Processing Objects at Different Levels of Specificity

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Abstract

■ How objects are represented and processed in the brain is a central topic in cognitive neuroscience. Previous studies have shown that knowledge of objects is represented in a feature-based distributed neural system primarily involving occipital and temporal cortical regions. Research with nonhuman primates suggest that these features are structured in a hierarchical system with posterior neurons in the inferior temporal cortex representing simple features and anterior neurons in the perirhinal cortex representing complex conjunctions of features (Bussey & Saksida, 2002; Murray & Bussey, 1999). On this account, the perirhinal cortex plays a crucial role in object identification by integrating information from different sensory systems into more complex polymodal feature conjunctions. We tested the implications of these claims for human object processing in an event-related fMRI study in which we presented colored pictures of common objects for 19 subjects to name at two levels of specificity—basic and domain. We reasoned that domain-level naming requires access to a coarser-grained representation of objects, thus involving only posterior regions of the inferior temporal cortex. In contrast, basic-level naming requires finer-grained discrimination to differentiate between similar objects, and thus should involve anterior temporal regions, including the perirhinal cortex. We found that object processing always activated the fusiform gyrus bilaterally, irrespective of the task, whereas the perirhinal cortex was only activated when the task required finer-grained discriminations. These results suggest that the same kind of hierarchical structure, which has been proposed for object processing in the monkey temporal cortex, functions in the human. ■

INTRODUCTION

How objects are represented and processed in the brain is a central topic in cognitive neuroscience. This issue has been studied from a variety of perspectives, ranging from neuroimaging studies with human subjects comparing the processing of different object categories (Moore & Price, 1999; Martin, Haxby, Lalonde, & Wiggs, 1995; Martin, Wiggs, Ungerleider, & Haxby, 1996; Tyler et al., 2003) or faces and objects (Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999; Kanwisher, McDermott, & Chun, 1997), to lesion studies in which behavioral deficits are related to lesion site (Tranel, Damasio, & Damasio, 1997; Tranel, Logan, Frank, & Damasio, 1997), to studies with nonhuman primates (Bussey, Saksida, & Murray, 2002; Buckley & Gaffan, 1998). An emerging theme from much of this research is that knowledge of objects is represented in a feature-based distributed neural system primarily involving occipital and temporal cortical regions, with different aspects of this system being more or less involved as a function of the processes that are required for the task at hand. However, the specific regions involved and their particular role within this system remains unclear.

Recently, there have been many studies that focus on the issue of whether different categories of object are represented and/or processed in different neural regions and what the basis of this differentiation might be (Martin & Chao, 2001). This approach has mainly derived from research in cognitive neuropsychology, where patients have been reported who have disproportionate deficits for different categories of knowledge, such as animals or fruits and vegetables (Warrington & Shallice, 1984). These dissociations have been interpreted as suggesting neural specialization for different types of knowledge or different types of feature (e.g., form, motion), which form the basis of knowledge representations. Neuroimaging studies investigating these claims fall into two broad classes—those that find evidence in support of neural differentiation for different object categories (Martin et al., 1995) and those that find evidence for a unitary distributed neural system (Devlin et al., 2002; Tyler et al., 2003). Perhaps the most prominent neural specialization account has been developed by Martin and Chao (2001). They claim that the different types of features that comprise an object (e.g., motion, visual form, color) are represented close to the sensory–motor systems that mediate the corresponding perceptual inputs and actions that they afford (e.g., grasping). For example, properties of visual form are represented close to the occipital cortex, while motion attributes are located in the left posterior middle temporal cortex directly anterior to the region containing

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neurons, which are claimed to be sensitive to motion perception. Different regions are more or less activated by different objects as a function of the features with which they are predominantly associated. Thus, tools activate a region of the left middle temporal gyrus, which is anterior to the region containing motion attributes, together with prefrontal regions associated with grasping, while animals preferentially activate areas of medial fusiform, which are involved in processing attributes of visual form, and regions of superior temporal sulcus associated with biological movement.

Damasio's ''convergence zone'' (CZ) hypothesis is similar in certain respects to the above account (Damasio, 1989; Tranel, Damasio, et al., 1997). According to the CZ hypothesis, processing an object activates a set of sensorimotor regions associated with its different attributes together with the intermediate regions of the association cortex that bind features together in what are termed *convergence zones*. Within this general framework, there is some regional specialization with, for example, the CZ for persons in right temporal pole and the CZ for tools in left temporal–occipital–parietal junction. CZs do not store complex configurations, they merely serve as pointers back to the sensory systems where content is represented; they are ''catalysts for the retrieval of the multidimensional aspects of knowledge which are necessary and sufficient for the mental representation of a concept of a given entity'' (Tranel, Damasio, et al., 1997, p. 1324). Simmons and Barsalou (2003) have recently proposed an elaboration of the CZ hypothesis, building on claims originally made by Damasio (1989), that includes an account of how objects can be processed at different levels of specificity. They propose that CZs are structured hierarchically such that the more posterior cortical regions contain CZs consisting of neurons that bind features of a specific type (e.g., color or shape), whereas CZs in more anterior regions combine features into increasingly complex configurations (e.g., color, shape, and visual motion) (Simmons & Barsalou, 2003). This kind of structure provides the basis for objects to be processed at different levels of specificity, with coarser-grained analysis recruiting more posterior neurons and finer-grained differentiation recruiting, in addition, more anterior regions in which neurons code for complex feature conjunctions.

Other research has approached the problem of object recognition in a slightly different way, by focusing on the issue of whether there are content specific systems for different kinds of objects (e.g., Gauthier et al., 1999; Kanwisher et al., 1997). The focus here has been on comparing faces and objects to determine whether they are processed by the same or different neural systems, with Kanwisher et al.'s (1997) work arguing for neural specialization for face processing. In contrast, Gauthier et al. (1999) have explored the hypothesis that face recognition and object processing differ in the kind of processes they typically engage. Whereas faces involve unique differentiation, objects are generally recognized at a less specific level, called the ''basic'' or ''entry'' level (e.g., identifying a picture as a monkey rather than a macaque). Studies have attempted to equate the level at which objects and faces are recognized by increasing expertise at differentiating between objects in a specific category (Gauthier et al., 1999). Under these conditions, recognizing objects at a more specific level activates the same neural regions as recognizing faces (i.e., fusiform face area [FFA]). This research suggests that the neural system underpinning the processing of objects varies as a function of the specificity of information that needs to be extracted from an object to perform a task.

