Functional Neuroanatomy of the Semantic System: Divisible by What?

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Abstract

■ Studies of patients with brain damage suggest that specific brain regions may be differentially involved in representing/processing certain categories of conceptual knowledge. With regard to the dissociation that has received the most attention—between the domains of living things and artifacts—a debate continues as to whether these category-specific effects reflect neural implementation of categories directly or some more basic properties of brain organization. The present positron emission tomography (PET) study addressed this issue by probing explicitly for differential activation associated with written names of objects from the domains of living things or artifacts during similarity judgments about different attributes of these objects. Subjects viewed triads of written object names and selected one of two response words as more similar to a target word according to a specified perceptual attribute (typical color of the objects) or an associative attribute (typical location of the objects). The control task required a similarity judgment about the number of syllables in the target and response words. All tasks were performed under two different stimulus conditions: names of living things and names of artifacts. Judgments for both domains and both attribute types activated an extensive, distributed, left-hemisphere semantic system, but showed some differential activation-particularly as a function of attribute type. The left temporo-occipito-parietal junction showed enhanced activity for judgments about object location, whereas the left anteromedial temporal cortex and caudate nucleus were differentially activated by color judgments. Smaller differences were seen for living and nonliving domains, the positive findings being largely consistent with previous studies using objects; in particular, words denoting artifacts produced enhanced activation in the left posterior middle temporal gyrus. These results suggest that, within a distributed conceptual system activated by words, the more prominent neural distinction relates to type of attribute. ■

INTRODUCTION

The issue of where and how the brain represents knowledge about the world is a topic of continuing debate in cognitive neuroscience. Studies of normal subjects and of patients with brain damage suggest that there may be significant distinctions in the cortical representation of different types of information. The most thoroughly documented conceptual distinction is between the domain of living things (including animals, fruits, vegetables) on the one hand and manufactured artifacts (such as tools, household objects, vehicles, etc.) on the other. There are now numerous reports of patients, most with bilateral inferomedial temporal lobe damage secondary to herpes simplex virus encephalitis, with significantly impaired semantic performance on living things relative to artifacts (Funnell & Davies, 1996; Hart & Gordon,

1992; Sartori, Job, Miozzo, Zago, & Marchiori, 1993; Silveri & Gainotti, 1988; Warrington & Shallice, 1984). It has been suggested that this dissociation might reflect a bias in some variable such as familiarity that inherently favors everyday artifacts, and indeed not all of the apparent reports of a deficit for living things have survived stringent stimulus matching (Funnell & Sheridan, 1992; Sartori, Coltheart, Miozzo, & Job, 1994). There are, however, some compelling demonstrations of this dissociation based on careful stimulus selection. Furthermore, the existence of cases with the opposite pattern (i.e., a deficit for artifacts relative to living things: Caramazza & Shelton, 1998; Hillis & Caramazza, 1991; Sacchett & Humphreys, 1992; Warrington & McCarthy, 1987) rules out any simple familiarity imbalance as an explanation of a selective living-things impairment.

Two main classes of explanation have been advanced

for the living thing-artifact dissociation. The most transparent account suggests a categorical organization of semantic information in the brain; that is, living things and artifacts might be so genuinely different that knowledge about the two domains is separately neurally implemented (Caramazza & Shelton, 1998; Laiacona, Barbarotto, & Capitani, 1993). An alternative and now more widely accepted account argues that there are substantial differences in the types of semantic features that constitute the core meaning of instances of these two broad categories. If living things are distinguished primarily by their perceptual (mainly visual) features and artifacts are more specified by functional/associative attributes (how an object is used, where it is found, etc.), the observed category effects may result from selective disruption to neural regions specialized for these two types of featural information (Farah & McClelland, 1991; Gainotti, Silveri, Daniele, & Giustolisi, 1995; Garrard, Patterson, Watson, & Hodges, 1998; Saffran & Schwartz, 1994; Warrington and Shallice, 1984). Consistent with this conceptual division are reports of deficits in perceptual relative to associative knowledge (Silveri & Gainotti, 1988).

In addition to these two principal accounts of category-specific effects, the literature offers several other proposals regarding this distinction. For example, Humphreys and colleagues have drawn attention to important differences between the two domains in the degree and detail of visual processing required to distinguish one member of a category from another. Animals or fruits and vegetables have more striking within-category structural similarities than artifacts, and thus are thought to place greater demands on a presemantic "structural description" system for object recognition (Forde, Francis, Riddoch, Rumiati, & Humphreys, 1997; Humphreys, Lamote, & Lloyd Jones, 1995). Furthermore, some recent accounts based on principles of distributed neural networks focus on differences between the domains in degree and pattern of intercorrelation between different elements of our knowledge about an object (Devlin, Gonnerman, Andersen, & Seidenberg, 1998; Durrant-Peatfield, Tyler, Moss, & Levy, 1997; Gonnerman, Andersen, Devlin, Kempler, & Seidenberg, 1997; McRae, de Sa, & Seidenberg, 1997). It is by no means clear at this stage whether these various explanations constitute mutually exclusive hypotheses about the conceptual basis of the category distinction, nor whether each leads to testable predictions about neuroanatomical differences underlying the effect.

Although this debate has been conducted primarily with reference to category-specific semantic deficits in neurological patients, another highly pertinent source of evidence is available from neuroimaging studies of normal individuals. Before we review the existing findings, it is worth commenting that, in the literature on both selective category deficits in patients and regional brain activation in normal individuals, there are often substantial differences between studies in the nature of stimulus materials, tasks, or both. Such diversity is not surprising and indeed should eventually assist progress toward a full characterization of the relevant phenomena; but at present, when so little of the experimental parametric space has been explored, these major differences tend to impede neat comparisons and summaries.

