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TECHNICAL REPORT

Voxel-based Lesion Analysis of Category-Specific Naming on the Boston Naming Test

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VOXEL-BASED LESION ANALYSIS OF CATEGORY-SPECIFIC NAMING ON THE BOSTON NAMING TEST

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Abstract

Case studies in the literature have reported individual patients who show striking dissociations in their ability to name items from distinct categories (e.g., living versus non-living things). Neuroimaging studies have attempted to delineate the brain basis of such category dissociations. Some of these studies have reported specific brain regions associated with discrete categories, while other studies have reported largely overlapping networks. In the current study, we analyzed naming performance in a large group of left hemisphere patients (n = 92), using voxel-based lesion symptom mapping (VLSM) to identify brain regions associated with specific categories of items (animals vs. tools, natural kinds vs. artifacts, and manipulable vs. non-manipulable items). The maps revealed very few dissociations across the three category comparisons but rather showed consistent regions in primarily left middle and superior temporal cortex associated with naming across categories. We also examined our dataset for individuals demonstrating a discrepancy in naming across categories. Out of 92 patients, there were four such individuals, but the lesion sites associated with impaired category naming were not consistent. The current findings are consistent with the notion of a distributed network in the left temporal lobe that underlies naming across different semantic and feature-based categories.

Keywords: semantics, conceptual organization, temporal lobe, neuroimaging, aphasia, anomia

Introduction

There is a longstanding debate as to how conceptual information is organized and stored in the brain. Some theories suggest that different brain regions are specialized to process concepts from distinct semantic categories. These theories are based in part on data from single-case reports of patients with deficits in processing items from one conceptual category versus another, for example, living versus non-living things (Caramazza & Mahon, 2003; Caramazza & Shelton, 1998; Hart et al., 1985; Warrington & McCarthy, 1983). Other theories suggest that conceptual information is based on sensory/functional attributes rather than object categories. For example, natural objects require processing of sensory attributes (e.g., visual, tactile aspects), whereas artifacts require one to pay closer attention to functional features (e.g., how they are used; Gonnerman et al., 1997; Moss et al., 1998, 2000; Tyler et al., 2000; Warrington & Shallice, 1984). More recently, however, newer theories have arisen suggesting that conceptual representations are largely overlapping and widely distributed in the brain (e.g., Devlin et al., 2002; Moss & Tyler, 2001; Tyler et al., 2003).

Lesion studies have attempted to clarify the neural basis of conceptual organization. A number of these studies have reported a category-specific region in left anterior temporal cortex for the ability to process living items (Brambati et al., 2006; Luckhurst et al., 2001; Strauss et al., 2000). Similarly, Gainotti (2000, 2002) reviewed 57 cases reported in the literature and found that patients with naming deficits for living items had lesions in left anterior and inferomedial temporal cortex. Tippett et al. (1996), however, found instead that left anterior temporal cortex was associated with naming non-living items. Gainotti's reviews also reported that patients with naming deficits for non-living items had lesions in left posterior, temporo-parietal cortex and left anterior, inferior temporal cortex.

Imaging studies in healthy participants using fMRI and PET have also tested the notion of category-specific brain regions, with mixed results. For living items, Perani et al. (1995) reported activation in bilateral inferior temporal cortex, while Moore and

Price (1999) and Mummery et al. (1996) reported bilateral activation in the anterior temporal lobes. Regions associated with processing non-living items have included left dorsolateral frontal cortex (Perani et al., 1995, 1999), and the inferior frontal and posterior middle temporal regions (Martin and Chao, 2001; Moore and Price, 1999; Mummery et al., 1998; Perani et al., 1999; Phillips et al., 2002; for a review, see Martin, 2007).