The spirit of the CZ framework, of a hierarchical system in which neurons are coded for increasingly complex featural configurations going from the posterior to anterior regions the of temporal cortex, is present in recent work attempting to account for object processing in nonhuman primates (Bussey & Saksida, 2002; Murray & Bussey, 1999). In Bussey and Saksida's (2002) model of the object-processing system in the macaque, visual representations are hierarchically structured with posterior neurons in the inferior temporal cortex (IT) representing simple features and anterior neurons representing more complex conjunctions of features. A critical aspect of this account is the role of the perirhinal cortex within this hierarchical system. Although this ventromedial temporal region has long been considered important in object-recognition memory (Meunier, Bachevalier, Mishkin, & Murray, 1993; Buckley & Gaffan, 1998). Bussey and colleagues have recently proposed that it also plays a crucial role in object identification by integrating information from different sensory systems into more complex feature conjunctions. The basis for this claim is the finding that the perirhinal cortex integrates different kinds of information about an object and that lesions to the perirhinal cortex disrupt discrimination performance in the monkey, especially when the discrimination requires access to conjunctions of features (e.g., Bussey et al., 2002). Thus, the perirhinal cortex appears to plays a crucial role in object identification by integrating information within and across sensory systems into more complex polymodal feature conjunctions necessary for fine-grained discrimination among similar objects (Bussey & Saksida, 2002; Murray & Bussey, 1999; Tanaka, 1996; Desimone & Ungerleider, 1989). The entorhinal cortex, which borders the perirhinal cortex, is claimed to have similar functions to the perirhinal cortex in that lesions to either region disrupt object recognition in nonhuman primates and impair performance on spatial tasks (Meunier et al., 1993). Taken together, these different accounts suggest that the visual properties of objects are processed within a ventral processing stream primarily involving the occipital and temporal cortices, with more posterior regions

coding for simpler features, and more anterior regions coding for complex conjunctions of features that are necessary for fine-grained discrimination.

The present study attempted to relate the human and nonhuman primate work by directly testing the hypothesis that regions of the temporal cortex are differentially activated, depending on the level of detailed information that must be extracted from an object under different processing conditions. Subjects were presented with pictures of common objects and asked to name the same object at two levels of specificity; they either named an object at a basic level or at a domain level. Naming at a ''basic'' level required subjects to identify the object itself (e.g., to name a picture as a *donkey* or *hammer*), while naming at a ''domain'' level required them to name the domain to which the object belonged (e.g., to name a picture of a donkey or a hammer as a *living thing* or *manmade* object). We reasoned that to name an object at a basic level requires finer-grained differentiation among similar objects (e.g., to recognize and name a tiger as a *tiger* rather than a *lion* or *leopard*) and, according to Bussey and Saksida's (2002) account, should therefore activate neurons in the anterior temporal cortex responsive to complex feature conjunctions. In contrast, to name the same object at a domain level (e.g., to identify and name a tiger as a *living thing*) does not require such subtle differentiation and thus should primarily involve neurons in lateral and ventral regions of the IT that are responsive to simpler features.

Implications for Patients with Semantic Deficits

Damage to a hierarchically organized processing stream in the ventral temporal cortex could provide the basis for an explanation of the distinctive pattern of semantic deficits that have been reported for patients with herpes simplex encephalitis (HSE) and semantic dementia (SD). These patients have severe semantic impairments that compromise some aspects of their knowledge of concepts more than others. Typically, the shared properties of concepts tend to be preserved, making it possible for the patients to name an object at a domain or category level (Tyler & Moss, 2001; Moss, Tyler, Durrant-Peatfield, & Bunn, 1998; Hodges, Graham, & Patterson, 1995). For example, in confrontation-naming tasks, such patients have severe difficulty in naming a picture of a *cow* as a cow and instead tend to name it as an animal. This pattern of impairment has been explained in a variety of different ways, but many accounts have been at a functional level and have not been linked to a specific theory of the neural representation of conceptual knowledge (Caramazza & Shelton, 1998; Warrington, 1975, but see Martin et al., 1998). However, damage to different regions within a hierarchical processing system has the potential to explain this pattern of deficits in patients with semantic impairments. Damage at different points along the ventral temporal processing stream should affect the patient's ability to process an object at different levels of specificity. Damage to anteromedial temporal regions should affect the ability to perform fine-grained discriminations on objects (e.g., naming at a unique level) leaving coarse discriminations intact (e.g., naming at a category or domain level). However, damage to posterior regions should affect the ability to perform even coarse discriminations.

To test this hypothesis, we selected four patients with semantic deficits consequent upon HSE: JBR, RC, JH, and WL, who have been described in detail elsewhere (Tyler et al., 2002; Moss et al., 1998; Bunn, Tyler, & Moss, 1997; Warrington & Shallice, 1984). All of the patients had structural MRI scans. For three of the patients (JBR, RC, and JH), the scans have been analyzed using voxel-based morphometry to determine changes in gray or white matter density (Ashburner & Friston, 2000). This analysis showed that the patients had extensive abnormality in the bilateral medial temporal structures including the rhinal (perirhinal and entorhinal) cortex (Gitelman, Ashburner, Friston, Tyler, & Price, 2001), while posterior temporal regions were relatively preserved. We first tested the patients to determine the extent to which they showed greater impairment for tasks involving fine-grained discrimination. We then compared the spatial extent of activations obtained in the present fMRI study on healthy subjects with the lesion site in the patients to address the question of whether damage to medial temporal regions, especially the rhinal cortex, affects a patient's ability to perform tasks that require fine-grained discrimination.