In the limited number of functional imaging studies contrasting objects from the living thing/artifact domains, some degree of consistency has emerged with respect to brain regions showing enhanced activation for artifacts (especially tools) relative to living things. Experiments employing either picture naming or verbal fluency for semantic categories have produced greater activation for artifacts than for living things in left posterior temporal or temporo-parietal areas (Damasio, Grabowski, Tranel, Hichwa, & Damasio, 1996; Martin, Wiggs, Ungerleider, & Haxby, 1996; Mummery, Patterson, Hodges, & Wise, 1996) and also in a left inferior frontal region (BA 44/6) (Grabowski, Damasio, & Damasio, 1997; Martin et al., 1996). A further study by Perani et al. (1995), involving same-different judgments on pictures of animals or tools rather than a naming task, revealed left frontal activity for tools (albeit 24 mm distant) but no posterior temporal locus. The opposite comparison has tended to yield somewhat weaker and less consistent results. When participants in the Damasio et al. (1996) study named animals (in comparison to naming tools), peak activation was found in the left inferior temporal lobe, still relatively posterior but somewhat anterior and medial to that observed for naming tools. Mummery et al. (1996) observed enhanced bilateral *anterior* medial temporal activation when subjects generated names of living things; both Martin et al. (1996) and Perani et al. (1995), however, reported more left unilateral medial occipital activation associated with viewing pictures of animals.

Even fewer functional imaging studies have contrasted different types of semantic features. Vandenberghe, Price, Wise, Josephs, and Frackowiak (1996) observed no selective activation for either perceptual or associative similarity judgments about triads of pictures or words. On the other hand, when Martin, Haxby, Lalonde, Wiggs, and Ungerleider (1995), asked subjects to imagine either a perceptual attribute of an object (its color) or a functional attribute (the object's typical action), the perceptual condition produced enhanced activation in the ventral temporal lobe (left lateralized when stimuli were words, bilateral when pictures were used), whereas the functional condition revealed increased activity in the left posterior middle temporal region. Given that the stimulus materials were limited to tools and that the focus of activation for the functional condition was close to that seen in the previously mentioned studies of naming artifacts, this result raises once again the ques-

tion of whether it is the type of object (natural kind/artifact) or the type of attribute (perceptual/functional), or indeed a separate property, that is central to category-specific phenomena.

The PET experiment reported here was designed to assess the relative effects of object domain and attribute type. We used written-word object names to minimize clues to visual/structural features of the object concepts. In each block of the PET experiment, subjects viewed a triangle of three words and chose one of the two lower response words as more similar to the upper target word on a specified dimension. The first experimental manipulation varied task, where the experimental task was a semantic similarity judgment and the control task a judgment about word length in syllables. The second manipulation varied object domain, where the triads in each block consisted entirely of words denoting either living things or artifacts. The final manipulation varied type of knowledge attribute: In half of the semantic conditions, subjects chose the response word more similar to the target on a perceptual attribute (object color); in the remaining half, the basis for the similarity judgment was a more functional or associative attribute: typical object location. Color was chosen as a perceptual attribute common to both living things and artifacts; it has been used with success in previous experiments (Martin et al., 1995), affording an opportunity to test for consistency across study designs. The location task required subjects to retrieve information about where an object was likely to be found, that is to say, its typical spatial location within the environment. This was chosen as an associative attribute that applies equally well to living things and artifacts, unlike the typical action associated with an object. This shows fundamental differences for the two domains—living things often have intrinsic action, whereas artifacts normally have extrinsic action placed upon them.

Our predictions, and their genesis, were as follows: (1) In keeping with prior functional imaging studies, we expected that semantic judgments (relative to phonological judgments about syllable number) would activate a distributed system, mainly in the left hemisphere, involving the inferolateral temporal lobe, the posterior inferior parietal lobe, and possibly the inferior frontal gyrus (e.g., Price, Wise, et al., 1996; Vandenberghe et al., 1996). (2) With regard to the two manipulations within the semantic conditions, we predicted more marked activation differences between attribute types than between object domains: Processing of what an object looks like, or where it is to be typically found, seems a more likely basis for neuroanatomical specialization than the conceptual distinction between living things and artifacts (Gainotti et al., 1995). (3) Regarding specific cortical regions, our prediction was based primarily on the differentiation between "what" and "where" poststriate visual processing (Ungerleider & Mishkin, 1992). That

is, we expected heightened ventral temporal activation in response to perceptual color judgments and enhanced dorsal temporo-parietal activation for location judgments.

RESULTS

Behavioral Data

The mean error rates and reaction times of the subjects for each task are shown in Table 1. ANOVA post hoc testing was performed to examine the data for significant differences between the conditions. The syllable task produced significantly longer reaction times (RTs) than the semantic tasks, (Scheffe test $p < 0.0001$), although this was not mirrored in the error rates. Within the semantic conditions, the location task for artifacts yielded significantly shorter RTs than any of the remaining semantic tasks ($p < 0.0001$). No other RT differences were significant. The error rates were too low to justify significance testing between the conditions.

PET Results

An initial descriptive (eigenimage) analysis was performed to characterize the activations in terms of distributed brain systems (Friston, 1994). The principal eigenvector, accounting for 49% of the experimental variance, showed positive loading in the scans corresponding to semantic tasks and negative loading in the scans corresponding to the syllable task. This vector correlated with changes in the left posterior temporo-parietal junction (BA 39) and bilateral supramarginal gyri (BA 40), respectively. No other eigenvector accounted for more than 9% of the variance. This result was not simply due to the difference between tasks in "difficulty": A further analysis factoring out RTs by using them as a covariate of no interest produced the same pattern. These results therefore confirm a dissociation in terms

Table 1. Mean Reaction Times, Standard Error, and Error Rates (as Mean Number of Errors) for the Group.

