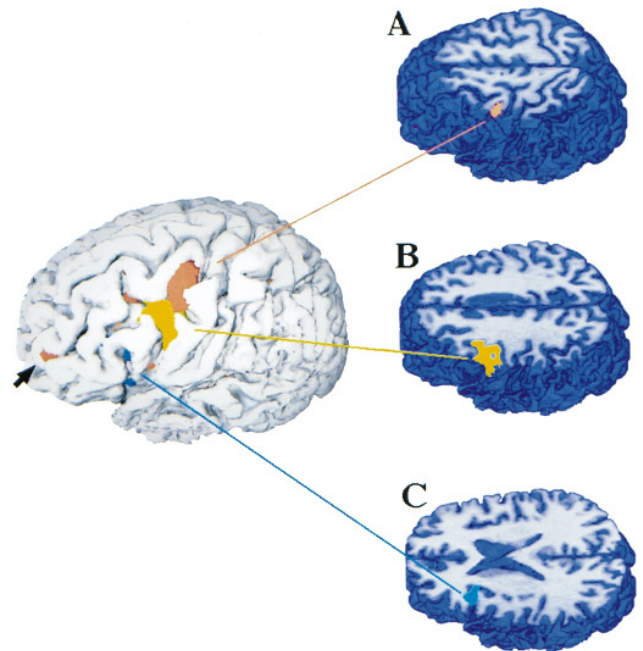


FIG. 1. Cortical anatomy of tool observation. Significant increases of rCBF during passive viewing of familiar tools versus two-dimensional fractals are shown in red/orange. (A) An activation is in the left dorsal precentral sulcus, i.e., premotor cortex (Brodmann's area 6, Talairach coordinates: $-39, -6, 51$) (Talairach and Tournoux, 1988). There is a second activation in the left inferior frontal gyrus (Brodmann's transitional area 45/46 (Rajkowska and Goldman-Rakic, 1995), Talairach coordinates $-32, 44, 17$, see arrow). Areas associated with increased activity during silent tool naming versus tool observation are shown in blue. Naming activates the Broca's site extending from the inferior frontal gyrus to the frontal operculum (Brodmann's area 44, Talairach coordinates: $-38, 17, 17$), shown best in C. Silent naming of a tool's use versus naming of a tool is shown in yellow. There is a further increase of activity of the left dorsal premotor cortex when subjects think of a tool's use (shown in A) as well as activation of more ventral precentral sulcus, i.e., ventral premotor cortex (Brodmann's area 6/44, Talairach coordinates: $-48, -2, 29$) shown in yellow in B.

A further activation was located in the inferior precentral sulcus (Brodmann's area 6/44), as shown in Fig. 1B. This ventral activation, distinct from that in Broca's area, was observed only when the use of objects had to be named. It was absent in the contrast "objects vs fractals," and in the contrast "object naming vs object observation."

Object observation, object naming, and object-use naming versus fractals activated a focus in the rostral-most portion of the inferior frontal sulcus (Fig. 1, arrow). Using the recent cytoarchitectonic criteria of Rajkowska and Goldman-Rakic, this activation is most likely located in a transition area between Brodmann's areas 45 and 46 (Rajkowska and Goldman-Rakic, 1995). Object naming or object-use naming were not significant with respect to object viewing in this area.

DISCUSSION

The present findings allow one to trace a schema that characterizes an orderly set of activations in the frontal lobe when a real 3-D tool is presented and when either its name or its use is retrieved. The simplest condition—object presentation without any verbal request—activated the left dorsal premotor cortex in a sector where arm/hand movements are represented (Deiber *et al.*, 1991; Matsumura *et al.*, 1996). In addition, this task activated a site on the border between area 45 and area 46.

These activations were observed after subtraction of observation of fractals from tools observation. Fractals were used to emphasize real graspable objects versus nongraspable, nonobjects and, since fractals arouse interest in subjects and are carefully inspected, as a control for eye movements. The lack of a bilateral precentral activation (commonly considered the location of frontal eye field; for review see Paus, 1996) confirmed the validity of our tasks for controlling eye movements.

We could not (obviously) use, as a control, tridimensional, nongraspable objects (e.g., animals, cars). On the other hand, we decided not to use bidimensional drawings of non-sense objects or animals because previous experiments showed that they do not activate premotor cortex but rather determine activation of other cortical areas (Martin *et al.*, 1995, 1996; Perani *et al.*, 1995). They were therefore not the most appropriate stimuli for a "neutral" control. Thus, although we cannot exclude the possibility that tridimensional objects other than tools may activate the dorsal premotor cortex, we think this possibility rather unlikely because the cortex activated in the present study corresponds to the hand/arm premotor cortex field. Its activation in relation to tool (manipulatable objects by definition) presentation may depend therefore on its basic motor functions.

