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KNOWLEDGE OF NATURAL KINDS IN SEMANTIC DEMENTIA AND ALZHEIMER'S DISEASE

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Abstract

We examined the semantic impairment for natural kinds in patients with probable Alzheimer's disease (AD) and semantic dementia (SD) using an inductive reasoning paradigm. To learn about the relationships between natural kind exemplars and how these are distinguished from manufactured artifacts, subjects judged the strength of arguments such as "Humans have a chemical called sebum. Therefore, frogs have a chemical called sebum." These judgments depend on subjects' perception of the similarity between the familiar objects named in the premise and the conclusion. Controls rated arguments generalizing from a natural kind to an artifact as significantly weaker than arguments generalizing from one natural kind to another natural kind. SD patients demonstrated a graded profile of generalization without evidence of a categorical distinction between natural kinds and artifacts. AD patients' judgments also suggested more difficulty than controls at distinguishing between natural kinds and artifacts. Both SD patients and AD patients resembled controls in their judgments of arguments where both objects are from the natural kinds category. Semantic knowledge thus appears to be sufficiently preserved in both AD and SD to support within-category similarity judgments. We suggest that SD patients may be impaired in part at identifying the features critical to diagnosing membership in a semantic category, while AD patients' performance is consistent with their semantic categorization deficit.

Keywords

semantic; semantic dementia; Alzheimer's disease; frontotemporal dementia

INTRODUCTION

Semantic memory involves the mental representation of object and action concepts, and the words denoting them. These representations are essential for success on a variety of tasks including picture naming, lexical acquisition and word-picture matching. Moreover, performance on tasks such as these is compromised in certain neurodegenerative diseases, including probable Alzheimer's disease (AD) and semantic dementia (SD). Both groups of patients are known to have difficulty on measures requiring semantic memory, such as confrontation naming and associativity judgments of words and pictures (Bozeat, Lambon Ralph, Patterson, Garrard, & Hodges, 2000; Grossman et al., 2003; Grossman et al., 2004; Garrard et al., 2001; Garrard, Patterson, Watson, & Hodges, 1998; Lambon Ralph, Patterson,

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& Hodges, 1997; Lambon Ralph, McClelland, Patterson, Galton, & Hodges, 2001; Lambon Ralph, Graham, Patterson, & Hodges, 1999). However, the nature of the semantic impairment across patient groups is still widely debated since there have been few studies of semantic memory directly comparing AD and SD (Koenig & Grossman, 2007). Although semantically compromised AD patients and SD patients both may be impaired on measures of semantic memory, it is reasonable to suggest that the source of semantic impairment may differ somewhat across the two groups, as their patterns of cortical atrophy are partially unique (Grossman et al., 2004). In this study, we evaluated semantic memory comparatively in AD and SD.

One possible cause of semantic impairment may be a degradation of the knowledge of features that make up semantic representations. Based on the observation that disease in SD involves visual association cortex in the temporal lobe, several studies have now shown that these patients have “reversal of the concreteness effect” (Breedin, Saffran, & Coslett, 1995; Yi, Moore, & Grossman, 2007). This refers to worse performance with concrete concepts than abstract concepts, presumably due to the degraded representation of visual perceptual feature knowledge in visual association cortex of these patients. Much work addressing degradation of feature knowledge to date has attempted to generalize this phenomenon to category-specific semantic memory difficulty, where patients have a relative disadvantage for either natural kinds or nonliving items after brain damage. According to the sensory-functional hypothesis, impairment results from differential dependence on different types of features in the natural kind (NK) and artifact (AR) domains. Representations of NK are thought to depend largely on perceptual features, whereas AR may depend more on functional information (Farah & McClelland, 1991; Hodges, Patterson, & Tyler, 1994; Shallice, 1988; Warrington & McCarthy, 1987). Thus, if atrophy occurs in areas of the brain that store perceptual features, NK will be more compromised than AR. Likewise, if functional features become degraded, AR will be more impaired than NK.