Condition	Mean	S Error	Mean No Errors
Living things (location)	2449.3	43.6	1.1
Artifacts (location)	2125.2	39.5	0.5
Living things (color)	2423.3	41.4	2.4
Artifacts (color)	2498.7	35.3	1.2
Living things (syllable)	2637.2	37.5	1.2
Artifacts (syllable)	2656.5	38.3	1.2

of cerebral processing between the semantic and phonological tasks.

Examining the data for regions activated in the semantic more than in the syllable tasks revealed mainly left lateralized activation spreading throughout the left lateral temporal lobe, from the temporo-occipito-parietal junction (BA 39/19) through the posterior middle temporal gyrus and anteriorly to the inferolateral and inferomedial temporal lobe (see Table 2 and Figure 1). Weaker activations were seen in the right temporal pole and right inferomedial temporal lobe. Analysis of individual subject activations showed that in all but one participant both anterior temporal lobes were activated, although in the posterior regions, only the left hemisphere was activated. Less significant activation of the left inferior frontal gyrus (BA 47) was present, and the left medial prefrontal cortex was also more active in the semantic tasks relative to control. The syllable judgment task, which was designed to emphasize phonological processes, showed significant activation relative to the two semantic tasks in bilateral supramarginal gyri (BA 40), bilateral premotor regions, left posterior fusiform gyrus (BA 19), right inferior temporal gyrus (BA 37/19), and cerebellum.

Within the semantic system, differences were observed depending upon attribute type (see Table 3 and Figure 2). Fitting reasonably well with our predictions, semantic judgments based on similarity of object location differentially activated the left temporo-occipito-parietal (T-O-P) junction (BA 39/19), posterior cingulate, and medial parietal lobe, whereas color judgments activated the anteromedial left temporal lobe and caudate nucleus. Comparison of object domains (Table 4 and Figure 3) showed no areas that were significantly activated for living things over and above artifacts common to both tasks. The reverse comparison revealed enhanced activation associated with artifacts in the left posterior middle temporal gyrus (BA 37/21) and left parahippocampal gyrus. There was enhanced activation in the left middle frontal gyrus (BA 9) and the right T-O-P junction (BA 39) for location judgments about living things relative to all other conditions. For location judgments there were *no* regions that were significantly more active for artifacts than living things and also none specific to color judgments about living things.

DISCUSSION

We predicted several specific findings in this study; results germane to these predictions are presented in two main sections: (1) those areas common to both semantic tasks for both object types and (2) areas showing differential activation for, firstly, attribute type and, secondly, object domain. The control and behavioral results are then briefly discussed.

Table 2. Regions of significant activation in the main effect of semantic and syllable tasks. Coordinates in millimeters refer to the location in the stereotactic space of Talairach and Tournoux (1988) of the voxels with the peak z score within a particular activated region [z score > 3.1 ($p <$ 0.001)].

Area of Activation	x y z	z Score
Semantic-Syllable		
Activations in predicted areas and/or reaching corrected level of significance		
Left T-O-P junction (BA 39)	−46, −72, 28	6.8
Left mTG	−56, −24, −6	5.1
Left PHG	−30, −30, −16	4.4
Left iTG/FG	−44, −22, −16	3.9
Left medial sup frontal gyrus	−6, 58, 26	7.2
Left orbitofrontal gyrus	−14, 54, −4	4.5
Left inferior frontal gyrus (BA 47)	−32, 18, −16	3.7
Activations not in predicted areas and reaching uncorrected level of significance		
Right temporal pole (med)	28, 10, −22	3.4
Posterior cingulate	−6, −56, 12	3.7
Caudate	−6, 12, 12	3.5
Syllable-Semantic		
Activations reaching corrected level of significance		
Left supramarginal gyrus (BA 40)	−56, −34, 34	6.3
Left premotor/precentral gyrus (BA 4/6)	−52, −8, 38	6.0
Right supramarginal gyrus (BA 40)	52, −40, 46	7.4
Right posterior iTG/FG (BA 37)	56, −50, −22	5.1
Activations reaching uncorrected level of significance		
Right middle frontal gyrus	38, 34, 20	4.2
Right premotor/precentral gyrus (BA 4/6)	26, 0, 54	4.1
Right thalamus	10, −10, 12	3.6
Precuneus	2, −46, 66	3.6
Left cerebellum	−28, −58, −30	3.9