In contrast to these category-specific findings, some studies have failed to find evidence of category-specific brain regions. Gerlach (2007) reviewed 20 functional imaging studies of category processing and found that 11 out of 29 regions showed activation for both natural kinds and artifacts, suggesting a significant overlap in areas deemed important for the processing of these two categories. Moreover, there was no single area consistently activated for any specific category across all studies. Similarly, Devlin et al. (2002) reviewed PET studies of category specificity and found considerable variability. For example, 16 distinct brain regions were reported in only a single study. One finding that was somewhat consistent (in 7 of 9 studies) was left posterior middle temporal gyrus activation in response to processing tools. Devlin et al. also ran a series of experiments on category processing using both PET and fMRI and found no consistent category differences using either methodology. They concluded that the lack of consistency across studies could be in part due to poor control of stimulus factors (e.g., visual complexity, frequency, etc.), as well as false positives due to liberal thresholds during image analysis.

As can be seen, prior lesion and imaging studies have produced mixed results with respect to the notion of category-specific naming regions. A number of potential explanations exist. One possibility is that previous studies have not carefully controlled for factors such as stimulus familiarity, difficulty, complexity, and frequency across categories (Devlin et al., 2002; Gerlach, 2007; Tyler et al., 2003). Another potential explanation for the inconsistent results is the inclusion of different subsets of stimuli across studies. For example, there is evidence that dissociations involving living versus non-living objects depend on whether the stimuli include animals, tools and/or manipulable items (e.g., Chao et al., 1999; Okada et al., 2000; Saccuman et al., 2006; but see Tyler et al., 2003). That is, distinct subgroups of items may recruit distinct brain regions. Last, it is also possible that there are regions of distributed, overlapping networks that subserve processing across semantic categories, making it difficult to identify consistent, category-specific areas.

In the current study, we sought to identify brain regions associated with naming across three mutually-exclusive category contrasts: 1) natural kinds versus artifacts, 2) animals versus tools, and 3) manipulable versus non-manipulable items. The goal of the study was to determine whether these three category contrasts would generate distinct patterns of dissociable brain regions and/or whether distributed, shared networks common to all contrasts would emerge. The study was novel in that we systematically tested three category dissociations, using the same set of stimuli across a large group of 92 patients with detailed neuroimaging data. Also, we used a voxel-based lesion mapping procedure (VLSM; Baldo et al., 2006; Bates et al., 2003) that allowed for the statistical analysis of the role of discrete brain regions in naming. This procedure obviates the need to separate patients based on lesion site (e.g., frontal vs. temporal) or performance (e.g., impaired vs. normal naming), so that a more continuous range of performance can be statistically related to anatomy on a voxel-by-voxel basis. Behavioral data were taken from the Boston Naming Test (BNT), a standardized and widely used test of naming, and items were carefully matched for a number of factors (e.g., familiarity, difficulty, complexity, etc.). Although inconsistent, previous findings of category-specific naming led us to make the following predictions: that naming natural kinds and animals would be associated with left anterior temporal cortex, and that artifacts and tools would be associated with left posterior middle temporal cortex, inferior parietal, and pre-motor cortex. Last, it was expected that manipulable items would show greater involvement of left motor and pre-motor regions, relative to non-manipulable items.

Methods

Participants

Data from ninety-two patients (21 women and 71 men) with a history of a single, left hemisphere stroke were analyzed retrospectively in the current study. Patients were selected based on the following inclusion criteria: a single left hemisphere stroke; native English proficiency; pre-morbidly right-handed; no previous neurologic, psychiatric or substance abuse history; at least 12 months post-stroke; and a lesion reconstruction derived from neuroimaging data. The majority of patients' lesions (over 90%) were due to middle cerebral artery infarcts, with the remainder arising from anterior communicating and posterior cerebral artery infarcts. Mean age of the patients was 60.2 years (SD = 11.1; range 31-80), mean time post-stroke was 60.1 months (SD = 57.3; range 12-272), and mean education was 14.5 years (SD = 3.1; range 5-20).

Testing took place at the Center for Aphasia and Related Disorders, VA Northern California Health Care System in Martinez, CA. Patients signed informed consent forms prior to participation, and the study was conducted in accordance with the Institutional Review Board at the VA and the Helsinki Declaration.