An alternate hypothesis, which does not necessarily rely on anatomical separation of functional and perceptual features, suggests that category specificity may arise additionally from statistical aspects of the feature information. Specifically, NK may have more redundant features than AR, and additionally, because more features are shared across NK exemplars, they may have relatively fewer distinctive features than AR exemplars. Based on these statistical properties, Gonnerman and colleagues (Gonnerman, Andersen, Devlin, Kempler, & Seidenberg, 1997) created a connectionist model predicting that the AR domain will become impaired linearly with increasing damage in conditions like AD, as random distinctive features are lost. In contrast, the NK domain will be relatively robust to mild damage because intercorrelated and shared knowledge can compensate for lost object features, but more severe damage will lead eventually to more rapid decline because large clusters of representations being affected by the loss of whole sets of shared features (Devlin, Gonnerman, Andersen, & Seidenberg, 1998; Tyler & Moss, 2001). Tyler and colleagues’ (2000) related model emphasized the association of particular functional and perceptual features that occurs with AR but not NK, making AR more robust to damage.

These hypotheses about category-specific degradation of feature knowledge are consistent with semantic memory impairment in single cases or small groups of patients, but a considerable number of inconsistencies and exceptions exist across studies (Caramazza & Shelton, 1998). For example, observations of patients with a deficit for NK without a disproportionate impairment for visual-perceptual features is inconsistent with the sensory-functional hypothesis (Lambon Ralph, Howard, Nightingale, & Ellis, 1998; Moss, Tyler, Durrant-Peatfield, & Bunn, 1998; Samson, Pillon, & De Wilde, 1998). The reverse pattern is also observed: SD patients often have a relative disadvantage for sensory knowledge compared to functional knowledge but show no category-specificity (Lambon Ralph, Patterson, Garrard, &

Hodges, 2003). Gonnerman and colleagues (1997) and Tyler and colleagues (2000) used the statistical properties of words to predict the nature of decline in specific categories of knowledge, but longitudinal evidence is inconsistent with these accounts. For example, one study found that AD patients and SD patients decline equally across both categories over time (Grossman et al., submitted). Another longitudinal report described more rapid decline for NK than AR in AD throughout the course of their disease (Garrard et al., 2001).

Other models of semantic memory have been forwarded recently that do not depend on category-specific difficulty. In examining the degradation of knowledge in patients with SD, Patterson and colleagues used statistical properties such as prototypicality, familiarity, and frequency rather than the features of a particular semantic category, to predict performance in SD (Patterson et. al., 2006; Ikeda, Patterson, Graham, Lambon Ralph, & Hodges, 2006). This account is similar to those described above in that features shared across many exemplars are relatively robust to damage. However, these researchers suggest that patients will have the greatest difficulty with atypical and less frequent objects because they do not benefit from as many shared features as typical objects and additionally, their atypical, less frequent structures make them more vulnerable to over-regularization errors. Rogers and colleagues (2004) developed a computational model of degraded conceptual knowledge based largely on observations of SD patients such as these who have pervasive semantic deterioration, typically without category-specificity. According to this model, a central amodal semantic system maps modality-specific perceptual information into an abstract semantic representation. These semantic representations can then be used for generalization of stored information to novel items as well as addition of new information to already stored representations of familiar objects. Category-specific difficulty may come out of this model because the hierarchical organization of NK semantic knowledge that emerges through learning appears to support feature-sharing among overlapping concepts more than for AR, which are less robustly hierarchical.

In the current study we examine object knowledge in AD and SD from a different perspective. The studies described above have relied primarily on naming and categorization tasks. It is possible that poor performance on these tasks results at least in part from impairment of the explicit processes that utilize feature knowledge, rather than the degradation of knowledge per se. We have shown elsewhere that AD patients have difficulty categorizing familiar objects (Grossman et al., 2003) and novel objects (Koenig et al., 2007), even when the relevant feature information is provided. Here we use a category-based induction paradigm that allows us to assess participants' feature knowledge from another perspective that is indirect and does not explicitly probe object feature knowledge or category membership. Participants are presented arguments in which premise and conclusion statements attribute an unfamiliar property to familiar objects, and they are asked to judge the extent to which the conclusion is true given that the premise is true. For example, given a premise statement such as "Cats have a vomeronasal," one can judge the strength of their belief in a conclusion statement such as "Therefore robins have a vomeronasal." In this kind of inductive reasoning, an unfamiliar property is used and familiar concepts are at the same semantic level in the premise and conclusion statements. Therefore, the major determinant of judgments is the similarity between the premise and conclusion objects (Osherson, Smith, Wilkie, Lopez, & Shafir, 1990). By looking at inductive judgments of AD and SD patients relative to controls, we can determine whether the conceptual knowledge required for similarity comparisons is impaired in patients, and we can compare semantic deficits across the two patient groups.

