

Regional brain activations differ for semantic features but not categories

Andy C. H. Lee,^{1,CA} Kim S. Graham,¹ Jon S. Simons,¹ John R. Hodges,^{1,2} Adrian M. Owen^{1,3} and Karalyn Patterson¹

¹MRC Cognition and Brain Sciences Unit, 15 Chaucer Road, Cambridge, CB2 2EF; ²University Neurology Unit, University of Cambridge, Box 165 and ³Wolfson Brain Imaging Centre, Addenbrooke's Hospital, Cambridge, CB2 2QQ, UK

^{CA}Corresponding Author

Received 7 May 2002; accepted 13 May 2002

Is human semantic knowledge neurally organised according to either category (e.g. living vs non-living) or attribute type (e.g. perceptual vs non-perceptual information)? Normal subjects were scanned using PET during a novel semantic production task, in which they generated either perceptual or non-perceptual information in response to names of living or non-living concepts. Analyses of blood flow in the temporal lobes revealed no significant differences associated with responses to living vs non-living con-

cepts. Comparisons between retrieval of perceptual vs non-perceptual information, however, revealed significantly greater blood flow in left posterior inferior temporal cortex and right fusiform cortex associated with perceptual information and in left middle temporal cortex with non-perceptual information. These findings support a primarily attribute-based neural organisation of semantic knowledge. *NeuroReport* 13:1497–1501 © 2002 Lippincott Williams & Wilkins.

Key words: Functional neuroimaging; PET; Semantic memory; Temporal lobes

INTRODUCTION

Semantic memory is our store of general knowledge of the world, facts, concepts, objects and the meanings of words. The existence of relatively selective impairments to either living or non-living object knowledge in some patients with semantic memory deficits suggests that the neural basis of semantic memory may be organised according to categories of knowledge (e.g. living vs non-living; for review see [1]). An alternative explanation of these findings is that the neural organisation of semantic knowledge is based upon the type of semantic attribute, (e.g. perceptual vs non-perceptual) and that various property types are differentially important in the representation of objects from different categories [2–4]. Warrington and Shallice [4] argued that living things are primarily distinguished on the basis of visual feature information while non-living things are primarily distinguished on the basis of functional features. Thus, damage to neural regions that mediate visual information should result in disproportionately impaired knowledge regarding living things, while damage to neural regions more critical for functional information should have a greater impact on knowledge regarding non-living things.

This debate has been addressed by a number of functional neuroimaging studies that have looked for differences in cortical activity in normal individuals during semantic tasks involving stimuli that are from different categories or that emphasise different attributes. While a number of studies have found differences related to category, it has been noted

that such effects have not been consistently observed [5], and some of the significant differences do not appear to be reliable at a statistical threshold corrected for multiple comparisons [5,6]. Several studies that have failed to find activation differences between categories [5,7] have concluded that a single distributed semantic neural system may represent all categories of knowledge [5]. Specific regions of increased activity associated with different feature types have been somewhat more consistently observed, in particular, left posterior temporal lobe regions such as the fusiform gyrus (BA 37) for visual information processing [8–11] and middle temporal regions, such as the left middle temporal gyrus (BA 21) and superior temporal sulcus (BA 39/22), for functional and motion information processing (for review see [12]).

The present study was designed to address this issue of the neural organisation of semantic knowledge in the temporal lobes with PET and a novel semantic generation task. The vast majority of imaging studies in this area, employing either simple semantic judgement tasks (e.g. 'is this object living or non-living?'), or naming tasks in response to visually presented words or pictures, have not required the explicit retrieval of detailed or extensive semantic information. In the current paradigm, subjects were scanned while retrieving perceptual or non-perceptual information about living or non-living concepts in response to the auditory presentation of their names. This novel approach enabled us to assess regional cerebral blood flow

associated with aspects of these concepts that the subjects themselves considered crucial. A comparison of regional cerebral blood flow associated with the two stimulus (concept) types (i.e. living *vs* non-living) should identify any activation differences related to semantic category. In contrast, a comparison of regional cerebral blood flow associated with the two response (attribute) types (i.e. perceptual *vs* non-perceptual) should identify any activation differences related to semantic attribute.

MATERIALS AND METHODS

Subjects: Twelve healthy right-handed subjects (four female) were scanned in total. However, two subjects' data could not be used due to excessive head movement or unsatisfactory task performance during scanning (see Results). The age of the subjects varied between 42 and 68 years (mean 59 years). Prior to scanning all subjects were medically screened by a qualified clinician and gave written consent for participation in the study after its nature and possible consequences were explained. The study received ethical approval from the Cambridge Health Authority Local Research Ethics Committee.