Materials and Procedures

Behavioral Tasks. Language and neuropsychological measures were administered to all patients as part of an existing research protocol. Patients' speech and language abilities were evaluated with the Western Aphasia Battery (WAB; Kertesz, 1982), which includes measures of fluency, repetition, naming, and comprehension. Patients' language impairments ranged from none to severe (mean WAB score = 72.9/100; range 11.8-100, SD = 28.6). The WAB also classifies patients based on subtest scores. In the current sample, the WAB classifications included 17 patients with Broca's aphasia, 21 with anomic aphasia, 10 with Wernicke's aphasia, 4 with conduction aphasia, 2 with global aphasia, 1 with transcortical sensory aphasia, 6 with unclassifiable aphasia, and 31 patients who scored within normal limits (WNL). Patients with apraxia of speech were not excluded, but all patients were given ample time and opportunity to respond.

Naming was tested with the Boston Naming Test (BNT; Kaplan et al., 2001), which consists of 60 black and white drawings of animate and inanimate objects (e.g., bed, pencil, octopus, abacus), roughly arranged in ascending order of difficulty. Patients were asked to name each item. Unlike the standard BNT administration, patients were asked to name all 60 items (starting with the first item), regardless of their ability level and the number of consecutive failures. Patients' naming performance was based on the percentage of correct items spontaneously produced for each distinct category (i.e., animals, tools, etc.). It is important to note that even patients who were identified as WNL on the WAB were not at ceiling for naming the BNT items.

In order to compare brain regions associated with different categories of objects, the BNT items were assigned to categories that allowed for the analysis of three comparisons: 1) natural kinds versus artifacts, 2) animals versus tools, and 3) manipulable versus non-manipulable items (see Table 1). (Manipulability was based on Arévalo et al., 2004, in which participants were asked to pantomime how they would interact with various objects.) In order to control for nuisance variables such as naming difficulty, visual complexity, etc., subsets of the BNT items were selected based on standard corpora and previous normative studies of the BNT so that the stimuli in the three category comparisons did not differ significantly with respect to the following factors: number of syllables, frequency (Burnard, 2007), difficulty (Tombaugh & Hubley, 1997), naming agreement (Himmanen, Gentles, & Sailor, 2003), familiarity (Himmanen et al.), and visual complexity (Himmanen et al.), all *p*s > .05. The only exception was that the animal and tool items were not perfectly matched with respect to familiarity (4.71 vs. 4.86, where 5 is highly familiar; $t(14) = -2.82$, $p = 0.01$) and visual complexity (2.29 vs. 1.80, where 1 is very simple; $t(14) = 2.84$, $p = 0.01$); however, there was no significant difference in naming accuracy between these two categories (see Results).

Table 1. Items in the three category comparisons.

Natural Kinds	vs.	Artifacts	Animals	vs.	Tools	Manipulable	vs.	Non-Manipulable
beaver		trellis	beaver		broom	compass		bed
cactus		sphinx	camel		comb	dart		bench
camel		pyramid	octopus		funnel	canoe		hammock
octopus		hammock	pelican		protractor	funnel		helicopter
pelican		helicopter	rhinoceros		racquet	hanger		house
rhinoceros		house	seahorse		stethoscope	palette		igloo
seahorse		igloo	snail		tongs	pencil		mask
snail		mask	unicorn		toothbrush	wreath		pyramid
volcano		bed				stethoscope		trellis
tree		bench				saw		sphinx

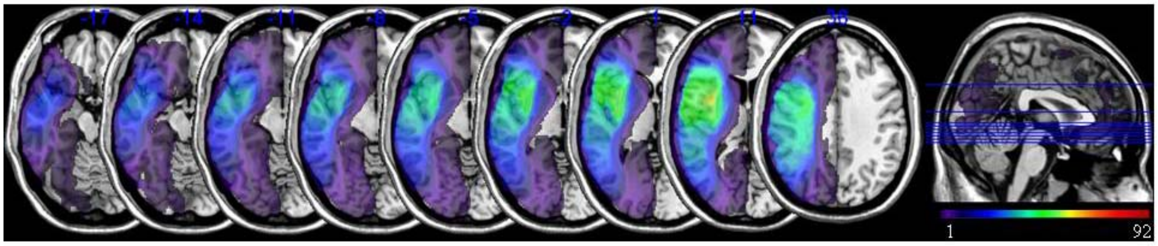

Figure 1. Lesion map showing the extent and overlap of all 92 patients' lesions. The color bar indicates degree of overlap of lesions, with the green regions representing approximately half of the group.