RESULTS

In this task, healthy volunteers were presented with a series of common objects and asked to silently name each one at either a basic (e.g., monkey) or domain (e.g., living thing) level.

Neuroimaging Study

Localization of the Perirhinal and Entorhinal Cortices

We identified the location of the perirhinal and the entorhinal cortices with reference to descriptions provided by Insausti et al. (1998) and Reber, Wong, and Buxton (2002). The entorhinal cortex (Brodmann's area 28/34) occupies the medial, anterior portion of the parahippocampal gyrus. It extends laterally to the medial bank of the collateral sulcus, where it borders the perirhinal cortex (see below). For the purpose of our fMRI analysis, we took the gray area of the anterior hippocampus as the superior boundary. The inferior boundary was defined by the ventral edge of the parahippocampal gyrus adjacent to cerebrospinal fluid. The

anterior boundary occurred at the anterior edge of the amygdala, and the posterior boundary was located in line (in the coronal plane) with the midpoint of the hippocampus.

The perirhinal cortex occupies the anterior portion of the parahippocampal gyrus around the collateral sulcus (BA 35, 36), lateral to the entorhinal cortex. For fMRI purposes, the superior boundary was defined, as for the entorhinal cortex, by the hippocampus, with the inferior boundary represented by the ventral edge of the parahippocampal gyrus adjacent to cerebrospinal fluid. Throughout its anterior–posterior extent, it is bordered laterally by the fusiform gyrus (BA 20). The anterior edge was defined as the anteromedial extent of the temporal pole (although it should be noted that fMRI is not currently able to adequately measure IT activity in regions anterior to the amygdala). As with the entorhinal region, the posterior edge of the perirhinal cortex was taken to be in line with the center of the hippocampus (along its posterior–anterior extent),

Basic-level Naming

Basic-level naming compared against baseline produced two large clusters of bilateral activation. The first encompassed the entire posterior to anterior extent of the left fusiform gyrus (BA 19/37/36), also extending to involve the inferior and middle occipital gyrus (BA 18) and calcarine sulcus (Table 1Ai and Figure 1Ai). The second cluster occupied an analogous, but smaller, region of the right hemisphere, involving the posterior and anterior aspects of the fusiform gyrus (BA 19/37) and the inferior and middle occipital gyrus (BA 18). To

Table 1. Brain Areas of Activity for the Contrast of (A) Basic-level Naming Minus Baseline and (B) Domain-level Naming Minus Baseline

		Voxel Level		*Coordinates*		
Regions	*Cluster Extent*	$P_{corrected}$	*t*	*x*	*y*	*z*
A. Basic Level Minus Baseline						
(i) Threshold = .001						
L fusiform gyrus (BA 37)	**3072**	**.004**	**8.31**	**−34**	**−56**	**−24**
L fusiform gyrus (BA 37)		.005	8.04	−44	−60	−22
L inf. occipital gyrus (BA 18)		.008	7.70	−26	−90	−2
R inf. occipital gyrus (BA 19)	**1911**	**.042**	**6.60**	**42**	**−82**	**−12**
R fusiform gyrus (BA 37)		.066	6.30	−34	−48	−18
R inf. occipital gyrus (BA 17)		.078	6.19	22	−98	−6
(ii) With SVC for L temporal lobe						
L entorhinal cortex (BA 28)	***123***	***.152***	***4.73***	***−22***	***−6***	***−20***
B. Domain Level Minus Baseline						
(i) Threshold = 0.001						
L inf. occipital gyrus (BA 18)	**1893**	**.001**	**9.09**	**−32**	**−90**	**−2**
L inf. Occipital gyrus (BA 18)		.007	7.75	−30	−88	−12
L fusiform gyrus (BA 19)		.040	6.57	−32	−70	−18
R fusiform gyrus (BA 19/37)	**1430**	**.077**	**6.13**	**26**	**−58**	**−20**
R fusiform gyrus (BA 37)		.188	5.53	32	−40	−22
R mid. occipital gyrus (BA 18)		.292	5.98	32	−90	6
(ii) With SVC for L temporal lobe						
		(no additional activations)				

Activations shown for (i) whole brain analysis and (ii) with SVC for the left temporal lobe. All clusters are significant at $p < .05$ after statistical correction are reported. Cluster extents are presented at an uncorrected threshold of .001. The highest three peaks within an extent are shown on subsequent lines, with the most significant shown in **boldface**. Activations after SVC are presented in *italics*. L = left, R = right, inf. = inferior, mid. = middle.

investigate further the regional activation in the temporal lobes, we applied an SVC to the temporal cortex. This produced significant activation in the perirhinal, extending into the entorhinal, cortex (BA 28, 35; Table 1Aii and Figure 1Aii), but only in the left hemisphere. At a lower threshold ($p < .01$, uncorrected, and only clusters that survived $p < .05$ correction for multiple comparisons across the entire brain), the cluster in the left hemisphere extended anteriorly and medially to include a greater part of the fusiform gyrus and the perirhinal cortex, the amygdala, and the hippocampus. Activation in the left calcarine (BA 17) gyrus was also significant at this level (Figure 1Aiii).

Domain-level Naming

Domain-level naming compared with baseline engaged posterior regions, including the inferior occipital gyrus and peristriate regions of the occipital cortex (BA 18, 19) and fusiform gyrus (BA 19, 37) bilaterally, although, again, activation was greater in the left hemisphere than in the right. The significant activation in the right hemisphere extended more anteriorally than