Figure 1. Regions of significant regional cerebral blood flow (rCBF) common to all semantic tasks versus the syllable (control) task. The threshold was set at $z > 3.1$ ($p < 0.001$) in this and all other contrasts. The figure is divided into three sections: top row shows glass brain depiction of activations in sagittal and transverse view with plot of rCBF from coordinate −6, 58, 26 ($z = 7.2$). The bottom row shows activations superimposed on the averaged MRI of the participating subjects. (For all contrasts: L = location judgment; C = color judgment; S = syllable judgment; -lt = for living things; -ar = for artifacts. Posterior = P, anterior = A, left = L, right = R).
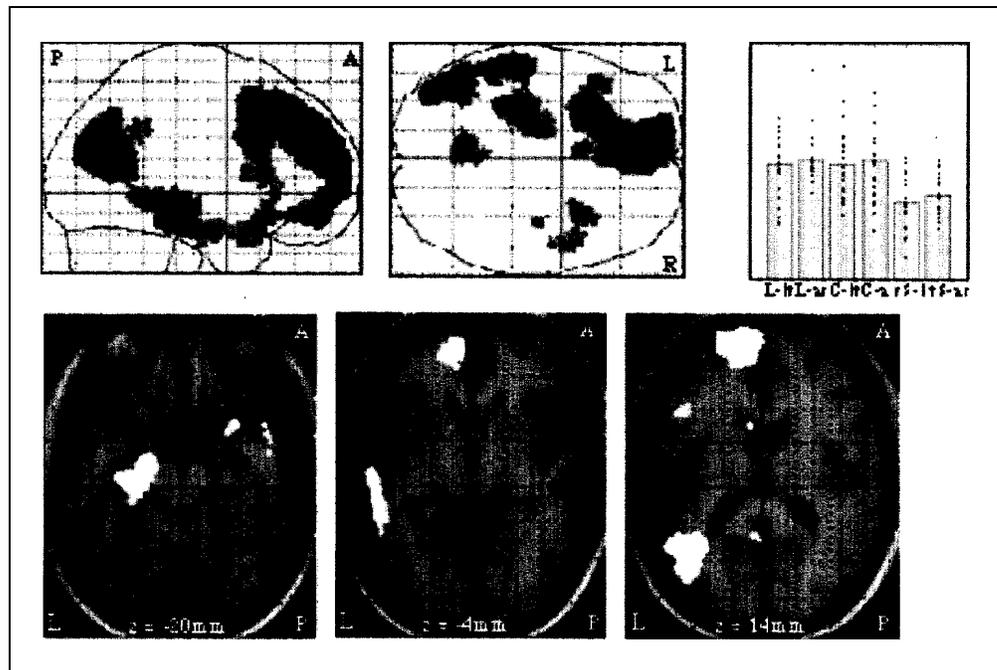
Common Semantic Activations

We have shown activation of a left-lateralized, distributed network, extending from the left T-O-P junction (BA 39) through the inferolateral temporal lobe to the inferior frontal gyrus (BA 47). The areas activated by the semantic tasks are largely consistent with previous imaging studies, supporting the hypothesis that these regions form a common network for the retrieval of semantic knowledge, regardless of stimulus modality (pictures versus words: Vandenberghe et al., 1996) and task (word generation: Martin et al., 1995; Warburton et al., 1996; Wise et al., 1991; semantic decision: Price, Moore, Humphreys, & Wise, 1997; Vandenberghe et al., 1996).

Temporal Activations

Some of the results from the present study are consistent with lesion data. In semantic dementia, a neurodegenerative condition characterized by a progressive decline in semantic knowledge (with relative preservation of other components of language, memory, perceptual, and spatial ability), the principal locus of pathology typically involves the left anterior and inferolateral temporal lobe (Hodges & Patterson, 1997; Hodges, Patterson, Oxbury, & Funnell, 1992). Consistent with the more posterior activations, Alexander, Hiltbrunner, and Fischer (1989) argued that stroke patients with transcortical sensory aphasia, in whom semantic knowledge is impaired, have lesions isolating the left posterior inferolateral temporal lobe and the left T-O-P junction (BA 39).

Our findings are also in accord with some previous experimental data both from functional imaging and from other methodologies such as event-related potentials (ERPs). The activation of anterior temporal regions is supported by ERP studies, such as that by Nobre, Allison, and McCarthy (1994), in which anteromedial temporal lobe regions close to the entorhinal cortex were found to be sensitive to semantic manipulations. The left anterior temporal lobe (BA 20/38) is also more active when subjects perform category fluency relative to initial letter fluency (Mummery et al., 1996), but the more posterior left T-O-P regions that were additionally activated in the current study (BA 39) showed no differential activation in the fluency tasks. In both studies the semantic task was compared to a phonological task: in the former, initial letter fluency and in the latter, syllable judgment. These areas therefore appear to be involved in differing aspects of semantic processing; however, any attempt at a more precise interpretation is premature in that the semantic tasks used in these experiments differ along several dimensions.

Frontal Activations

The role of the frontal lobes in semantic processing is more controversial. The left inferior frontal region (BA 47) observed in some previous semantic tasks (Petersen, Fox, Posner, Mintun, & Raichle, 1988; Vandenberghe et al., 1996) was also activated in this study, although the z score was smaller than for the temporal regions. Our previous study (which compared semantic category and initial letter based verbal fluency) did not produce activation of the left inferior frontal region in the semantic task, perhaps because this area supports a process com-

Table 3. Regions of significant activation in the contrast of similarity judgments for location and color. Main effects are reported, followed by the simple main effects for each attribute type in that particular region.

Area of Activation	Main effect		Location-Syllable		Color-Syllable	
	x y z	z Score	x y z	z Score	x y z	z Score
Location-Color Common to Both Domains						
Left sOG (BA 19)	−32, −78, 32	4.4	−32, −72, 38	4.6	−	−
Left T-O-P junction (BA 39)	−50, −68, 20	4.2	−44, −72, 26	7.6	−44, −72, 26	4.8
Left occipitoparietal sulcus	−16, −56, 14	3.8	−12, −58, 18	6.1	−	−
Posterior cingulate gyrus	−4, −58, 26	4.1	−2, −58, 20	4.7	−	−
Medial parietal lobe	−12, −60, 20	3.8	−8, −60, 20	3.8	−	−
Location-Color for Living Things Only						
Left mFG (BA 9)	−32, 22, 30	5.0	−32, 20, 28	5.1	−36, 16, 20	1.9
Right T-O-P junction (BA 39)	48, −66, 26	4.6	48, −64, 22	4.1	46, −54, 14	2.2
Color-Location Common to Both Domains						
Left anteromedial temporal lobe	−10, −4, −24	3.4	−	−	−14, −6, −24	4.0
Caudate	6, 8, 2	3.4	−	−	2, 8, 6	4.0