Lesion Analysis. The majority of patients' lesions were visualized with high-resolution T1-weighted structural 3D MRI scans obtained from a 1.5T Phillips Eclipse scanner. T1-weighted images were acquired with a Spoiled Gradient Recall (SPGR) sequence (TR/TE = 15/4.47 ms, FOV = 240 mm, 256 x 256 imaging matrix, flip angle=35°, 0.94 x 1.3 x 0.94 mm^3 voxels, 212 coronal slices). Patients who could not undergo MRI scanning (e.g., due to the presence of magnetic materials in the body) were scanned with a Picker 3D CT scanner.

For the recent cases, where digital MRI images were available, lesions were traced directly onto patients' T1 scans using MRIcro software (Rorden & Brett, 2000), and a board-certified neurologist (blind to the patients' diagnoses) reviewed the reconstructions for accuracy. The scans were then non-linearly transformed into MNI space (152-MNI template) in SPM5, using a procedure outlined by Brett et al. (2001). Specifically, lesion masks were created for each reconstruction so that the SPM normalization procedure would not be distorted by the presence of the lesion (i.e., cost function masking).

In cases where digital MRI images were not available, lesions were reconstructed from available CT or MRI onto an 11-slice, standardized template (based on the atlas by DeArmond et al., 1976) by the same board-certified neurologist who was blind to the patients' behavioral presentation. This 11-slice template was developed for use in earlier lesion studies, and reliability was demonstrated previously using this technique (Friedrich et al., 1998; Knight et al., 1988). These templates were then digitized using in-house software and non-linearly transformed into MNI space (Collins et al., 1994) using SPM5 running on Matlab software (Mathworks, Natick, MA). Specifically, slices from the two templates were aligned using 50 control point pairs to match anatomical features on the two templates. The slices were then aligned using a local weighted mean transformation implemented by the *cpselect*, *cp2tform* and *imtransform* functions in Matlab 6.5. These algorithms were then applied automatically to warp all the lesion reconstructions from the 11-slice template into MNI space.

An overlay of all patients' lesions is shown in Figure 1 (above), indicating the range of affected brain regions throughout the left hemisphere. As can be seen, the largest degree of overlap was focused in anterior regions.

Next, we computed a power map in order to determine those voxels in which there was enough power to detect significant differences (see Figure 2, below). Power was based on an alpha of .05 and a large effect size (0.8; Cohen, 1988, 1992; Kimberg et al., 2007). As shown in Figure 2, there was adequate power throughout the majority of the middle cerebral artery territory, with less power in very anterior, posterior, and inferior regions. For this reason, our predictions were necessarily restricted to regions in the middle cerebral territory.

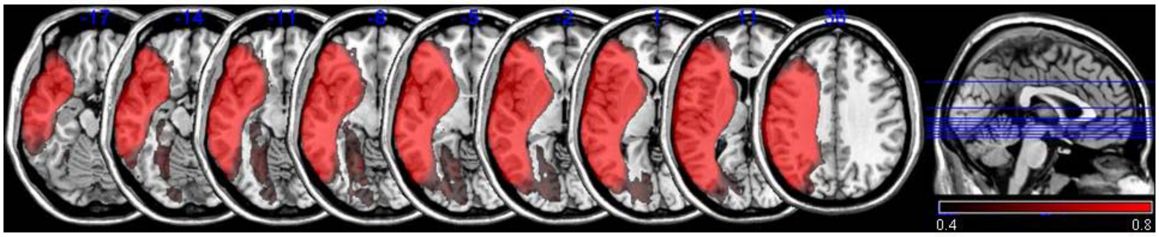

Figure 2. Map showing distribution of power, ranging from 0.4 (grey) to 0.8 (red). Very anterior, posterior, and inferior regions had low power and thus were excluded from predictions in the current study.