We showed previously that AD patients are relatively normal with this inductive reasoning paradigm (Smith, Rhee, Dennis, & Grossman, 2001), but have not yet examined SD performance on this task. Previous work with this paradigm has focused on arguments that include only items belonging to a single superordinate semantic category, namely NK. In the

present study, we included arguments with objects from both NK and AR domains to examine how induction across the NK-AR boundary affects the strength of inductive reasoning judgments. In subjects who have intact representations of the features contributing to NK and AR, and who understand which features distinguish between these categories, we should see a graded decline in ratings within NK and/or within AR categories as the conclusion object becomes less similar to the premise object. Moreover, we should see a categorical effect where there is a sharper decline in their ratings when the NK-AR boundary is crossed. If patients have degraded knowledge of features of exemplars, by comparison, they should have significant difficulty judging the similarity of the premise and conclusion (Sloman, 1993; Smith, Shafir, & Osherson, 1993; Tversky, 1977). Patients with degraded feature knowledge thus should not show a systematically graded decrease in argument strength ratings as a function of decreasing object similarity within a category. Moreover, if patients have relatively preserved feature knowledge but are less aware of the diagnostic value of features that contribute to category membership, then we should not see a categorical effect at the category boundary.

METHODS

Subjects

Participants were 11 patients with AD and 9 patients with SD identified in the outpatient clinic of the Department of Neurology at the University of Pennsylvania. These patients were diagnosed on the basis of a modification of published criteria (Grossman & Ash, 2004; McKhann et al., 1984; McKhann et al., 2001; Neary et al., 1998), and were assigned to these groups using a consensus mechanism that reviewed a full medical history, a detailed neurological exam, and a complete mental status evaluation. MRI ruled out structural causes of cognitive difficulty such as stroke, and serum studies ruled out infectious or metabolic causes of cognitive decline. There was no history of primary depression or psychosis, although the patients may have been taking a low dosage of a non-sedating anti-depressant. We also assessed 16 healthy elderly controls. Table 1 summarizes the demographic characteristics of these groups. There was no difference in age [$F(2,33) = 0.96$, $p > 0.1$] or education [$F(2,33) = 0.01$, $p > 0.1$]. The patient groups were matched in dementia severity [$t(18) = 0.15$, $p > 0.1$] and disease duration [$t(18) = 1.02$, $p > 0.1$]. Table 1 also shows that SD and AD patients were worse than controls for 2 tasks requiring semantic memory [Pyramids and Palm Trees (Howard & Patterson, 1992) and Boston Naming Test (Kaplan, Goodglass, & Weintraub, 1976)], but not significantly different from each other; AD patients were worse than controls and SD patients on an assessment of episodic memory involving delayed recognition of a ten-item word list presented for three learning trials two minutes earlier.

Materials and Procedure

This study focused on knowledge of 13 familiar objects: 8 NK and 5 AR. These are listed in Table 2. NK stimuli were selected to span the phylogenetic spectrum. Each of the five AR was chosen because it shares a prominent property with NK (e.g. computers “think,” bikes “move,” dolls superficially resemble NK). For our analyses, the 13 stimuli were ordered from most to least animate, starting with NK and ranging from human to flower (according to decreasing phyla) and continuing down through AR and ending with bike.