mon to both category *and* letter fluency (Mummery et al., 1996). The left medial prefrontal region (BA 10/11) also showed activation in the semantic relative to the control task. The reason for this activation is uncertain, although BA 11 has been seen before in semantic similarity judgments (Vandenberghe et al., 1996). In the macaque, this region is known to receive visual input from the inferior temporal cortex and temporal pole, and it projects efferents back to the inferior temporal cortex and cingulate cortex. Certainly the region is involved (in animals) in the successful performance of an action appropriate to learning of reward related behavior (Rolls, 1996). Whether it is also related to some form of hypothesis testing is unknown but feasible. These frontal regions are less likely to be involved in the representation of semantic knowledge per se, in that there are no cases we are aware of where lesions of this medial frontal region, or indeed of the inferior frontal region, cause deficits in semantic knowledge.

Dissociations within the Semantic System

Attribute Type

As previously described, neuropsychological data suggest that different cortical regions may be differentially involved in certain types of knowledge. Our results provide some support for this notion, although the substantial consistency of activation patterns across semantic conditions suggests that implicit processing of all aspects of semantic knowledge may occur regardless of

explicit task. Nevertheless, although the cortical areas activated by our associative and perceptual tasks overlap considerably, some regions were differentially activated depending upon the type of semantic attribute critical for performance of the task. Judgments about the location in which objects are typically found, relative to judgments about object color (common to both object domains), involved the left posterior T-O-P region (BA 39 and BA 19), posterior cingulate, and medial parietal lobe. The posterior parietal region was superior to that seen in the study by Martin et al. (1995), who compared imagining the *action* of an inanimate object with imagining its color. In the present study, the associative task involved a spatial colocation judgment rather than a motion judgment, and the spatial component might be expected to activate a more dorsal region in the posterior inferior parietal cortex (Ungerleider & Mishkin, 1982), as indeed the results demonstrate.

The associative location task is complex, perhaps engaging a number of different strategies as well as intrinsic semantic properties, but we can base some hypotheses about the possible contribution of the regions activated on lesion data from both humans and monkeys. Lesioning the parieto-occipital region in the macaque monkey has been shown to disrupt the ability to locate a foodwell with reference to a landmark, indicating an impairment on spatial discrimination tasks (Mishkin, Lewis, & Ungerleider, 1982). In humans, this region has been associated with the syndrome of neglect (albeit mainly with lesions to the right hemisphere),

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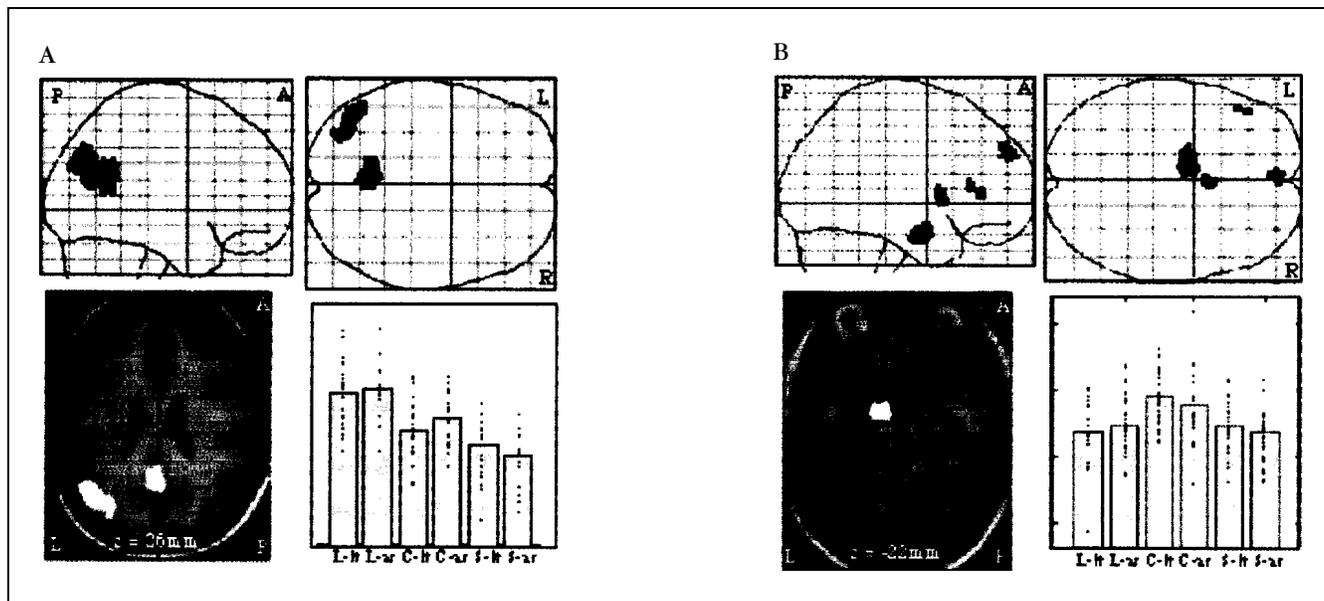
Figure 2. Regions of significant rCBF for (A) location judgments versus color judgments and (B) for color judgments versus location judgments. As in Figure 1, this is divided into glass brains, plot of significant rCBF [A coordinates −50, −68, 20 (z = 4.2); B coordinates −10, −4, −24 (z = 3.4)], and activations superimposed on the averaged MRI.

often attributed to a deficit in directed spatial attention; however, it has been shown that such lesions can also cause deficits in representational memory (Bisiach & Luzzatti, 1978), and it has been postulated that the disorder of neglect involves a disrupted mental representation of space (Hussein, 1996). The inferior posterior parietal lobe therefore appears to be critical not only for the integration of sensory information for spatial judgments about objects within the current visual field but also for spatial judgments involving representational space. Activation of the medial parietal lobe in this task, an area thought to be important in "mind's eye imagery"

(Fletcher et al., 1995) is consistent with the hypothesis that the location judgments require internal imagery. Indeed, several subjects reported that there was a greater degree of visualization of objects in this task than in the color judgments.