Image acquisition: Twelve PET scans (two for each experimental condition) were obtained for each subject using a GE Advance PET system (General Electric Medical Systems, WI, USA), although only eight of these are relevant to the current study. This system produces 35 simultaneous image slices per scan at an intrinsic resolution of $\sim 4.0 \times 5.0 \times 4.5$ mm. For each scan, regional cerebral blood flow (rCBF) was measured using the bolus $H_2^{15}O$ method. Subjects received a 20 s i.v. bolus of $H_2^{15}O$ through a forearm cannula at a concentration of 300 Mbq/ml and a flow rate of 10 ml/min before each scan. With this method, each scan provides an image of rCBF integrated over a period of 90 s from when the tracer first enters the cerebral circulation.

Data pre-processing and analysis: The scans were pre-processed individually and then combined with the other subjects' scans for collective statistical analysis using the Statistical Parametric Mapping 99 package (SPM99, Wellcome Dept of Cognitive Neurology, London, UK). For pre-processing, the functional images were first realigned as implemented in SPM99 to create a mean image. This was then normalised for global CBF value and also spatially normalised to conform to the standard Montreal Neurological Institute (MNI) brain template. Finally, each image was spatially smoothed using an isotropic Gaussian kernel at 16 mm.

For the statistical analysis, the global CBF value was averaged across subjects for each activation state. Blood flow changes between each condition were then estimated for each voxel according to the general linear model, as implemented in SPM99. Scan order and head movement were entered as covariates of non-interest in the analysis [13]. Given that activations within temporal cortex were of primary interest, a region of interest (ROI) analysis was carried out in the temporal lobes bilaterally. This ROI was defined using MRICro [14] by an experienced neurologist blind to the PET data and encompassed the inferior and

middle temporal gyri and the ventral surface of the temporal lobe (posterior limit: $y = -72$). Activations within the temporal lobes that survived an intensity threshold of $p \leq 0.05$ (corrected for multiple comparisons) are reported. This threshold, based on 3-D Gaussian random field theory, predicts the likelihood of obtaining a false positive in an extended 3-D field. To estimate the Brodmann areas (BA) corresponding to regions of significant activation, the MNI coordinates provided by SPM99 were transformed (see <http://www.mrc-cbu.cam.ac.uk/Imaging/mnispace.html>) to Talaraich atlas coordinates [15].

Experimental procedure: A 2×2 factorial design was used and consisted of four different experimental tasks: living-perceptual (LP), non-living-perceptual (NLP), living-non-perceptual (LNP) and non-living-non-perceptual (NLNP). Each task was performed twice with a different set of stimuli each time. The order in which the tasks were scanned was varied across the subjects. The subjects were given instructions and adequate practice with these tasks before entering the scanner.

The stimuli used in all the tasks were highly imageable English nouns balanced across semantic domains for familiarity and syllable length. These words were read out by the experimenter at a rate of one every 15 s into an amplified sound system in the PET control room and delivered to the subject in the scanner via a pair of headphones. An auditory beep preceded the presentation of each word. During the living tasks, the subjects were presented with names of animals (e.g. lobster, tiger, fox); during the non-living conditions, the subjects were presented with names of non-living objects (e.g. hammer, whistle, windmill). The subjects were instructed to produce information about each object by speaking aloud during the 15 s following its presentation. The content of the requested information was varied according to the task. Thus, during the perceptual tasks, the subjects were instructed to generate information of a perceptual nature (e.g. 'a lobster is often red in colour with a hard shell') while during the non-perceptual tasks, the subjects were asked to produce information of a non-perceptual nature (e.g. 'lobsters are prized food, usually very expensive'). Each condition lasted 90 s and consisted of six stimuli. The stimuli were completely counterbalanced across subjects such that words assigned to the non-perceptual tasks for half of the subjects were used in the perceptual tasks for the other half. This technique ensures that any differences obtained between response conditions (attribute type) cannot be due to stimulus differences.

All the subjects' responses were tape recorded and later assessed by two blinded raters for their non-perceptual or perceptual content and the number of facts produced for each stimulus. The semantic content was rated on a scale from 0 to 4, with 0 indicating information that was entirely non-perceptual and 4 indicating information that was entirely perceptual. The number of facts for each stimulus was counted and averaged across each scan. If a subject was judged to have provided a high proportion of information that was inappropriate to the task during a particular scan (non-perceptual information during a perceptual task or vice versa) or judged to have recalled an inadequate amount

of information, then that scan was excluded from the data analysis.