The lesion reconstructions and BNT data for all patients were then analyzed using voxel-based lesion symptom mapping (VLSM; http://crl.ucsd.edu/vlsm/), which relates lesion site to behavioral performance (see Bates et al., 2003). Importantly, VLSM allows for a voxel-by-voxel analysis of the role of distinct brain regions in a given behavior, without having to divide patient groups based on anatomy (e.g., frontal vs. temporal lobe patients) or performance (e.g., good vs. poor naming ability). Only voxels containing at least 10 patients with and without a lesion were analyzed. Specifically, a general linear model (GLM) was run where the predictor variable was lesion (present or not in that voxel), and the outcome variable was percent correct (spontaneously named) on the different categories. The VLSM analysis employed a permutation testing procedure to determine a critical t cut-off (at $p < .05$), based on 1,000 random permutations of the data (see Kimberg et al., 2007). Specifically, we randomly reassigned the naming scores to the patients 1,000 times, and for each permutated dataset, we refit the GLM and recorded the size of the largest t-values. A colorized map was then generated, based on the resultant t values at each voxel. The VLSM maps below show only those voxels reaching this critical t value ($t = 4.30$ for animals, 4.25 for tools, 4.29 for artifacts, 4.28 for natural kinds, 4.35 for manipulable, and 4.30 for non-manipulable items). We also set a cluster size threshold of ≥ 100 voxels with respect to our description of regions implicated in the VLSM results.

Results

Natural Kinds versus Artifacts

Patients' behavioral performance on the BNT was analyzed with a paired samples t-test, which revealed a small but significant difference between naming natural kinds versus artifacts, $t(91) = -2.44$, $p = .02$, with a slightly higher percentage of natural kinds correctly named (58.8% vs. 55.1%, respectively).

The VLSM maps for naming natural kinds and artifacts were very similar (see Figure 3, below). On both maps, the significant regions included primarily left middle temporal and superior temporal cortex (Brodmann's areas (BA) 21 and 22), as well as portions of left anterior temporal cortex (BA 38), the inferior temporal gyrus (BA 20), and posterior temporal cortex (BA 37). Portions of left inferior parietal cortex (BA 39/40), inferior frontal cortex (BA 45/47), and the insula were also significant on both maps. With respect to differences between the two maps, there were only very small divergences, such as slightly larger regions of significance in inferior frontal cortex (BA 45) and inferior parietal cortex (BA 40) for natural kinds.

Animal versus Tool Naming

Although the VLSM maps for natural kinds versus artifacts were similar, some research in the literature has suggested that these categories need to be more narrowly defined (e.g., Chao et al., 1999). For this reason, we compared a subset of natural kinds and artifacts—animals versus tools. With respect to the behavioral data, there was no significant difference in naming between animals and tools (55.7% vs. 53.5% correct, respectively), $t(91) = 1.19$, $p = .24$.

The VLSM maps of animal and tool naming were also very similar to each other (see Figure 4, next page). Again, the significant regions included primarily left middle and superior temporal gyri (BA 21-22, 37, 38), the insula, as well as smaller but significant regions in left inferior parietal cortex (BA 39/40) and inferior frontal cortex (BA 45/47). As above, there were very few discrepant regions on the two maps, the only exceptions being slightly larger areas of significance in the left inferior frontal gyrus and inferior parietal cortex for animals.