Enhanced activation was seen for location judgments about living things relative to artifacts: Specifically, location judgments for artifacts activated left BA 39 as discussed above, whereas the same task for living things activated bilateral BA 39 and left BA 9. The right T-O-P area has been activated in a previous experiment in a contrast of verbal fluency for living things versus arti-

Table 4. Regions of significant activation in the contrast of similarity judgments for the two object domains. Main effects are reported, followed by the simple main effects for each domain in that particular region.

	Main effect		Artifacts-Syllable		Living Things-Syllable	
Area of Activation	x y z	z Score	x y z	z Score	x y z	z Score
Artifacts-Living Things Common to Both Attributes						
Left post mTG (BA 37/21)	−54, −54, 0	3.7	−54, −50, −2	3.7	–	–
Left PHG	−30, −28, −16	3.2	−30, −26, −14	4.8	–	–
Living Things-Artifacts Common to Both Attributes						
Nil significant						
Living Things-Artifacts for Location Only						
Left mFG (BA 9)	−30, 24, 26	3.6	−30, 20, 32	2.1	−32, 20, 28	5.1
Right T-O-P junction (BA 39)	48, −66, 26	3.8	–	–	48, −64, 22	4.1

Figure 3. Regions of significant rCBF for the contrast of words denoting artifacts versus those denoting living things. As in Figure 1, this is divided into glass brains, plot of significant rCBF from coordinate −54, −54, 0 (z = 3.7) and activations superimposed on the averaged MRI.
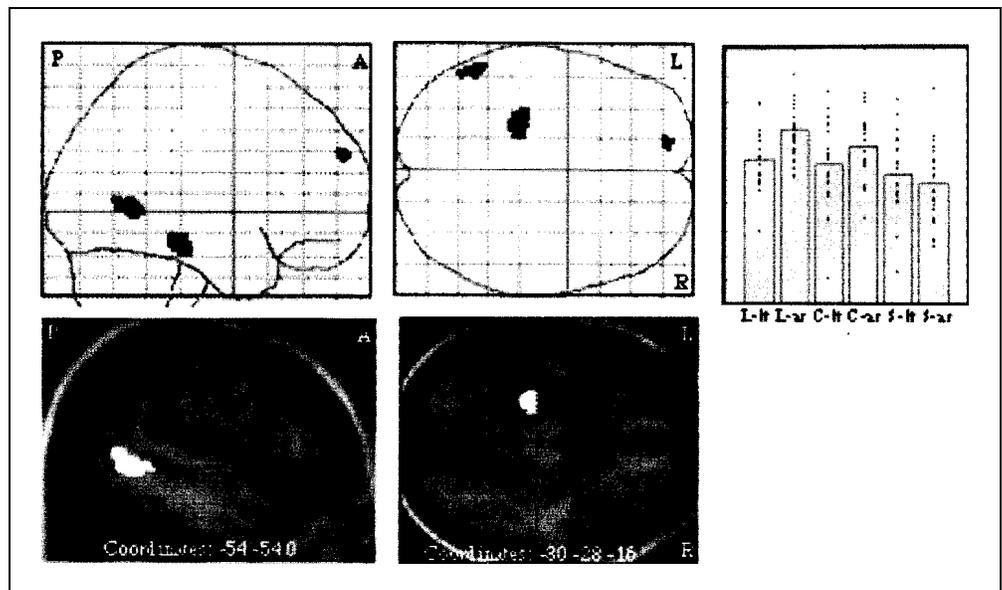
facts (Mummery et al., 1996). The left prefrontal region (BA 9) has been seen in several studies involving semantic retrieval (e.g., Frith, Friston, Liddle, & Frackowiak, 1991a; Martin et al., 1995; Martin et al., 1996); however, it is unclear why this area might be involved particularly for retrieval of the typical location of a living thing.

We also saw areas more active for color than for location judgments. The color task produced stronger activation in regions of the left anteromedial temporal lobe and the caudate nucleus, the latter being an area observed in a recent study of color naming (Price, Moore, Humphreys, Frackowiak, & Friston, 1996). The left anteromedial temporal activation corresponds closely to that found in category fluency when subjects generated the names of living things versus artifacts (Mummery et al., 1996; maxima 4 mm distant). Work on the macaque monkey, lesioning the perirhinal cortex, has suggested that this area may be important in the association and integration of different visual features characteristic of individual objects (Gaffan, 1994). This medial temporal region may be critically involved in the representation of items that are differentiated on the basis of fine-grained visual information: The task of deciding whether a salmon or a cherry is closer in color to a flamingo requires precisely that differentiation. In contrast, the anterolateral temporal lobe is commonly activated by all semantic judgments relative to syllable judgments, and for category fluency relative to letter fluency, suggesting that this area is important in semantic retrieval but is not differentially activated by different object domains or types of semantic feature. This seems consistent with the fact that patients with semantic dementia (and anterolateral temporal lobe damage) very rarely show a strong living-things deficit, except perhaps where the atrophy extends medially (Barbarotto, Capitani, Spinnler, & Trevelli, 1995).