RESULTS

Behavioural performance: One subject was judged to have provided a high proportion of inappropriate information for a number of the tasks, and was consequently excluded from the final data analysis. For the remainder of the subjects, the information produced during the non-perceptual scans was judged to be mainly non-perceptual (mean rating 0.57) and the facts generated in the perceptual condition were judged to be mainly perceptual (mean rating 3.41), resulting in a significant difference in ratings, $t=49.38$, $p < 0.001$. This measure establishes that the subjects followed the task instructions correctly.

No subject's data had to be excluded on account of producing an inadequate number of facts. The subjects produced more facts per stimulus during the perceptual scans (average 4.69) in comparison to the non-perceptual scans (mean 4.26), $t=5.69$, $p < 0.001$. The subjects also produced more facts per stimulus during the living scans (average 4.60) than in the non-living scans (mean 4.37), $t=3.30$, $p < 0.001$.

Finally, in all four conditions (LP, LNP, NLP, NLNP) there were no significant differences between the six responses within each scan in terms of either the average ratings for perceptual content (all $F < 1.8$, $p > 0.1$) or the average number of facts produced (all $F < 2.5$, $p > 0.06$). This demonstrates that there was consistent behavioural performance across the 6 different stimuli within each scan.

Blood flow changes: living vs non-living concept domains: When the two living tasks were contrasted with the two non-living tasks (i.e. (LP+LNP)-(NLP+NLNP) and (NLP+NLNP)-(LP+LNP)), neither contrast was associated with any significant regions of rCBF change in the temporal lobes. Even a lowered statistical threshold ($p \leq 0.001$, uncorrected) failed to reveal any regions of significant rCBF change in the temporal lobes for generation of information about living things; but with this lenient criterion, production of attributes for non-living artifacts was associated with a region of rCBF change in the left middle temporal cortex (BA 37, (-48, -56, -1), $Z = 3.65$).

Blood flow changes: perceptual vs non-perceptual information: The contrast between the two perceptual tasks and the two non-perceptual tasks (i.e. (LP+NLP)-(LNP+NLNP)) demonstrated that generation of perceptual information yielded a single significant region of rCBF increase in the left posterior inferior temporal (PIT) cortex (BA 37; (-51, -68, -2), $Z = 4.79$, $p(\text{corr}) = 0.003$; Fig. 1). When the significance threshold was lowered to explore the data further ($p \leq 0.001$, uncorrected), an additional region of rCBF change in a similar region (BA 37) but in the right hemisphere was observed (50, -61, -9; $Z = 3.84$). In the opposite contrast (i.e. (LNP+NLNP)-(LP+NLP)) non-perceptual information was associated with significant activation in the left middle temporal cortex (BA 21; (-59, -10, -15), $Z = 4.06$, $p(\text{corr}) = 0.056$) and the right fusiform cortex (BA 37; (32, -49, -16), $Z = 4.48$, $p(\text{corr}) = 0.012$).

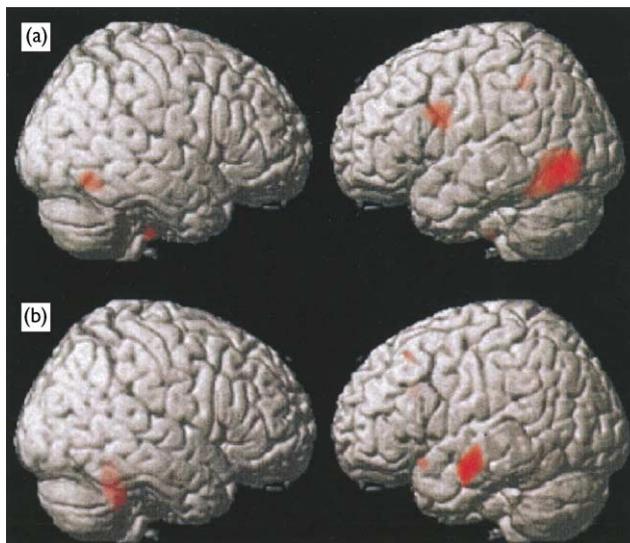


Fig. 1. Diagram showing the regions of significant rCBF change when (a) the non-perceptual task was subtracted from the perceptual task; and (b) the perceptual task was subtracted from the non-perceptual task, superimposed on an average 3D rendered MRI scan.

Finally, since the aim of this study was to explore two factors in semantic memory (i.e. object domain and feature type), the interactions between these two variables, e.g. (LP-LNP)-(NLP-NLNP) and (LNP-LP)-(NLNP-NLP), were examined. No significant differences were observed.