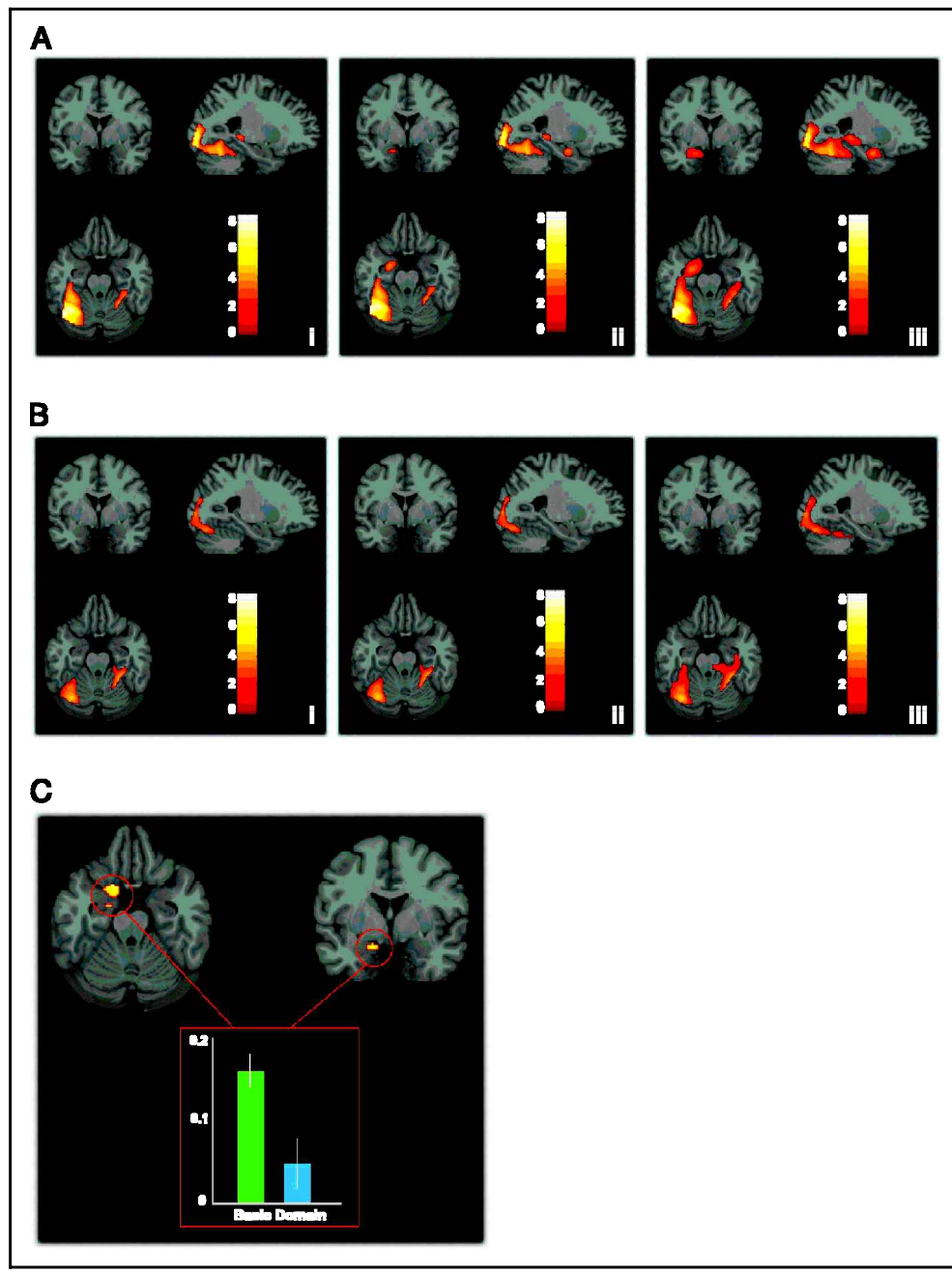

Figure 1. (A) Significant activations for the contrast of basic-level naming minus baseline are shown superimposed on a T1 anatomical image transformed into the standard stereotactic space of Talairach and Tournoux (1988). The color bars indicate strength of activation (voxel level *T* values). The areas shown survived $p < .05$ correction for multiple comparisons at the cluster level and were thresholded at (i) .001, (ii) .001 (with SVC for the left temporal cortex), and (iii) .01. We use neurological convention where left = left. (B) Significant activations for the contrast of domain-level naming minus baseline are shown superimposed on a T1 anatomical image transformed into the standard stereotactic space of Talairach and Tournoux. The color bars indicate strength of activation (voxel level *T* values). The areas shown survived $p < .05$ correction for multiple comparisons at the cluster level and were thresholded at (i) .001, (ii) .001 (with SVC for the left temporal cortex), and (iii) .01. We use neurological convention where left = left. (C) Significant activations for the contrast of basic level minus domain-level naming are shown superimposed on a T1 anatomical image transformed into the standard stereotactic space of Talairach and Tournoux. The activations shown were thresholded at .001 and survived $p < .05$ correction for multiple comparisons at the cluster level. The plot shows a representative effect size in the two conditions in the perirhinal cortex. We use neurological convention where left = left.

on the left and encompassed fusiform gyrus (BA 19/37/36), extending superiorly to include superior aspects of the inferior and middle occipital gyri (BA 18). Activation in this condition did not extend as far anteriorly (or laterally) as that resulting from basic-level naming (Table 1Bi and Figure 1Bi). SVC in the left temporal cortex did not produce any additional significant areas of activation (Table 1Bii and Figure 1Bii). Domain-level naming did not involve any aspect of the perirhinal cortex (BA 35/36) even at a lower threshold (Figure 1Biii).

In a direct comparison between basic against domain-level naming, basic-level naming produced significantly more activation in the left entorhinal and perirhinal cortices (BA 35; Table 2A and Figure 1C). Domain-level naming produced more activation than basic-level naming in the middle frontal gyrus but not in any region of the temporal cortex (Table 2B).