Subjects were given a pair of written statements, each containing the name of one of the stimuli. We refer to these statements as the premise and conclusion. Each premise statement described an unfamiliar property of a familiar object. These premise statements were in bold letters and were emphasized by the experimenter as being absolutely true (albeit unfamiliar) facts about the particular object. Each premise statement was followed by a concluding statement that attributed the same unfamiliar property to a different object (e.g. “Humans have a chemical called sebum. Therefore, frogs have a chemical called sebum.”) After piloting the statements

containing only object names and a simple (unfamiliar) property, we added a modifier to each property (e.g. “chemical” in the previous example) so that participants would be more willing to accept the premise statements as facts. Subjects were asked to judge on a 5-point Likert scale (ranging from “very likely” to “very unlikely”) the probability that the concluding statement is true, based on the fact presented in the premise. Since the property in the premise was unknown to the participants, judgments about the truth of the conclusion could be based only on the similarity of the familiar object in the premise and the familiar object in the conclusion of each problem. Moreover, this paradigm allowed us to examine the relationship between the meanings of these objects without asking subjects explicitly to compare them.

Each of the 13 objects was paired with every other object twice — once in the premise statement and once in the conclusion statement — resulting in a total of 156 trials. These were divided into four conditions: 56 trials in which both the premise and conclusion arguments included a natural kind (NK→NK), 20 trials with both objects being artifacts (AR→AR), 40 trials with an NK premise object and an AR conclusion object (NK→AR), and 40 trials with an AR premise object and an NK conclusion object (AR→NK).

The trials were presented in large print, three to a page, in a fixed random order. The premise was presented above the concluding statement for each argument. The experimenter read the arguments out loud as patients read along, and patients were given as much time as they desired to respond. The problems were repeated at the request of the patient. The subjects indicated their response on a horizontally-arrayed visual diagram of the Likert scale, and the scale included five equidistant points marked by a small vertical line and verbal descriptors (e.g. “very likely”). A practice/training procedure preceded the experiment. This familiarized participants with the format of the problems, and served to reassure patients that the unfamiliar properties were in fact true properties of the objects named in the premise statements.

RESULTS

Distinguishing between semantic categories

As shown in Table 3, SD patients treated the NK-AR domain boundary differently than controls and AD patients in their inductive reasoning judgments. SD patients rated arguments that generalize a property from an NK object to an AR object, or from an AR object to an NK object, much more acceptable than both controls and AD patients. However, arguments with both premise and conclusion objects from the same domain (either AR or NK) were rated relatively similarly across the three groups.

We examined this observation statistically with a repeated-measures ANOVA, using a group (3: controls, AD, SD) × premise domain (2: NK, AR) × conclusion domain (2: NK, AR) design. We found a significant group × premise domain × conclusion domain interaction effect [$F(2,33) = 5.15, p = 0.01$]. AD patients performed similarly to controls with respect to generalization from the premise object to the conclusion object across domain boundaries. There were no significant differences between controls' and AD patients' judgments [$p > 0.05$ for all four conditions: NK→NK, AR→AR, AR→NK, NK→AR]. Relative to controls, however, SD patients gave higher ratings when the arguments included one NK and one AR object [NK→AR: $t(23) = 2.74, p = 0.01$ AR→NK: $t(23) = 2.42, p = 0.02$]. There was no main effect for group in the 3-way ANOVA [$p > 0.1$], suggesting that the groups' ratings were about the same across conditions. However, SD patients generally gave higher ratings than AD patients. It is unlikely that this reflects a regression to the mean of the scale in SD patients who are uncertain about their semantic judgments because there is no overall group effect in judgments using this scale, and because their absolute ratings of NK are further from the mid-point of the scale than AD patients. Nevertheless, we controlled for this potential rating bias by performing a similar analysis on scaled rating scores. We created an average within-category

rating score for each subject to use as a baseline comparison for subjects' between-category ratings. A ratio of the between-category rating to the baseline rating was created for each patient (i.e. $NK \rightarrow AR / \text{mean within category rating}$; $AR \rightarrow NK / \text{mean within category rating}$). Comparisons of these scaled rating scores indicated that both SD and AD patients rate between-category arguments significantly higher than control subjects [all $p < 0.05$].