Object Domain

Turning to the brain regions that were activated more by one or other object domain, differences found were smaller than those related to differing types of knowledge. In fact, when the data were examined for regions that activated more for words denoting living things than for names of artifacts, *no* significant differences were seen across tasks (see previous section for discussion of enhanced activation for location judgments). This failure to find any regions specifically associated with processing of living things regardless of task is interesting in light of the rather dramatic deficits specific to living things that have been reported in the neuropsychological literature (Hart & Gordon, 1992; Sartori et al., 1993; Silveri & Gainotti, 1988; Warrington & Shallice, 1984). One possible interpretation is that presemantic differences in the processing of natural kind concepts may be in part responsible for category-specific differences in patients (Humphreys et al., 1995). If the difference between the object domains were largely in actual visual processing, one might only expect to see differential activation for artifacts and living things when they are presented in picture form but not (as in the present study) in word form. This account does not, however, explain the dramatic deficits sometimes observed for living things in word as well as picture tasks (e.g., Warrington & Shallice, 1984). It must also be remembered that in this study the difference between attribute types (color vs. location) was an explicit focus of judgments for subjects, whereas the difference between object domains (natural vs. manufactured) was never drawn to the subjects' attention, thus remaining implicit. The advantage of designing the experiment in this manner is that any differences seen for category should be genuine; however, we cannot yet claim a full understanding of the

conditions under which concepts from the domain of living things do produce regional activation. It is possible that the ventral temporal areas are critical for natural kind identification, but are equally capable of being engaged by any object if a subject is explicitly focused on a task requiring access to perceptual knowledge.

Despite a lack of significant differential activation for natural kind relative to artifact concepts across tasks in this experiment, the reverse comparison revealed activation in the left posterior middle temporal gyrus (BA 21/37) for words denoting artifacts. The rare reports of category-specific deficits for artifacts have been described in patients who have extensive left middle cerebral artery strokes, which are likely to have included this region (Gainotti et al., 1995; Hillis & Caramazza, 1991; Warrington & McCarthy, 1987). This region is close to, and overlaps with, that found by Martin et al. (1995) and Martin et al. (1996) when subjects either imagined actions of inanimate objects or named tools (distance between respective activation maxima = 8 mm). The exact function of this region within the semantic system remains an open question. What can be concluded, however, is that this region (1) is activated more for artifacts than living things (represented both as words and pictures), (2) responds only to semantic tasks (see blood flow plot Figure 3), and (3) is activated more by imagining an action than by imagining a color (Martin et al., 1996). These findings suggest that this area is indeed critical for artifacts, especially because it is one of the few regions that has been reliably observed in studies from separate research centers using differing semantic tasks but for a consistent class of concepts. It remains a plausible hypothesis that this specialization results from the relative importance of functional/associative knowledge for artifacts as opposed to living things.

The left parahippocampal gyrus also showed greater activation for artifacts than for living things. This area has previously been activated in a semantic comparison task, more for words than for pictures (Vandenberghe et al., 1996), more for category than for letter fluency (Mummery et al., 1996), and more for naming of animals than tools [although activated to some degree for both object categories (Damasio et al., 1996)]. No clear conclusion about this region can yet be drawn from functional imaging studies of the semantic system, although there is increasing consensus that it must play some semantic role.

Control Activations

The syllable judgment task was designed to control for basic visual, orthographic, phonological, and working memory processes common to both the semantic and syllable tasks. The regions activated by the syllable judgments more than by the semantic attribute judgments are consistent with previous findings for syllable judgments on words (Price et al., 1997), letter fluency con-trasted with category fluency (Mummery et al., 1996), and phonological monitoring studies, which showed activation of (1) the left premotor gyrus, attributed to prearticulatory phonological encoding (Demonet et al., 1992; Mummery et al., 1996; Zatorre, Meyer, Gjedde, & Evans, 1996), and (2) supramarginal gyrus, attributed to phonological short-term memory (Paulesu, Frith, & Frackowiak, 1993). In the basal temporal lobes, bilateral posterior fusiform/inferior temporal gyrus activations were also seen, consistent with a role in the processing of words presented visually (Nobre et al., 1994).

Behavioral Results

Subjects found the syllable judgment task more demanding than the semantic tasks, and this difference was reflected in the mean RTs, though not in the error rates for the two tasks. This RT difference suggests that any activation by semantic as opposed to syllable judgments is unlikely to be confounded by difficulty. Within the semantic tasks, RTs for location judgments on artifacts were significantly shorter than those for all other semantic decisions. Previous RT-based studies of feature judgments by normal subjects have produced similar results (Laws, Humber, Ramsey, & McCarthy, 1995), which the authors attributed to the critical status of this kind of associative knowledge for artifacts. In keeping with our data, Laws et al. also found no significant RT difference between associative and perceptual judgments about living things. This pattern suggests a greater differential in the weighting between perceptual and associative knowledge for artifacts than for living things.

CONCLUSIONS

We have shown that, when normal adults make semantic similarity judgments on written words, a network of cortical areas is activated, remarkably consistent with those found in other studies using both spoken words (Binder et al., 1997), and pictures of objects (Vandenberghe et al., 1996). Within this common distributed system, there were regions that were differentially involved when the system was weighted for a certain type of task. Judgments about object location (relative to color) were associated with enhanced activation of the left T-O-P region, whereas the reverse contrast (color vs. location) produced stronger activation in the left antero-medial temporal lobe and caudate nucleus. Consistent activation of the left posterior middle temporal gyrus for words denoting artifacts for both perceptual and associative tasks also confirms the importance of this region for inanimate objects. On the other hand, the lack of any differential activation for words denoting living things relative to artifacts may suggest that, when the task demands and stimulus attributes are carefully controlled, there are no areas specific to the semantic processing of words denoting living things. These results suggest that

the more prominent neural distinction relates to type of semantic attribute rather than object domain.