To further examine the pattern of activation during basic- and domain-level naming throughout object-processing regions, we plotted percent signal change for each condition relative to baseline at 12 points along the posterior to anterior extent of the inferior temporal and occipital cortices (Figure 2). In the most posterior region of the fusiform gyrus BA 18, roughly equivalent to visual area V2 (Amunts, Malikovic, Mohlberg, Schormann, & Zilles, 2000; Clarke, 1993), the response for basic- and domain-level naming relative to baseline was virtually identical. In more anterior extrastriate cortex (BA 19 and posterior BA 37), areas associated with color stimulation (Mesulam, 1998; Chao et al., 1997), activation was also undifferentiated by task demands. This region overlaps with the lateral occipital complex (Malach et al., 1995), which responds preferentially to pictures of identifiable objects relative to visual textures without obvious form interpretations (Grill-Spector, Kourtzi, & Kanwisher, 2001). Malach et al. (1995) found no evidence for differential activation in the lateral occipital complex as a function of familiarity (pictures of real-life objects vs. degraded, nonidentifiable objects), suggesting that the region is not involved in the semantic stages of representation. Similarly, in a review of the literature, Grill-Spector et al. (2001) conclude that the lateral occipital complex functions as a general-purpose system for the analysis of object shape and is not associated with a conceptual level of representation. It is not surprising, therefore, that there is equal activation for domain- and basic-level naming in these posterior areas (Figure 2i), given that the same visual stimuli were presented in each of these conditions.

In more anterior regions of the fusiform gyrus (anterior BA 37 and 20), there is a progressively increasing discrepancy of signal change during basic-level naming relative to domain-level naming (Figure 2ii). There is strong evidence for successive object-processing stages throughout the posterior to anterior aspects of the fusiform gyrus (Gauthier et al., 1999; Grill-Spector et al., 1998). The present findings suggest that, in addition to purely stimulus-driven activation of anterior temporal areas, recruitment in this region may also reflect specific task demands in relation to the nature of the discriminations that the subject must make. The greatest difference in signal change during basic-level naming relative to domain-level naming was found in the most anterior temporal regions, corresponding to the entorhinal and perirhinal cortices (Figure 2iii), consistent with studies of object discrimination performance in nonhuman primates (e.g., Bussey et al., 2002; Murray & Bussey, 1999).

Relating Activations to Lesion Site

Patients: Behavioral Data

The neuroimaging results support the hypothesis that the rhinal cortex (perirhinal and entorhinal cortices) is involved in processing objects when relatively fine-grained discrimination is involved. The question we

Table 2. Brain Areas of Activity for the Contrast of (A) Basic-level Naming Minus Domain-level Naming and (B) Domain-level Naming Minus Basic-level Naming

		Voxel Level		*Coordinates*		
Regions	*Cluster Extent*	$P_{corrected}$	*t*	*x*	*y*	*z*
A. Basic Level Minus Domain Level						
L entorhinal cortex (BA 34)	**226**	**.152**	**5.75**	**−14**	**8**	**−18**
L entorhinal cortex (BA 28/34)		.904	4.07	−10	8	−18
B. Domain Level Minus Basic Level						
R mid. frontal gyrus (BA 8)	**300**	**.655**	**4.58**	**40**	**18**	**40**
R mid. frontal gyrus (BA 8)		.768	4.38	30	10	38

All clusters significant at $p < .05$ after statistical correction are reported. Cluster extents are presented at an uncorrected threshold of .001. All peaks within an extent are described, and shown on subsequent lines, with the most significant shown in **boldface**. L = left, R = right, mid. = middle.

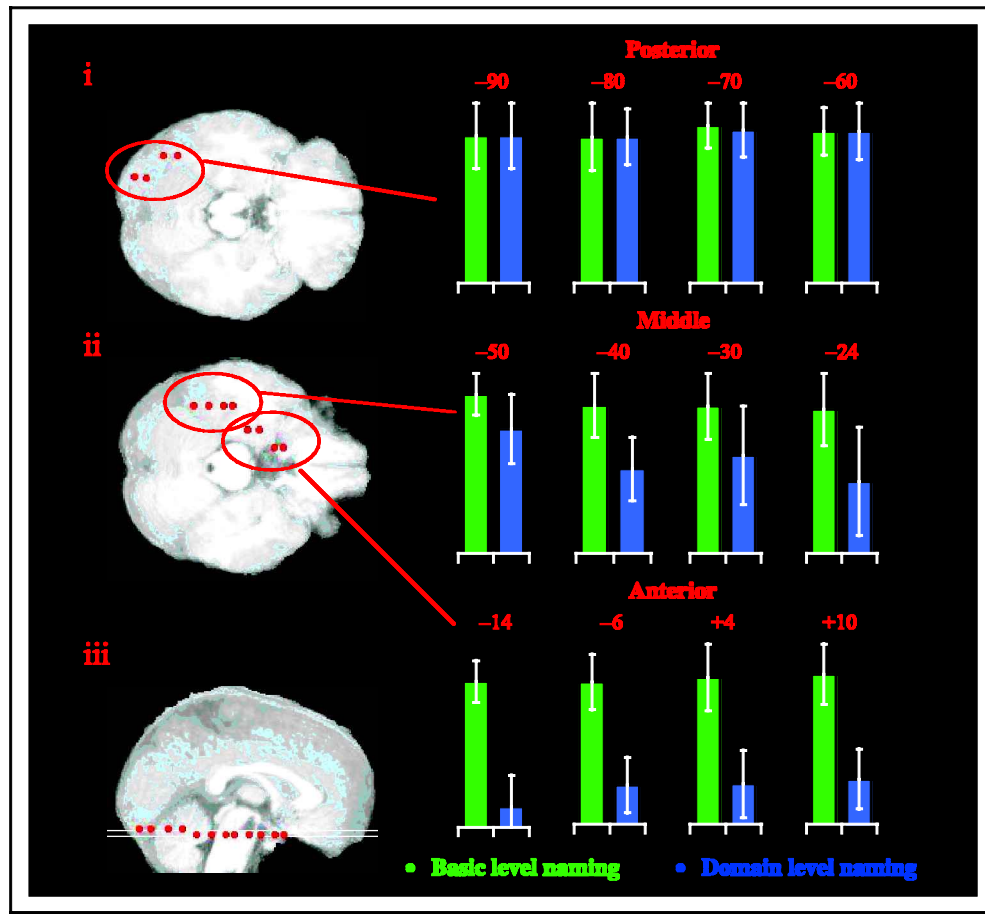

Figure 2. Plots of signal change (with standard error bars) for basic- and domain-level naming relative to baseline at 12 points along the posterior to anterior extent of the left inferior occipital and temporal cortices (values shown in arbitrary units). See text for additional detail. The approximate location of each point is shown superimposed on axial (i and ii) and sagittal (iii) slices of a normalized brain. Figures above each plot indicate the position on the *y* (coronal) axis in MNI space.

now address is whether the four HSE patients have damage to the same cortical region that is selectively activated by naming objects at a basic level in the neuroimaging study. We first report behavioral data on each of the patients establishing that they exhibit a pattern of poorer performance on tasks that require finer-grained discrimination. We focus on object processing to ensure comparability between the behavioral tests and the neuroimaging study.