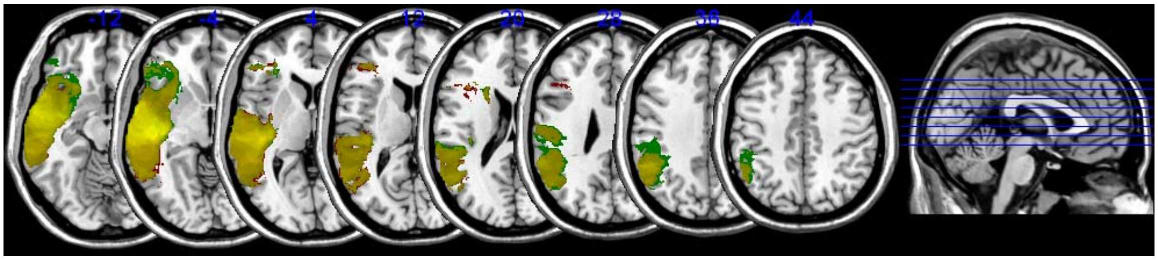

Figure 3. VLSM maps showing brain correlates of naming natural kinds (green) and artifacts (red). Regions that are significant for both conditions are in yellow. Only significant voxels are shown, based on a critical t-threshold determined by permutation testing.

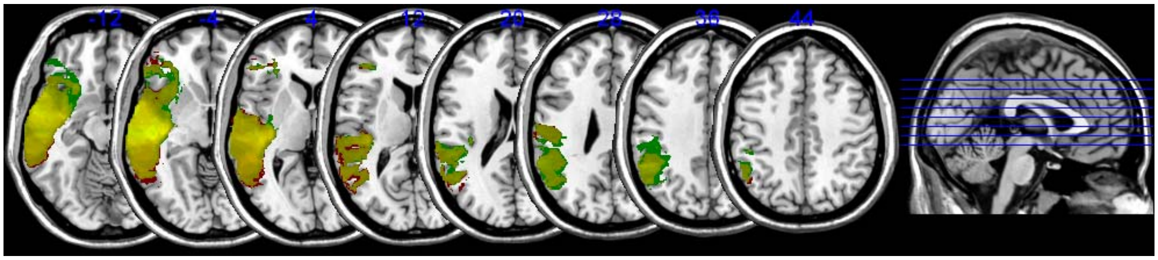

Figure 4. VLSM maps showing regions associated with poor performance on naming animals (green) and tools (red). Regions that were significant for both conditions are shown in yellow. Only significant voxels are shown, based on a critical t-threshold determined by permutation testing.

Manipulable versus Non-manipulable Items

A third distinction that has been made in the literature is processing items which are manipulable versus non-manipulable. To look at this contrast, we analyzed naming performance for manipulable versus non-manipulable artifacts, excluding tools. In this way, we focused on the manipulability distinction, unbiased by other category membership. The patients' behavioral performance did not differ for manipulable versus non-manipulable items (53.8% vs. 55.1% correct), $t(91) = -1.04$, $p = .30$.

The VLSM maps associated with naming manipulable and non-manipulable items on the BNT also resembled each other. Significant regions were again noted in left temporal lobe regions (BA 20-22, 37, 38) for both maps, as well as smaller regions in left inferior parietal cortex (BA 39/40) and inferior frontal cortex (BA 45/47; see Figure 5, below). Again, differences between the maps were small, although there was a slightly larger area of significance associated with naming non-manipulable items in left parietal white matter and inferior frontal cortex.

Individual Cases

Because much of the patient literature is based on category dissociations observed in individual cases, we did a post-hoc examination of our dataset for patients whose naming performance diverged by at least 40% across two categories (cut-off based on reports in the literature, e.g., Sartori et al., 1993). Out of the 92 patients, there were four patients who showed such a discrepancy in naming performance. One patient with very mild aphasia showed impaired naming on natural kinds relative to artifacts (40% vs. 90%). His lesion involved medial temporo-occipital cortex. Another patient with moderately severe Wernicke's aphasia showed impaired tool naming but was perfect on animal naming (50 vs. 100%). His lesion encompassed the middle and superior temporal gyri, as well as smaller portions of inferolateral frontal cortex and inferior parietal cortex. The other two patients had mild, anomic aphasia and showed impaired naming for artifacts relative to natural kinds (both 50% vs. 90%). One of these patients had a lesion in lateral frontal cortex, including ventral pre-motor cortex (BA 6, 9, 44, 45), and the other individual had a subcortical lesion in the basal ganglia. It is important to note that a number of individuals in our dataset had lesions similar to these four patients but did not show a pattern of discrepancy in naming across categories.