Detailed analysis within natural kinds

A detailed item analysis examining knowledge within NK did not reveal a deficit in SD or AD. In order to assess patients' understanding of the structure of the natural kinds domain, the unit of analysis is a premise object associated with a set of ordered conclusion objects. We assessed this with a series of individual patient analyses. In the first analysis, we adopted the assumption that "humans" are the prototypical natural kind (Carey, 1985). We assessed the willingness of subjects to generalize from "humans" to successively lower phyla. Progressively decreasing generalization as the phylum becomes more distant from "human" would reflect sensitivity to the structure of the category of natural kinds (and the feature knowledge that supports these representations). Generalization from "human" in the premise to "cat" in the conclusion, for example, should be stronger than from "human" to "flower."

We compiled mean ratings for each premise-conclusion pair for each of the three groups of participants (Table 4). We examined individual performance profiles within each group to assess the number of generalizations from "human" to lower phyla that demonstrate a well ordered decline as the conclusion objects become successively more distant from "human" ([human $\rightarrow$ cat] greater than [human $\rightarrow$ squirrel] greater than [human $\rightarrow$ robin] etc...). For all of our nonparametric analyses, the criterion for significance was set at $p < 0.06$ (using a one-tailed binomial test) since this is the closest to a p-value of 0.05 that is possible with the number of items being analyzed here. This is equivalent to 5 comparisons out of 7 going in the expected direction. We found that the controls, AD patients, and SD patients all attained this criterion and gave successively lower generalization ratings as the conclusion objects become more distant phylogenetically from "human."

In a second analysis, we examined whether subjects are more willing to generalize from "human" to the set of lower phyla (and thus, to less typical NK) than from the set of lower phyla to "human." The dependent variable was the rating for each premise-conclusion object pair, based on an analysis of individual patient performance profiles within each group. We added together the total number of reasoning problems where generalization from "human" to the conclusion object (e.g. "cat") was greater than generalization of the reverse problem in which lower phyla (e.g. "cat") appeared in the premise and "human" appeared in the conclusion. We again found that all three groups reached our criteria and reliably rated human $\rightarrow$ animal arguments higher than the corresponding animal $\rightarrow$ human arguments.

Osherson et al. (1990) showed that relative prototypicality effects and asymmetries in inductive reasoning involve not just "human," as suggested by Carey (1985), but also involve any argument in which the objects vary in typicality. We examined knowledge of natural kinds from this broader perspective using an analysis of individual performance profiles within each group, similar to the above analyses. First, we examined whether subjects are systematically more willing to generalize when premise and conclusion items are more similar. For each premise object, we counted the number of conclusion objects for which generalization ratings decreased in an orderly fashion as the conclusion object came from a phylum further from the premise object (and thus was less similar to the premise object). For this analysis each premise object does not have the same number of conclusion objects in its set (e.g. there are 7 conclusion objects from lower phyla for the "human" premise, but only 4 lower than "robin"). To allow for these differences, the dependent variable in this analysis was the number of premise objects for which the majority of mean generalization ratings decreased as the conclusion objects were

from successively lower phyla. All three groups reached criterion: For at least 5 of the 6 possible premise stimuli [$p < 0.02$], mean generalization ratings decreased systematically in a majority of arguments as the conclusion objects were from successively lower phyla.

We also compared mean argument ratings for the two directions of generalization for each pair of objects in the sets as we did with the human/animal pairs. Here, we assume that higher phylum objects are more typical of the NK domain than lower phylum objects. We tallied the number of premise objects for which the majority of higher $\rightarrow$ lower phylum natural kind arguments had a higher mean similarity rating than the corresponding lower $\rightarrow$ higher arguments (e.g. cat $\rightarrow$ squirrel is judged greater than squirrel $\rightarrow$ cat). We found that only the control group reached criterion for this contrast. Both the AD patients and the SD patients did not consistently rate arguments with a premise containing an object from a higher phylum relative to the conclusion object stronger than arguments where the same objects reversed roles (lower phylum object in the premise).

In the model of induction proposed by Osherson et al. (1990), generalization from a premise statement to a conclusion statement is largely a function of the similarity between the premise and conclusion objects. To see if this model holds for all three of our groups, we performed correlations between individual subjects' generalization ratings (collapsed across the direction of generalization) and similarity ratings from 12 young controls for each pair of premise-conclusion objects. Correlations were significant for all groups when collapsed across domains (controls: $r = 0.79$; AD: $r = 0.76$; SD: $r = 0.72$; $p < 0.01$ for all groups).