Details of the patients' performance across a range of tasks has been reported previously (Tyler et al., 2002; Moss et al., 1998; Bunn et al., 1997). Although the patients are not cognitively impaired, as evidenced by their scores on the Ravens Progressive Matrices that are within the normal range, they have profound semantic impairments, whether processing words or pictures (Tyler et al., 2002). In this article, we report data from two picture-processing studies that involve naming, and are particularly relevant for the issues we are considering here.

In the first picture-naming task, patients were presented with colored photographs of common objects and were asked to name the objects at a basic level. There were 227 pictures taken from 13 different categories, including animals, insects, birds, fruits, vegetables, foods, body parts, vehicles, toys, household tools, clothing, musical instruments, and furniture (see Bunn, Tyler, & Moss, 1998, for details). All of the patients were significantly impaired on naming the pictures correctly at a basic level JBR, RC, and WL were especially poor at basic-level naming JBR 42%, RC 38%, and WL 26% correct) and although JH's performance was somewhat better (60%), it was still well below that of the controls. The results from the patients contrast sharply with that from healthy controls, who make an average of only 5% naming errors (Bunn et al., 1998). The patients tended to make two types of error; either they produced category coordinate errors (i.e., they named a picture of a *cow* as a horse) or they made superordinate errors (i.e., they named a *cow* as an animal). Fifteen percent of JBR's errors were superordinate errors and 26% were category coordinates; JH produced 39% superordinate errors and 47% category coordinates; RC made 39% superordinate errors and 38% category coordinates; made WL 26% superordinate errors and 35% category coordinates. Both types of error indicate that the patients have difficulty discriminating between similar objects. The remaining errors tended to be cases where the patients responded "don't know" to a picture.

We were subsequently able to test two of the patients RC and JBR in a picture-naming study that was directly comparable to that used in the neuroimaging study (the other two patients were not avail-

able for further testing). The patients were presented with colored photographs from eight different categories and were asked to name each photograph at two different levels of specificity—at a basic level and at a domain level (living thing vs. manmade object). As predicted from their performance on the first naming task, they were considerably impaired on naming at a basic level and very accurate on naming at a domain level. JBR scored 34% correct on basic-level naming and 94% correct on domain-level naming. Similarly, scored RC 30% correct on basic-level naming and 99% on domain-level naming. Perhaps, most importantly, as in the earlier study, the errors that the patients made in the basic-level naming task were very different from the kinds of responses made by healthy subjects; they either named a picture at a category level (i.e., they named a *hammer* as a tool or a *horse* as an animal) or they made within-category errors (e.g., they named a picture of a *microwave* as a record player, a picture of a *banana* as a tomato, or a *rabbit* as a snake). Of RC's naming errors, 44% consisted of category-level naming rather than basic-level naming and 37% were within-category errors. In contrast, very few (8%) of JBR's errors consisted of category names, and almost all of them (81%) were within-category or within-domain category errors (e.g., naming a picture of a donkey as a wolf, a dolphin as a frog, or a microwave as a record player). Both types of response indicate an inability to accurately differentiate between objects.

Patients: Neuroanatomical Data

Figure 3 shows the T1 anatomical images obtained on a 2-T MR scanner for the four HSE patients.[1] The images were transformed into the standard stereotaxic space of Talairach and Tournoux (1988), within SPM. The images were spatially normalized with 12 linear affine transformations and $7 \times 8 \times 7$ nonlinear basis functions. To prevent image distortions, the lesioned areas were excluded (masked) from the nonlinear calculations (Brett, Leff, Rorden, & Ashburner, 2001). Lesion masks were constructed with MRIcro (www.mricro.com). All patients demonstrated extensive damage in the medial and anterior temporal regions, including the hippocampus, amygdala, entorhinal, perirhinal, and parahippocampal cortices. In each case, the lesion also extended to involve orbitomedial frontal regions, consistent with recent neuropathological and neuroimaging findings in HSE (e.g., Kopelman, 2002; Colchester et al., 2001; Kapur, Craik, Tulving, & Wilson, 1994). Although each patient showed bilateral atrophy, in one patient (WL), the damage was predominantly left-sided. The extent of more lateral temporal involvement varied among the patients, although middle (BA 21) and superior temporal gyri (BA 38) changes are present in all cases.

Figure 3 presents activation outlines for domain-level naming minus baseline (red) and basic-level naming minus baseline (green) in healthy subjects (thresholded at $p = .01$ and corrected at .05 at a cluster level), superimposed on inferior axial sections of each patient's brain. In all cases, the anterior regions of activation, which are associated with basic-level naming, are severely damaged in these patients, but the more posterior regions of activation, associated with domain-level naming, are relatively preserved. It follows that these areas identified in the normal brain as involved when fine grained discriminations are necessary (which critically include the perirhinal and entorhinal cortices), may underpin the patients' failure to correctly name objects. However, those regions activated during more general, domain-level naming are preserved in these patients, which may explain their unimpaired performance on this type of task.