DISCUSSION

At a corrected intensity threshold level, no significant regions of rCBF difference were observed in association with information retrieval regarding living vs non-living concepts. In other words our study, along with several others [5,7], fails to support the hypothesis that semantic memory is regionally organised in terms of these two broad domains. A further analysis of the current data using an uncorrected threshold did reveal a region of rCBF increase in the left middle temporal cortex associated with feature generation for manmade artifacts. It has previously been reported that tools can produce greater activity in this region in comparison to living things and other object categories [16,17]. Rather than being a specific locus for tool knowledge, however, it has been suggested that this region may be involved in knowledge about or processing of non-biological motion, which may facilitate object identification [12]. While this suggestion may seem plausible considering that this region is located adjacent to visual motion processing areas (e.g. area MT/V5), there is as yet no direct evidence for it.

In line with previous functional neuroimaging studies [8,10,11], significant differences in rCBF were associated with the recall of perceptual vs non-perceptual information about familiar concepts. More specifically, a significant increase in activity in the left posterior inferior temporal (PIT) cortex (BA 37) was observed during the retrieval of perceptual attributes while significant increases in activity were observed in the left middle temporal cortex (BA 21)

and right fusiform cortex (BA 37) during the retrieval of non-perceptual features. The left PIT activity associated with perceptual information was posterior in location to that observed by Martin *et al.* ($y = -46$, [10]) during object colour naming and by Cappa *et al.* ($y = -60$, [8]) and Thompson-Schill *et al.* ($y = -53$, [11]) during retrieval of various kinds of visual information. Moreover, the middle temporal lobe activity associated in the current study with retrieval of non-perceptual attributes was anterior in location to that identified by Thompson-Schill *et al.* ($y = -45$, [11]) during the retrieval of non-visual information. On the whole, though, the current results map reasonably well onto these previous findings, especially in view of the very different experimental paradigms. For example, while most previous studies investigating perceptual information have emphasised visual properties (see [9] for an exception), subjects in the current study retrieved a variety of different perceptual attributes of familiar objects, including visual, auditory and tactile properties. In addition to this, the present results are consistent with suggestions that perceptual and non-perceptual semantic processing differentially engage posterior and anterior regions of the ventral temporal lobe respectively [18].

The paradigm used here has important advantages over those typically employed in functional imaging studies of semantic memory. A particular strength is its similarity to techniques considered well-suited to probing the structure and content of semantic knowledge for concepts: feature-listing experiments in which participants are asked to speak (or write) at some length to describe what they know about everyday objects (e.g. [19,20]). We offered less time per concept (15 s) than the typical feature-listing study, and asked subjects to restrict their descriptions to the perceptual or non-perceptual properties of the concepts rather than instructing them to list everything they know; but otherwise, the procedures are identical. Although it would be naive to think that this procedure provides a transparent window on the content of conceptual knowledge, it certainly has good face validity as a technique for activating conceptual knowledge, and has the advantage that it permits the participants to provide the attributes that they consider relevant to these concepts rather than forcing them to make judgements about experimenter-defined properties.

The factor yielding reliable differences in our study, attribute type, was explicitly drawn to the participants' attention, because they were instructed to provide exclusively perceptual or non-perceptual information in each scan condition. In contrast, the factor that yielded no (corrected) significant effects, living *vs* non-living object, was implicit in the sense that subjects were given each object name without direct reference to its semantic category. This difference is unlikely to explain our current observations. First, non-explicit distinctions are commonly used in functional imaging studies and often produce significant patterns of activation. Second, none of the researchers advocating separate neural bases for living *vs* non-living domains [1] has ever suggested that differences associated with this distinction require deliberate reference to or awareness of an object's domain.

It should be noted that to conclude against neuroanatomical separation of living and manmade categories on the basis of the current results is to give interpretational weight

to the absence of a significant difference. We are only too aware that absence of evidence does not constitute evidence of absence. There are, however, cases where a particular effect is so crucial to a theoretical debate that the failure to observe it is highly informative; and it seems clear that different patterns of brain activation in response to different semantic categories is one of these cases. Our paradigm was sensitive enough to yield significant regional blood flow differences and did so for attribute type; but none emerged in association with the living/manmade distinction.