METHODS

Subjects

Ten male subjects (age range 25 to 31 years) took part in the study. All subjects were fit, healthy, on no medication, and free from any history of neurological or psychiatric illness. They were all strongly right-handed on the Edinburgh Handedness Inventory. The study was approved by the local hospital ethics committee and the Administration of Radioactive Substances Advisory Committee (UK) (ARSAC).

PET Scanning

Each subject underwent 12 PET estimations of brain activity over a 2-hour period. Scans were obtained using an ECAT EXACT HR+ PET Scanner (CTI, Knoxville, TN) with collimating septa retracted. Volunteers received a 20-sec intravenous bolus of $H_2^{15}O$ at a concentration of 55 Mbq ml^{-1} and a flow rate of 10 ml min^{-1} through a forearm cannula.

Psychological Tasks

Stimuli for each scan consisted of a series of word triads. These series were matched across all scans for frequency and number of syllables; no triad was seen more than once during a scanning session. In half of the scans the triads consisted entirely of words denoting living things, and in the other half the words described artifacts. Subjects had to perform one of three tasks: the two experimental tasks involved semantic judgments, either a color similarity decision or a location similarity decision. For the color judgement the subject decided which of two alternative response words represented an object closer in color to the target word (e.g., FLAMINGO: salmon, cherry). For the location judgment, subjects decided which of the two response words was typically found in the same location as the target object (e.g., PAPER: rake, ruler). This task required subjects to visualize the usual spatial location of each object in relation to one another, as well as in relation to the environment. Subjects responded to each triad by pressing a response key in the right or left hand depending on whether they considered the left or right response word to be the best choice. The control task emphasized phonological rather than semantic processing: Subjects decided which of two response words had the same number of syllables as the target word. This task was used as a control because it produces robust differences between semantic and phonological processing (Price et al., 1997) and should control for activation due to visual, orthographic, and phonological processing of the words in the experi-

mental tasks. Reaction times and errors were recorded for each judgment. Prior to scanning, subjects practiced until they understood and were able to perform the task. Examples of stimulus triads are given in the Appendix.

Data Analysis

The data were analyzed with statistical parametric mapping (using SPM96 software from the Wellcome Department of Cognitive Neurology, London; http//www.fil.ion.ucl.ac.uk/spm) implemented in Matlab (Mathworks Inc, Sherborn, MA). Statistical parametric maps (SPMs) combine the general linear model and theory of random Gaussian fields to make statistical inferences about regional effects (Friston, Holmes, et al., 1995). Scans from each subject were realigned using the first as a reference. Following realignment, all images were transformed into a standard space (Talairach & Tournoux, 1988). This normalizing spatial transformation matches each scan to a reference template image that already conforms to the standard space (Friston, Ashburner, et al., 1995). As a final preprocessing step, images were smoothed with a Gaussian 16-mm filter. The condition and subject effects were estimated according to the general linear model at each voxel (Friston, Holmes, et al., 1995). To test hypotheses about regionally specific condition effects, the estimates were compared using linear compounds or contrasts. The resulting set of voxel values for each contrast constitutes an SPM of the t statistic (SPMt). The SPMt values were transformed to the unit normal distribution (SPMZ) and thresholded at $p = 0.001$ uncorrected for multiple comparisons. In the analysis, we examined the data for three types of main effect: (1) regions common to all semantic tasks versus syllable judgment, and vice versa, (2) regions showing differential activity for associative (location) judgments and perceptual (color) judgments, and (3) areas differentially activated for living things and artifact stimulus triads. Examination of the data was constrained to those regions activated by the semantic task relative to the control syllable task for comparisons of object domain and comparisons of type of knowledge to ensure that the regions showing differential activation for either task or domain were involved in semantic processing over and above control processes. Significance threshold for regions implicated in semantic tasks in previous studies (Mummery et al., 1996; Petersen et al., 1988; Vandenberghe et al., 1996; Warburton et al., 1996) (posterior, inferior parietal lobe; inferolateral and anterior temporal lobe; inferior frontal gyrus; premotor frontal cortex) was set at an uncorrected $p < 0.001$ (z score greater than 3.1). For all other brain regions, we report regions surviving the same threshold, but interpret only those areas that satisfy a corrected threshold of $p < 0.05$.

Appendix

Examples of stimuli used for each of the conditions (Note that in these examples, the correct response is always the left-hand stimulus. In the experiment, the correct response was randomly right or left.)

Animate	Inanimate
Color Judgment	
FLAMINGO: salmon, cherry	ARMOUR: tinfoil, vaseline
LIME: grass, lemon	BUS: fire engine, lifeboat
FROG: lettuce, onion	TRUMPET: crown, key
MOUSE: dove, crow	GOLFBALL: paper, ladle
Location Judgment	
APPLE: squirrel, badger	PAPER: ruler, rake
MOLE: termite, toad	COMB: lipstick, candle
TADPOLE: goldfish, salmon	SAUCEPAN: ladle, toothbrush
CABBAGE: strawberry, plum	BLACKBOARD: crayon, hoover
Syllable Judgment	
TANGERINE: butterfly, alligator	CHAIR: spade, canoe
HORSE: snake, holly	PAINTBRUSH: blackboard, typewriter
LETTUCE: spinach, conifer	CANNON: guitar, bikini
TREE: plum, lily	SWAN: pear, lion

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