DISCUSSION

Patients and controls performed an induction task in which they judged generalizations of an unfamiliar property from one familiar object to another familiar object. In order to do this successfully, patients must use their semantic knowledge to compare the objects of interest. We found that SD patients are more willing than controls to generalize an unfamiliar property from an NK object to an AR object as well as from an AR object to an NK object. AD patients perform more similarly to controls, giving arguments with objects from different domains lower ratings than SD patients, although a ratio analysis considering different uses of the rating scale found that both groups differ from controls. SD and AD patients resemble controls for judgments within NK: They show systematically graded ratings that reflect the similarity between the premise object and the set of conclusion objects when both the premise and conclusion objects are NK exemplars. This challenges the notion that difficulties with categorization are due to the undifferentiated degradation of semantic knowledge. We argue instead that SD patients have difficulty interpreting the importance of available feature knowledge for object meaning, and that AD patients have a categorization deficit that interferes with the comparison process within semantic memory.

Consider first the performance of SD patients. The resemblance of SD patients' induction patterns within NK to that of controls suggests that patients retain adequate representations of the test stimuli. To the extent that similarity judgments rely on an analysis of the number of features that are shared by two items (Osherson et al., 1990; Smith et al., 1993; Tversky, 1977), the orderly decrease in ratings as premise and conclusion objects become less similar indicates that SD patients' feature knowledge about the test items is preserved at least to some degree. Observations that attribute semantic memory difficulty in SD largely to degraded feature knowledge (Breedin et al., 1995; Yi et al., 2007) thus must be viewed cautiously.

Carey (1985) argues that "human" is the prototypical member of the NK category, and that decreasing phyla are progressively less representative of NK. From this perspective, our findings also support preserved sensitivity to representativeness within a category in SD when

probed in an indirect manner. This representativeness structure appears to be most robust with “human” as the prototype. We see considerable evidence for graded representativeness even in lower phyla in these patients, although less typical NK appear to serve as somewhat less reliable premise objects in SD patients’ judgments. The reduced reliability of less typical NK as premise objects is consistent with observations that highly representative exemplars of a category are preserved relatively better than less representative exemplars in SD (Rogers et al, 2004; Patterson et al., 2006; Ikeda et al., 2006). However, we do not find that less representative exemplars become undifferentiated from the prototype of the category. It is thus less likely that preferential degradation of less typical exemplars of the NK category can fully explain SD patients’ difficulty distinguishing NK from AR. Moreover, a correlation between object similarity ratings and argument strength judgments that resembles controls’ suggests that patients’ feature knowledge is sufficiently intact to support similarity judgments between objects during generalization. Observations of relatively normal graded judgments during within-category comparisons are also consistent with findings of preserved similarity-based categorization in the acquisition of a novel, naturalistic category in SD (Koenig, Smith, & Grossman, 2006). In this study, SD patients were seen to endorse a picture of a stimulus as a member of a novel category in proportion to the number of features that the stimulus shared with the prototype of the category. Thus, these data are not fully consistent with accounts that attribute semantic deficits in SD patients entirely to degradation of feature knowledge associated with less typical exemplars possessing features that are less redundant and inter-correlated (Rogers et al, 2004; Patterson et al., 2006; Ikeda et al., 2006).

SD patients’ semantic deficit becomes evident in the present study only when performance requires a comparison of arguments that include one object from each semantic domain. For AR concepts that resemble NK concepts because of shared features (e.g. “doll” or “robot” relative to “human”), an understanding of the essential properties determining the category membership of NK items constrains controls, but not SD patients, from generalizing a property of NK objects across a major category boundary to AR objects. There are two possible explanations for this finding. One possibility is that feature knowledge specifically supporting this NK-AR distinction is degraded in SD, and therefore SD patients are insensitive to the NK-AR boundary. This hypothesis is unlikely to explain SD patients’ performance fully, as there is little evidence to suggest that the features supporting such a distinction are any different from the other relatively preserved features required for similarity comparisons within a semantic category. Indeed, it is difficult to define the NK domain with any specific combination of sensory-motor features, despite our strong intuitions about what is a member of the NK domain (Carey, 1985).