We are not surprised by the absence of a main effect for semantic category (e.g. living *vs* non-living) because, with a few notable exceptions [1], most theorising about the organisation of semantic memory seems to concur that attribute type (e.g. perceptual *vs* non-perceptual) is a more plausible basis for neuroanatomical separation than semantic category. The absence of a significant interaction between the two factors in our study is, however, somewhat more surprising. In an fMRI study in which subjects answered yes/no questions about visual or non-visual properties of living or non-living things, Thompson-Schill *et al.* [11] reported that the left fusiform cortex (BA 37) was preferentially activated for visual information regarding objects from both domains, but was also active in response to non-visual questions about concepts from the living domain. In the context of a hypothesis that semantic memory recruits discrete but highly interactive modality-specific regions, the authors interpreted this result as indicating that visual knowledge is automatically activated when people process a living concept, whatever explicit property of the concept happens to be the target of the task. Although our study provided no direct support for this proposal, it seems a reasonable hypothesis, and may in fact go some way to accounting for the absence of a modality-specific pattern (i.e., differential deficits to visual *vs* non-visual information) in some patients with category specific impairments [4,21].

CONCLUSION

Using a novel, neuropsychologically informed paradigm the current study supports the hypothesis that the neural basis of conceptual knowledge is primarily organised according to semantic attribute rather than semantic category. More specifically, the rCBF findings reported here suggest an association of left posterior inferior temporal lobe regions with perceptual information about both living and non-living concepts, and a link between middle temporal lobe regions and functional or encyclopaedic (non-perceptual) attributes of objects from both categories. There may be further specificity within each of these regions, with different areas subserving different types of perceptual (e.g. colour, shape, sound) and non-perceptual (e.g. functional, motion) information [9,22]. The superior spatial resolution of functional magnetic resonance imaging offers a useful experimental tool to investigate this further in the future.

REFERENCES

1. Caramazza A and Shelton JR. *J Cogn Neurosci* 10, 1-34 (1998).

2. Allport DA. Distributed memory, modular subsystems and dysphasia. In: Newman SK and Epstein R, eds. *Current Perspectives in Dysphasia*. Edinburgh: Churchill Livingstone; 1985, pp. 32–60.
3. Saffran EM and Scholl A. Clues to the functional and neural architecture of word meaning. In: Brown M and Hagoort P, eds. *The Neurocognition of Language*. Oxford: OUP; 1999, pp. 241–272.
4. Warrington EK and Shallice T. *Brain* **107**, 829–854 (1984).
5. Devlin JT, Russell RP, Davis MH *et al.* *Neuropsychologia* **40**, 54–75 (2002).
6. Joseph JE. *Cogn Affective Behav Neurosci* **1**, 119–136 (2001).
7. Mummery CJ, Patterson K, Hodges JR *et al.* *J Cogn Neurosci* **10**, 766–777 (1998).
8. Cappa SF, Perani D, Schnur T *et al.* *NeuroImage* **8**, 350–359 (1998).
9. Kellenbach ML, Brett M and Patterson K. *Cogn Affective Behav Neurosci* **1**, 207–221 (2001).
10. Martin A, Haxby JV, Lalonde FM *et al.* *Science* **270**, 102–105 (1995).
11. Thompson-Schill SL, Aguirre GK, D'Esposito M *et al.* *Neuropsychologia* **37**, 671–676 (1999).
12. Martin A and Chao L. *Curr Opin Neurobiol* **11**, 194–201 (2001).
13. Brett M, Bloomfield P, Brooks D *et al.* *NeuroImage* **9**, S56 (1999).
14. Rorden C and Brett M. *Behav Neurol* **12**, 191–200 (2001).
15. Talairach J and Tournoux P. *Co-planar Stereotaxic Atlas of the Human Brain*. New York: Thieme Medical Publishers; 1988, pp. 649–652.
16. Martin A, Wiggs CL, Ungerleider LG *et al.* *Nature* **379**, 649–652 (1996).
17. Perani D, Schnur T, Tettamanti M *et al.* *Neuropsychologia* **37**, 293–306 (1999).
18. Ungerleider L. *Science* **270**, 769–775 (1995).
19. Garrard P, Lambon Ralph MA, Hodges JR *et al.* *Cogn Neuropsychol* **18**, 125–231 (2001).
20. Tyler LK, Moss HE, Durrant-Peatfield MR *et al.* *Brain Lang* **75**, 195–231 (2000).
21. Farah MJ, Hammond KM, Mehta Z *et al.* *Neuropsychologia* **27**, 193–200 (1989).
22. Chao LL, Haxby JV and Martin A. *Nature Neurosci* **2**, 913–919 (1999).

Acknowledgements: We thank staff of the Wolfson Brain Imaging Centre, Cambridge, UK for their assistance with this study. We also thank Marion Kellenbach and Matthew Brett for providing help with data analysis and Stefanie Hassel and Marjolijn Hovius for rating the subjects' responses. We are grateful to the volunteers who participated.