Dorsal premotor activation in response to tool presentation, in the absence of any motor request, strongly resembles the activation of area F5 in the monkey where, as discussed in the Introduction, there are neurons which became active to the mere presentation of graspable objects. The homology between human and monkey premotor cortex is by no means clear. If one takes as the basis for the homology the location of the frontal eye fields in the two species, the described premotor activation could correspond to F5. In the monkey, F5 hand field is adjacent to the frontal eye field, with the two fields being located on the ventral and dorsal banks of the arcuate sulcus, respectively. Similarly, in humans, eye and hand fields are adjacent and in this case are located on the opposite banks of the precentral sulcus. Traditionally, however, the posterior medial frontal gyrus is considered to correspond to monkey dorsal cortex rather than ventral premotor cortex (Preuss *et al.*, 1996). Accepting this traditional point of view, the location of our dorsal premotor activation should correspond to the monkey dorsal premotor area.

In the monkey, dorsal premotor cortex (areas F2 and F7) has been implicated in associative motor learning (Halsband and Passingham, 1985; Passingham, 1985; Petrides, 1985) on the basis of lesion experiments. Furthermore, some dorsal premotor neurons fire only when a link has been formed between a (arbitrary) stimulus and a movement (Mitz *et al.*, 1991). It must be stressed, however, that the cortex crucially involved in associative motor learning appears to be located rostrally in dorsal premotor cortex—F7—and not in its caudal sector—F2 (Passingham, 1985; Petrides, 1985).

Man-made tools form a special category of objects that are strongly associated with specific movements. The associative motor learning mechanism described for the monkey could be, therefore, the basis for forming connections between those physical aspects of graspable objects that characterize them as tools and the appropriate movement necessary for using them. According to this view, the dorsal premotor cortex of adults would contain a storage of schemata (Arbib, 1972) representing movements appropriate for using different tools. The relevant schema would be automatically activated by the visual presentation of a given object.

The second activation present during tools observation was located in area 45/46. There is evidence that rostral 45 and the adjacent area 46 intervene in the analysis of word meaning (Kapur *et al.*, 1994). More recently, however, this frontal sector was shown to be involved also, specifically, in recognition of man-made objects. A verbal component was excluded because no activation was observed when the subjects had to categorize other visual objects that are as easily verbalized as tools (e.g., animals) (Perani *et al.*, 1995). This

finding, indicating a nonverbal role for rostral 45/46, is consistent with the present data.

The main effect of silent naming (compared to both fractal and object viewing) was on Broca's area (area 44). The activation was located close to an area 44 site previously reported to be active for silent naming of tool and animal drawings (Martin *et al.*, 1996) and for verb retrieval (Wise *et al.*, 1991). It is possible therefore that the site at which we observed activation is involved in coding words corresponding to the name and/or actions of the presented object. An alternative possibility is that the phonological encoding of words describing the objects and their use occurs at this site (Demonet *et al.*, 1992; Paulesu *et al.*, 1993; Zatorre *et al.*, 1992). The two alternatives are not mutually exclusive.

Object-use naming increased the activation of dorsal premotor cortex and determined, in addition, an activation of ventral premotor cortex (area 6/44). The dorsal premotor activation appears to indicate that the verbal evocation of an action related to a tool activates the same motor area that is activated by tool observation, but to a stronger degree. The activation of ventral premotor cortex (Fig. 1B) during action naming might be explained in two ways: it could be due to the verbal representation of the actions or to mental imagery of the action movements. The latter explanation seems to us to be more likely because the ventral premotor cortex site active in the present experiment was found to be also active during mental imagery of grasping movements (Decety *et al.*, 1994; Grafton *et al.*, 1996).

In conclusion, our findings indicate that the observation of man-made tools produces an activation of the premotor cortex. This object-determined activation should reflect the neural activity underlying object usage. In addition, it is possible that premotor activations (dorsal and ventral) play a role in describing the object meaning via fronto-temporal recurrent circuits. To categorize an object, it is not enough to have a description of its visual characteristics; it is necessary also to understand its use. The premotor activations found in the present study may subserve the motoric aspects of object semantics.

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