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Categorization of novel tools by patients with Alzheimer's disease: Category-specific content and process

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ABSTRACT

We examined the interaction of content and process in categorizing novel semantic material. We taught patients with Alzheimer's disease (AD) and healthy age-matched seniors a category of plausible novel tools by similarity- and rule-based processes, and compared the results with our previous parallel study of categorization of novel animals, in which AD patients were selectively impaired at rule-based categorization. AD patients demonstrated learning in the novel tool study; however, in contrast to the novel animal study, they were impaired in similarity-based as well as rule-based categorization relative to healthy seniors. Healthy seniors' categorization strategies reflected process irrespective of category content; they frequently attended to a single feature following similarity-based training, and always attended to all requisite features following rule-based training. AD patients' categorization strategies, in contrast, reflected category content; they frequently attended to a single feature when categorizing novel animals by either categorization process, but rarely did so when categorizing novel tools. AD patients' ability to categorize novel tools correlated with preserved recognition memory, a pattern not found in the novel animal study. The category-specific role of memory, along with AD patients' performance profile, suggests content-specific distinctions between the categories. We posit that tool features are relatively arbitrary, placing greater demands on memory, while prior knowledge about animals such as constraints on appearance and feature diagnosticity facilitates the assimilation of novel animals into semantic memory. The results suggest that categorization processes are sensitive to category content, which influences AD patients' success at acquiring a new category.

1. Introduction

Semantic memory, our long-term knowledge about things and events, is frequently impaired in patients with neurological damage. Category-specific deficits, in which memory for some semantic category is impaired while a contrasting category is relatively preserved, have received particular attention. The contrasting categories most commonly reported are natural kinds—typically animals, but sometimes including non-animate living things—and manufactured artifacts—typically tools, but also including other man-made objects (e.g., Cappa et al., 1998; Garrard, Patterson, Watson, & Hodges, 1998; Garrard et al., 2001; Gainotti, 2007; Silveri, Daniele, Giustolisi, & Gainotti, 1991; Warrington & Shallice, 1984). In this study, we examine the interaction of category-specific knowledge and categorization processes in patients with Alzheimer's disease (AD): We assess acquisition of a category of novel tools by two different categorization processes, and compare the results with our analogous prior study of categorization of novel animals.

A rich body of theories has developed to account for category-specific deficits in semantic memory. While some cases may be open to various explanations such as imbalanced frequency or familiarity of test items (Tippett, Grossman, & Farah, 1996), the most influential theories focus on aspects of category content and its interaction with the distribution of knowledge representation in the cortex. The sensory-motor theory (Martin, Ungerleider, & Haxby, 2000; Martin & Chao, 2001) posits that semantic knowledge is stored in modality-specific cortical areas, and that various categories differ in their dependency on particular modalities. For instance, identification of living things is thought to depend primarily on visual-perceptual feature information such as shape, while identification of manufactured artifacts is thought to depend primarily on visual motion and action associated with function. Hence, category-specific deficits should arise in accordance with

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patterns of damage to and sparing of modality-specific brain regions in which feature knowledge is represented, such as visual or motor association cortex (Martin, 2007). The distributed theory (Gonnerman, Andersen, Devlin, Kempler, & Seidenberg, 1997; Moss & Tyler, 2000; Taylor et al., 2007; Tyler, Moss, Durrant-Peatfield, & Levy, 2000) posits that representation of objects' composite features is distributed in a network throughout the cortex irrespective of modality. Category specificity reflects differing degrees of feature clustering and uniqueness among categories. Natural kinds, it is proposed, contain commonly held and inter-correlated features; for instance, many animals have heads, eyes, ears, fur, and tails, allowing for loss of knowledge about any one animal's features to be compensated for by patterns of feature co-occurrence in other animals. Manufactured artifacts, on the other hand, tend to be defined by relatively unique features, such as a hammer's head or a saw's blade. Sparsely represented knowledge is more vulnerable to loss; category-specific deficits thus should be predicated on the extent of neurological damage.

