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Research report

Task-independent semantic activation for numbers and animals

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Abstract

Semantic processing of numbers and animals was contrasted with PET in two different tasks (comparison and classification) to test the hypothesis that knowledge about numbers is associated with increased activation in the parietal cortices, regardless of the semantic task (i.e. Classification: *is seven odd?* Comparison: *is seven larger than 5?*). By contrast, processing animal names was expected to produce activation in inferior temporal areas. Task-independent activation was observed in the left and right intraparietal sulci for number names, whereas task-independent activation of the left inferior temporal gyrus was found for animal names. No significant interaction between the category (numbers or animals) and the semantic task (comparison or classification) was observed. Accordingly, the IPS activation classically observed during numerical processing appears to be related to category-specific semantic knowledge about numbers. Likewise, the activation of the inferior temporal gyrus associated with the processing of animal names is probably related to category-specific knowledge about animals. The results strongly support the hypothesis that different brain regions are important for storing conceptual knowledge about different semantic categories.

Theme: Neural basis of behavior
Topic: Cognition

Keywords: Fusiform gyrus; Inferior temporal cortex; Intraparietal sulci; Living things; Number magnitude; Parity; Positron emission tomography (PET); Semantic category

1. Introduction

The study of category-specific semantic impairments following brain damage has proved very useful in understanding the organization of conceptual knowledge in the brain [4,41]. Category-specific semantic impairments are characterized by impaired performance of one category of knowledge (e.g. living things) despite relatively unimpaired performance in other categories. The deficit is generally independent of the presentation format of the stimuli (e.g. words or pictures) and it is observed in every task requiring the retrieval of semantic information (e.g. picture naming, word/picture matching, or semantic classification). Many studies have reported cases of patients with selective impairment of living things (e.g. animals and plants) or non-living things (e.g. tools, means of transportation). The observation of such dissociations suggests that different categories of knowledge or different types of semantic attributes rely on different brain regions [1,4,41], and in fact, the analysis of the localization of lesions in patients showing a category-specific semantic deficit tends to support this hypothesis. Selective deficits of the category of living things are frequently observed after damage to the antero-mesial and inferior parts of the temporal cortex, while selective impairment of the category of man-made objects is more frequently observed after fronto-parietal lesions [18].

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Brain imaging techniques have also been used to try mapping more precisely the neural substrate of living and non-living categories. Some researchers have found results in relatively good accordance with lesion studies. For instance, one study reported increased activity in the lateral fusiform gyrus bilaterally for processing items from the category of animals compared to performing the same tasks with items from the category of tools [5]. The same increase of activity was observed for picture naming, word reading, picture matching, and when the subjects passively viewed pictures. However, globally the results have been relatively inconsistent. Activity specifically related to living things have been observed from the most posterior parts of the inferior temporal cortex, at the limit of the inferior occipital gyrus, up to the entorhinal cortex in the mesial aspect of the anterior temporal lobe [5,8,19,22,29,31]. In addition, non-living categories like tools have also been found to activate specific regions of the inferior temporal cortex [5,8]. Finally, many studies have failed to show any significant difference between categories in the expected cerebral areas [2,15,16,21,25]. This has led some researchers to question the hypothesis of anatomical segregation between semantic categories and to argue that cerebral activity in posterior semantic areas would be modulated by the characteristics of the task rather than by the category of knowledge [14,15,39].

Knowledge about numbers can also be selectively impaired [7,11] or preserved [3,38] following brain damage. In case of selective impairment for the category of numbers, patients are able to say, for example, that a duck is a bird but are unable to say that seven is odd and larger than five. This suggests that knowledge about numbers might rely on a specific cerebral substrate. The determination of this neuronal substrate has not been possible through the analysis of lesions because the two patients presenting a clear category-specific impairment for numbers had extensive left parietal lobe lesions [7,11]. Several brain-imaging experiments suggest however that the intraparietal sulci (IPS) play a key role in number processing. These studies have shown significant activation of the left and/or right IPS when subjects compare the magnitude of two numbers [6,23,26,30,33,34], enumerate dots [32], or solve simple addition, multiplication, or subtraction problems [6,12,30,43]. In addition, the IPS activation seems to be independent of the language (English, French, or Russian) of the participants and the number format (Arabic or verbal) [9,12,23]. However, the tasks used in previous experiments emphasize the retrieval of number magnitude, and other aspects of number knowledge, such as the odd/even status of numbers, have been neglected. Furthermore, it has been recently argued that the IPS activation observed during numerical processing could be attributed to general mechanisms involved in stimulus and response selection [20]. Unless the numerical task and the control condition are perfectly matched in terms of response latencies, one cannot exclude the hypothesis that the IPS activity is due to an increase in the difficulty of the selection process in the main task. The conclusion that the IPS is involved in the representation of conceptual knowledge about numbers would be reinforced if it could be shown that the IPS is involved for number processing irrespective of the semantic task performed by the subjects, and not for another semantic category. The present experiment was designed to test this hypothesis.

2. Materials and methods

2.1. Subjects and tasks

Six male volunteers (mean age 27.5 ± 4 years) gave written informed consent to participate in the experiment. All were right-handed with corrected-to-normal vision and were free from medication. They participated in six active conditions resulting from the combination of three different tasks (two semantic tasks and a non-semantic control task) with two different categories of words (numbers and animals). The six conditions are described in Table 1. In the comparison task with numbers (CPNUM), the subjects viewed number words between one and nine and had to decide if the number was larger than five or not; in the comparison task with animals (CPANI), the subjects viewed animal names and had to decide if the animal was more ferocious than a dog or not [37]. In the classification task with numbers (CLNUM), the subjects viewed number words and had to decide if the number was even or not; in the classification task with animals (CLANI), the subjects viewed animal names and had to decide if the animal was a mammal or not. The non-semantic control tasks required low level visual processing of the stimuli (number words or animal names); the subjects had to decide if the word appearing on the screen was written in plain characters or not (in this latter case, only the outline of the letters was drawn). Half of the subjects responded first to

Table 1
Experimental design

	Number words	Animal names
Comparison task	*Is it larger than five?* e.g. SIX (Yes)	*Is it more ferocious than a dog?* e.g. BEAR (Yes)
Classification task	*Is it an even number?* e.g. SIX (Yes)	*Is it a mammal?* e.g. BEAR (Yes)
Control task	*Is it written in plain characters?* e.g. SIX (Yes)	*Is it written in plain characters?* e.g. BEAR (Yes)

The following number words were used: one, two, three, four, six, seven, eight, nine. The following animal names were selected (in brackets their median scores on a ferocity judgment based on a 7 point scale on which dog scored 3): canary (1), hen (1), fawn (2), donkey (2), eagle (5), vulture (6), bear (6), wolf (6). See text for details.