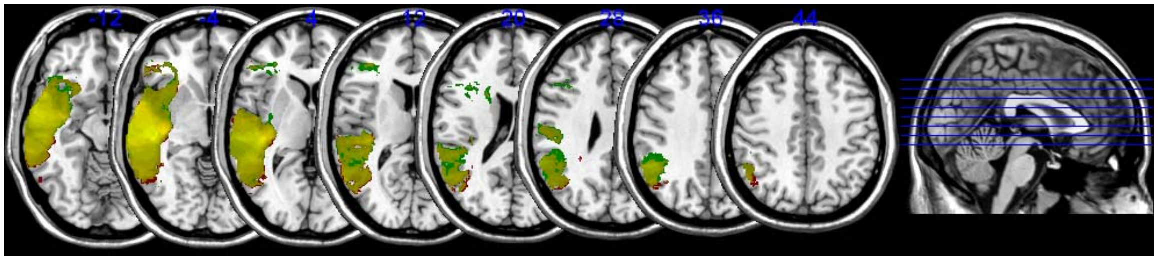

Figure 5. VLSM maps showing brain correlates of naming manipulable (red) and non-manipulable (green) items from the BNT. Regions that are significant for both conditions are in yellow. Only significant voxels are shown, based on a critical t-threshold determined by permutation testing.

Discussion

The current study assessed the effect of lesion site on category-specific naming performance in 92 patients with single, left hemisphere strokes. Naming performance was analyzed for three category comparisons: 1) natural kinds versus artifacts, 2) animals versus tools, and 3) manipulable versus non-manipulable items. A statistical lesion analysis method, voxel-based lesion symptom mapping (VLSM; Bates et al., 2003), was used, so that patients did not have to be divided a priori based on anatomy or performance. The VLSM maps were very similar across categories, implicating primarily left middle and superior temporal cortex in naming. This finding is consistent with studies in the literature that have associated naming across categories with left temporal cortex (Damasio et al., 2004; Tyler & Moss, 2001). Smaller regions of significance in left inferior parietal cortex and inferior frontal cortex were also associated with naming across categories in the current study. Differences between the maps were limited, however, and only involved slightly larger areas of significance in the same regions (e.g., a somewhat larger extent in inferior frontal cortex for naming animals and natural kinds), but there were no double dissociations across regions and categories as had been predicted.

We also examined our dataset for individuals whose naming performance diverged across categories. There were four patients out of the group of 92 who showed such a pattern. One patient with a lesion in inferior, mesial temporo-occipital cortex was impaired at naming natural kinds, which is consistent with a number of previous studies (e.g., Perani et al., 1995). The other three patients were relatively impaired at naming tools or artifacts. Consistent with previous findings (Gerlach, 2007; Tranel et al., 1997), two of these patients had lesions that involved ventral pre-motor cortex, but the third patient had a subcortical, basal ganglia lesion. However, there were also a number of patients with lesions in the same regions as these four patients who did not show any discrepancy in naming. For example, two patients with large mesial temporo-occipital lesions showed relatively preserved naming for natural kinds. The presence of these individual cases in our dataset shows that category-specific naming deficits arise in a subset of patients, but that when a large dataset is considered, these effects are not common and are not associated with consistent lesion sites.

In the present study, we addressed dissociations across categories with respect to naming only. In the literature, some reports of category dissociations are based on naming, but others are based on more conceptual tasks (e.g., feature matching). Functional imaging studies have shown that different types of tasks result in similar activation patterns (Martin, 2007), though some studies constrain their analyses to conceptual/semantic tasks (Tyler & Moss, 2001). Damasio et al. (2004) directly compared performance in a large group of patients on object naming versus conceptual knowledge. They concluded that naming relied more heavily on left temporal cortex, while conceptual knowledge (tested by recognition) relied more on the right hemisphere. In a more recent study by this group, Rudrauf et al. (2008) again found evidence linking naming to left temporal cortex, but in this study, there was a large degree of overlap in brain regions associated with naming of non-unique entities (e.g., animals, tools, fruits/vegetables).