We have previously argued that semantic memory involves not only knowledge content such as items' general appearance, features, and function, but also the processes by which such knowledge is assembled into coherent concepts (Grossman et al., 2003; Koenig & Grossman, 2007; Koenig, Smith, & Grossman, 2006; Koenig, Smith, Grossman, Glosser, & Moore, 2007). We focused on categorization processes as the primary means by which this integration takes place because semantic memory generally entails identifying objects as members of a class (e.g., *a dog*) rather than as unique individuals (e.g., "Fido"). Two well-studied categorization processes—similarity-based and rule-based (Pothos, 2005; Smith & Sloman, 1994; Smith, Patalano, & Jonides, 1998)—seem to capture the range of ways in which objects are classified in normal day-to-day use of semantic memory (Koenig & Grossman, 2007; Koenig et al., 2007, 2006). Similarity-based processing, whereby an item is identified by comparison with an established representation such as a category prototype, tends to be perceptually based, and is relatively quick and effortless (Ashby, Alfonso-Reese, Turken, & Waldron, 1998; Medin, Goldstone, & Gentner, 1993; Medin & Schaffer, 1978; Smith & Medin, 1981). We posit that this is the default process by which we identify most of what we encounter. Rule-based processing, which involves identifying an item by adherence to rules of necessity and sufficiency, is more effortful and resource-demanding (Smith, Langston, & Nisbett, 1992). We posit that this process is employed for special cases, such as when there is no pre-established representation (e.g., the category is unfamiliar), or when the item is atypical of its class. For instance, identifying a bat as a *mammal* rather than as a *bird* requires selectively attending to the defining features (e.g., fur rather than feathers), inhibitory control to ignore salient features that are misleading or irrelevant (e.g., wings rather than typical mammalian forelegs), and working memory to keep features in an active mental state while they are being assessed. Hence, we have posited that semantic memory impairment can reflect a loss of processing ability, in addition to loss of knowledge content.

We explored this notion in several previous studies comparing similarity- and rule-based acquisition of a category of novel animals. In the study that most closely parallels the current one, we taught a novel animal category to AD patients and their neurologically healthy counterparts by both rule-based and similarity-based categorization processes (Koenig et al., 2007). To address the processing component of categorization independently of content, we varied the categorization processes while holding the category content constant. Neurologically intact adults successfully employed either process. AD patients were as successful at similarity-based categorization as their healthy counterparts, but were selectively impaired at rule-based categorization, in keeping with their impaired executive resources (Grossman et al., 2003; LaFleche & Albert, 1995; Patterson, Mack, Geldmacher, & Whitehouse, 1996; Perry & Hodges, 1999). Consistent with this, AD patients' difficulty with rule-based processing correlated with their impairment on standard psychometric tests of executive function, while executive function was unrelated to patients' similarity-based performance. Although the patients' episodic memory was profoundly impaired, there was no correlation between degree of episodic memory loss and AD patients' categorization success by either categorization process.

We have previously speculated that processing deficits could potentially contribute to category-specific deficits if different categories are relatively more conducive to different categorization processes: Exemplars of categories of natural kinds, particularly those with clusters of features in common (as posited by the distributed theory), presumably tend to bear a general "family" resemblance, and thus could be more readily classifiable by similarity-based processes. In contrast, man-made objects, which are generally manufactured for a specific function, can be unpredictable in appearance despite containing a common essential feature. For instance, while a pencil sharpener by definition must contain a mechanism for sharpening pencils, pencil sharpeners come in a boundless array of shapes, sizes, colors, and materials. Objects of such disparate appearance may not be classifiable on the basis of similarity, and thus rule-based processing seems more suitable for discerning the defining feature and ignoring those that may be perceptually salient but irrelevant. Our previous studies with novel animal stimuli, however, did not address category specificity empirically. The present study allows us to compare processing of contrasting categories.

In the present study, we taught AD patients and healthy seniors a category of realistic novel tools by similarity-based and rule-based processes. As in the animal studies, we used novel items rather than familiar ones to minimize bias from prior knowledge and to examine category processes independently of knowledge retention or loss. We again used plausible, realistically drawn stimuli to approximate the qualities of ordinary objects that are represented in semantic memory. In addition to comparing results across the two processing conditions in the present novel tool study, we looked for comparisons and differences with our parallel novel animal study. As in that study, we anticipated that healthy seniors would be successful at using either categorization method (Allen & Brooks, 1991; Grossman et al., 2003; Patalano, Smith, Jonides, & Koeppe, 2001) and that AD patients would be impaired relative to controls. A different pattern of categorization success for tools compared to animals would suggest a role for content specificity in AD patients' performance. We correlated task performance with psychometric measures of episodic and working memory, and we performed fine-grained analyses of responses to individual items to assess category endorsement strategies.

2. Methods

2.1. Subjects

Twenty AD patients, 13 female and 7 male, participated. All were right-handed native speakers of English, except for one native Dutch speaker who was fluent in English. The patients were mildly impaired, with a mean MMSE score (Folstein, Folstein, & McHugh, 1975) of 22.7 (±3.6). Their mean age was 73.5 (±7.6), and they had a mean of 13.5 (±2.6) years of education. MMSE scores, age, and years of education did not differ from those of the AD patients who participated in the novel animal study (Koenig et al., 2007), $p > .23$ by t-test for all comparisons. AD patients' diagnoses were based on NINCDS-ADRDA criteria (McKhann et al., 1984), which include a progressive anterograde memory deficit associated with naming and language difficulty, visual impairment, and/or executive limitation. We excluded patients with other causes of dementia such as vascular disease or hydrocephalus, psychiatric disorders such as primary depression or psychosis, medical illnesses or metabolic conditions that may have resulted in progressive intellectual decline, and/or other medical conditions that may have an impact on cognitive performance. Twenty healthy seniors, all right-handed native speakers of English, mean age 70.8 (±6.5),