DISCUSSION

The neuroimaging results show clear evidence for differences in cortical activation when processing the same object at different levels of specificity. When the task requires more detailed information to differentiate between similar objects, anteromedial temporal regions in the left hemisphere are recruited, supporting claims that neurons in this region integrate information in more complex configurations, thus providing the basis for finer-grained discriminations. When processing the same object does not require this degree of differentiation, activation remains limited to bilateral posterior regions of IT including the fusiform gyrus. This finding supports recent claims from work with nonhuman primates for the role of the perirhinal cortex in object identification. Although the perirhinal cortex has long been considered to be important in object-recognition memory (Buckley & Gaffan, 1998; Meunier et al., 1993), research with nonhuman primates has shown that perirhinal lesions disrupt discrimination performance (Bussey et al., 2002). Thus, the evidence suggests that this region is important for fine-grained discrimination and for the resolution of feature ambiguity.

Damasio and colleagues' (Tranel, Damasio, et al., 1997; Damasio, 1989) account of the role of different aspects of the human temporal cortex is broadly consistent with the account we are proposing here. They claim, based on lesion–behavior associations, that there are differences in the roles of the anterior and posterior regions of the temporal cortex. Processing simple combinations of visual attributes of objects involves posterior regions of the temporal cortex whereas more anterior temporal sites are involved in combining multimodal features enabling more complex differentiation. Damasio and colleagues (Grabowski et al., 2001) further differentiate between the functions of medial temporal and polar regions, claiming that the left temporal pole is a mediational system for word retrieval and thus unique-level naming recruits this

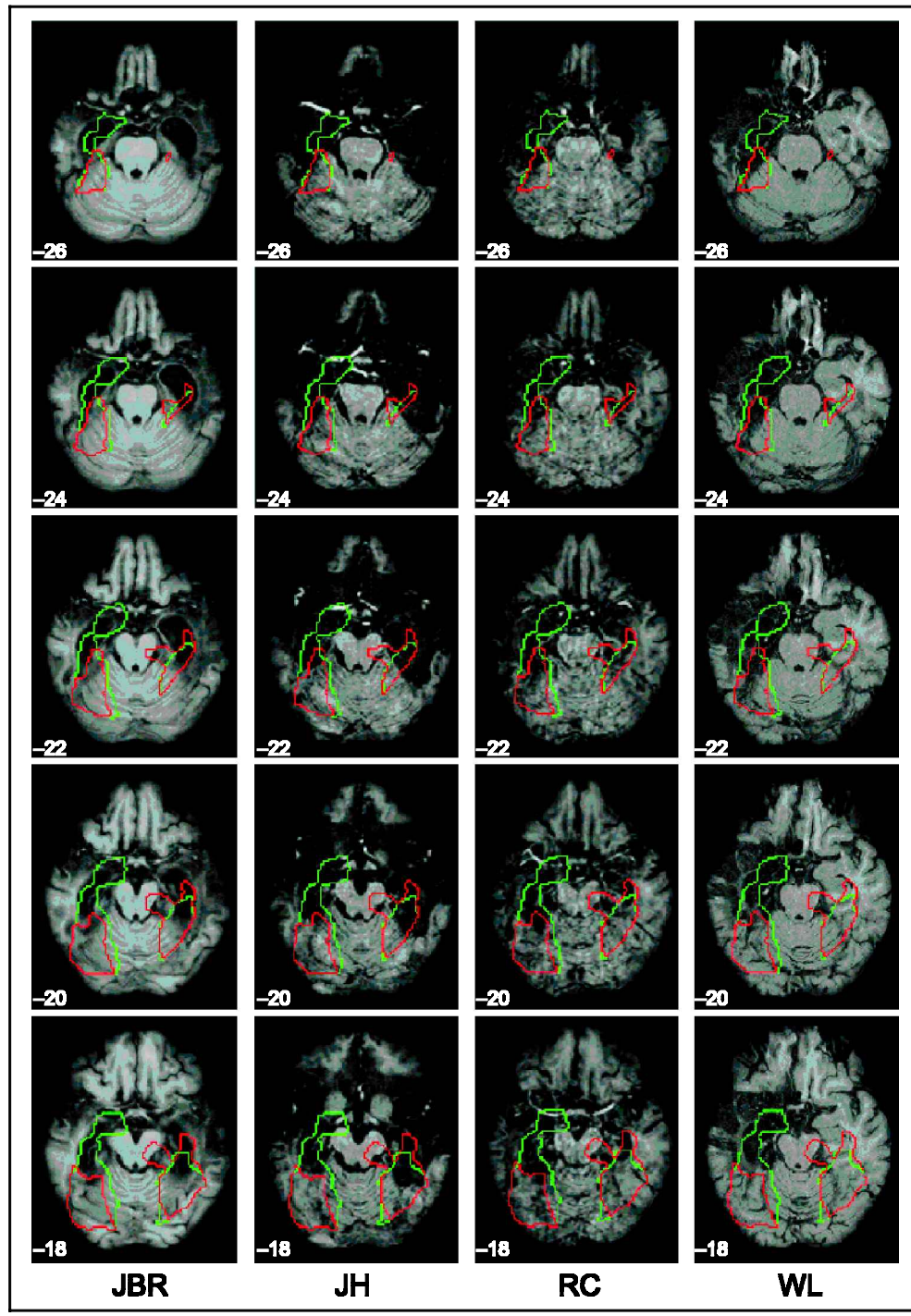

Figure 3. Outlines of the significant activations for the contrasts of domain-level naming minus baseline (in red) and basic-level naming minus baseline (in green) are shown superimposed on T1 anatomical images of four HSE patients. The images were transformed into the standard stereotactic space of Talairach and Tournoux (1988). The activations shown were thresholded at .01 and survived $p < .05$ correction for multiple comparisons at the cluster level. We use neurological convention where left = left.

region. In contrast, the right temporal pole is involved in unique recognition. Thus, patients with bilateral anterior temporal damage have particular difficulty in recognizing individual faces because they cannot recognize objects at a basic level (but are relatively intact at category- or domain-level recognition). There is considerable overlap in the general structure of the Bussey and Saksida and Damasio et al.'s account, with the main difference being concerned with whether the temporal poles or the perirhinal cortex are more critically involved in processing unique objects. In the present study, we were not able to image the temporal poles, given the susceptibility artifacts present when this region of the cortex is imaged using fMRI (Devlin et al., 2000) and therefore could not determine whether they were also activated.