Other studies have suggested that distinct categories are represented differentially in the two hemispheres (e.g., artifacts represented in the left hemisphere, but natural kinds represented bilaterally; Gainotti, 2000). However, these differences are generally found with respect to conceptual knowledge, not naming. The group of patients reported in the current study did not have general conceptual deficits (determined by a BNT recognition procedure), only difficulty with naming. We have recently begun testing both left and right hemisphere patients on a more conceptual task (semantic triads), and thus will be able to empirically test whether the pattern observed for naming in the current study differs when patients perform a more conceptually-based task.

The current study allowed us to look for neural dissociations in naming across a large sample of left hemisphere patients who met strict inclusion criteria. It is important to note that our VLSM findings cannot be attributed to an artifact of the distribution of strokes in the sample, because the areas of significance associated with naming (predominantly left temporal cortex) were distinct from the regions of common lesion overlap (predominantly anterior regions). Nor can our findings be attributed to an artifact of the methodology, as previous studies have used VLSM to identify specific regions throughout the left hemisphere associated with discrete cognitive processes (e.g., Baldo et al., 2007; Bates et al., 2003; Dronkers et al., 2004; Saygin, 2007). For example, this methodology was recently applied to the same patient dataset and identified posterior, inferior temporo-occipital regions associated with a visuospatial task (Baldo, Bunge, Wilson & Dronkers, submitted). In another study, Baldo et al. (2006) found that word retrieval in a category fluency task (e.g., naming animals) was associated with primarily left middle/superior temporal cortex (consistent with the current findings), while word retrieval based on phonemic cues (e.g., words beginning with the letter *F*) was associated with left prefrontal regions.

The current study used stimuli from the Boston Naming Test, which has been used previously to measure category-specific naming deficits in lobectomy patients (Strauss et al., 2000). Unlike previous studies, however, we carefully selected subsets of items that were matched across categories, controlling for frequency, naming agreement, difficulty, etc. This resulted in a limited set of stimuli but one comparable to previous studies of category-specific naming (e.g., Ilmberger et al., 2002) and one that allowed us to detect significant effects at a strict statistical correction.

The VLSM maps in the current study are consistent with the notion of a distributed neural network underlying conceptual representations, as has been previously reported in recent work (e.g., Devlin et al., 2002; Tyler & Moss, 2001). There is always the potential concern, however, that such findings simply represent null effects. Two things argue against this possibility. First, the individual VLSM maps represent highly significant effects at a strict correction using permutation testing to set a critical *t*-threshold value (Kimberg et al., 2007). Second, these effects were extremely consistent for naming across a number of different subsets of stimuli that were carefully selected and matched. Moreover, our findings are consistent with recent work as well as meta-analyses suggesting a widely distributed network in the left temporal lobe for naming across categories in the normal brain (Gerlach, 2007; Tyler et al., 2003).

Because our study was focused on regions within the middle cerebral artery territory (for the large group analysis), we were not able to test some regions previously reported in functional imaging studies to show category specificity (e.g., ventral temporal cortex; Martin et al., 1996). However, our large sample allowed us to test predictions in a number of areas previously reported to show category specificity for example, left pre-motor and motor cortex, the inferior frontal gyrus, anterior temporal cortex, and inferior parietal cortex. Moreover, we had a number of patients (described above) with lesions in regions outside the middle cerebral artery distribution (e.g., infero-temporo-occipital cortex) who did not show expected naming dissociations that would be predicted by previous functional imaging studies.

In short, the current study suggests that a distributed network in the left temporal lobe mediates naming across a range of semantic- and feature-based categories. Further work is necessary to determine whether these same regions are involved in conceptual-level tasks or whether these regions are specific for lexical retrieval associated with naming.

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