The differences in activation we find in the neuroimaging study provide a possible basis for explaining the patterns of deficits observed in patients with semantic impairments following HSE. The four patients described in this study have a profile of damage that is typical of HSE—namely, damage is extensive in medial

temporal structures, including the perirhinal and entorhinal cortices (Gitelman et al., 2001). In addition, the patients exhibit a specific behavioral impairment in which they can process the general properties of objects while being severely impaired when making finer-grained discriminations. Thus, in picture-naming tasks, they show profound difficulties when asked to name a picture at a basic level, but are relatively unimpaired when naming the same picture at a domain level. The association of damage to anteromedial structures and difficulty in naming at a basic level, which, we argue, involves finer-grained discrimination, suggests that anteromedial regions of the left hemisphere are critically involved in processes of finer-grained differentiation in processing objects.

In conclusion, the present results strongly support claims for an object-processing pathway extending from the occipital cortex, along the fusiform gyrus and into the medial regions of the anterior temporal cortex. The differential recruitment of cortical regions as a function of processing demands we have identified in this study suggests that processing an object is not an invariant process that is completely driven by stimulus. Instead, the details that are extracted from an object depend on the nature of the discriminations that the observer needs to make.

METHODS

Neuroimaging Study

Subjects

Nineteen right-handed subjects (aged between 20 and 39 years; 9 men and 12 women) participated in this study. All gave informed consent. The study was approved by Addenbrookes NHS Trust Ethical Committee.

Materials and Procedure

Stimuli consisted of 144 colored photos of common objects presented in the middle of the screen on a plain white background. We collected relevant statistics on the set of items either from published norms or from pretests carried out in our laboratory (Table 3). We also included 45 baseline events, consisting of a fixation cross. Each event lasted 2.5 sec. In the test trials, an event consisted of a picture presented for 500 msec followed by a 2.0-sec response delay. In the baseline condition, the fixation cross was presented for 1.5 sec followed by a 1-sec delay. Test and baseline trials were pseudorandomly ordered. Scanning was carried out on a 3-T Bruker Medspec Avance S300 system at the Wolfson Brain Imaging Centre, Cambridge, England. A gradient-echo EPI sequence was used (TR = 3200 msec, TE = 30 msec, flip angle 90°, FOV 25 × 25 cm, 21 oblique slices, 4 mm thick), 1 mm gap between slices, 128 × 128 in-plane resolution, 152 repetitions with head coils, 200 kHz bandwidth, and spin echo-guided reconstruction. T1-weighted scans were acquired for anatomical localization.

Table 3. Statistics for the Stimuli

	Mean
Frequency (per million)[a]	20
Number of syllables	2
Visual familiarity[+]	3.2
Visual complexity[+]	2.6
Word familiarity[b]	490
Imageability[b]	601
Concept agreement[c]	95%

[a]From Baayen and Pipenbrook (1995).

[b]From Coltheart (1981).

[c]Based on overt naming data obtained in our laboratory.

[+]Pretests conducted in our laboratory.

In two separate sessions, with session order counterbalanced across subjects, subjects were asked to silently name each picture at two levels of specificity. Naming at a ''basic'' level required subjects to identify the object itself (e.g., to name a picture as a *donkey* or *hammer*), while naming at a ''domain'' level required them to name the domain to which the object belonged (e.g., to name a picture of a donkey or a hammer as a *living* or *manmade* object). These two domain names were chosen as they have the same syllabic length (two syllables) and similar phonemic lengths (five vs. six phonemes). During the baseline trials, subjects were instructed merely to fixate on the cross. Presentation and timing of stimuli were controlled by DMDX software (Forster & Forster, 2003). Each session was preceded by a short practice session of 20 items before scanning started. Responses to all stimuli were covert to avoid excess movement in the scanner. Given that we were unable to obtain naming data while subjects were in the scanner, we carried out pretests prior to scanning to ensure that each picture consistently elicited a single name (i.e., to ensure high concept agreement; see Table 3).

Test and baseline trials were arranged into a pseudorandom order where no more than four living or manmade pictures appeared in a row. This order was different for the two tasks but the stimuli presented were the same.

Data Analysis

Data analysis was performed using SPM99 software (Wellcome Institute of Cognitive Neurology, www.fil.ion.ucl.ac.uk), implemented in Matlab (Mathworks, Sherborn, MA). Preprocessing of the data involved slice timing correction and image realignment to account for

different slice acquisition times and head motion, followed by spatial normalization to a standard EPI template based on the Montreal Neurological Institute (MNI) reference brain, using 7 × 8 × 7 nonlinear basis functions. The images were then smoothed with an isotropic 12-mm FWHM Gaussian kernel. The data for each subject were analyzed using the general linear model (Friston et al., 1995). Two sessions and four variables were modeled (basic-level naming and baseline for the first and domain-level naming and baseline for the second session) using the canonical hemodynamic response function with temporal derivatives. The first four scans of each time series were discarded to allow for T1 equilibrium before the test trials started. The time series in each voxel were highpass-filtered to remove low-frequency noise. We entered three variables (familiarity of the name of each item, imageability, and visual complexity of the picture) as parametric modulators with linear expansion. Contrast images from each subject were combined into a group random effects analysis (RFX). For the calculation of basic- and domain-level naming versus their respective baselines at the RFX level, we used one sample t tests and for the comparison of basic- versus domain-level naming we used a paired t test since the two variables were modeled in different experimental sessions. Results were thresholded at $p < .001$, uncorrected, and only clusters that survived $p < .05$ correction for multiple comparisons across the entire brain volume were considered significant. SPM coordinates are given in MNI space, so to identify regions, we converted the coordinates to Talairach space with a nonlinear transform (Brett et al., 2001). Peak voxels are reported in MNI coordinates.

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The data reported in this experiment have been deposited in the fMRI Data Center (http://www.fmridc.org). The accession number is 2-2003-1143R.

Note

1. The patients were scanned at the Functional Imaging laboratory, London. We thank Dr. C. Price for her cooperation.

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