Given SD patients’ relatively orderly judgments within a semantic domain, we suspect instead that SD patients have some difficulty honoring the major NK-AR boundary because of a relative deficit recognizing the diagnosticity of certain features that contribute to category membership. In particular, objects often seem to possess diagnostic features that help determine the category membership of an object. These are distinct from the characteristic features that are a property of an object even though they do not help distinguish between categories (e.g., Smith, Shoben, & Rips, 1974). For example, the manner of reproduction and the mechanism for extracting oxygen are critical features that help identify the category membership of a dolphin (mammal) and a shark (fish), even though both of these animals share many characteristic features like living in water, swimming, possessing fins, being gray in color, having an adult length of about five feet, etc. A recent fMRI study provided some support for this distinction by showing that diagnostic features of a category have a different pattern of neural activation compared to characteristic features (Grossman, Troiani, Koenig, Work, & Moore, 2007). One of the relevant areas associated with a diagnostic feature contributing importantly to word meaning was the ventral temporal lobe, an area that is compromised in SD. The observations of the present study thus appear to be consistent with the claim that SD

patients experience some difficulty distinguishing between NK and AR in a categorical manner in part because they have a deficit identifying the features that are more likely to contribute to category membership. From this perspective, similarity decisions within a category (such as NK) are less dependent on the ability to identify the features that are diagnostic of category membership, and such a deficit at identifying features diagnostic of category membership would not prevent SD patients from making appropriately graded similarity decisions about objects taken from the same semantic category. This conclusion is consistent with previous findings showing that, when given the diagnostic features that determine the category membership of a novel NK concept, SD patients identify category members in a manner that reflects representativeness within the category (Koenig et al., 2006).

Consider next the AD patients. Although our initial analysis revealed a significant difference between AD and SD patients on ratings across the domain boundary, a second analysis controlling for overall rating bias suggests that AD patients also may be impaired on this task. AD patients are known to have a deficit with similarity-based categorization, and this may be the basis for their impairment. This similarity-based deficit seems to emerge when less representative instances of a category are being judged. This includes items that share fewer perceptual features with a prototype of the category (Bozoki et al., 2006) or whose features are less representative of the category (Koenig et al., 2007). A similar impairment pattern was seen in the present study, although the deficit was not so evident that it interfered with judgments within the NK domain. As with SD, we do not believe that AD patients' deficit is due primarily to the degradation of feature knowledge since their judgments within the NK domain do not differ from those of controls. Previous work showed that AD patients are able to perform this inductive reasoning task (Smith et al., 2001), so we do not think that non-specific difficulty with a reasoning task can explain their deficit appreciating a category boundary.

Our findings thus suggest that SD patients and AD patients are impaired on a novel measure of semantic memory that probes object knowledge indirectly. SD patients, and to a somewhat lesser extent AD patients, have difficulty respecting the category boundary between NK and AR, although their within-category judgments do not differ from those of controls. In SD, this deficit may be due in part to interpreting the diagnostic value of a feature for category membership. The deficit in AD may be due to their limited similarity-based categorization.

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TABLE 1
MEAN $\pm$ S.D. CLINICAL AND DEMOGRAPHIC FEATURES OF PARTICIPANTS

	ALZHEIMER'S DISEASE	SEMANTIC DEMENTIA	HEALTHY SENIORS
N (male/female)	11 (4/7)	9 (9/0)	16 (4/12)
Age (years)	73.3 $\pm$ 11.2	68.33 $\pm$ 8.8	68.5 $\pm$ 8.9
Education (years)	15.3 $\pm$ 3.4	15.1 $\pm$ 3.3	15.2 $\pm$ 2.9
Disease duration (months)	6.2 $\pm$ 3.1	5.0 $\pm$ 1.7	-
MMSE (max=30)	21.6 $\pm$ 5.9	21.2 $\pm$ 6.5	-
Memory Recognition ^{†*}	-2.56 $\pm$ 1.1	-1.46 $\pm$ 1.1	-
BNT [*]	-3.94 $\pm$ 2.5	-4.88 $\pm$ 4.3	-
Pyramids & Palm Trees [*]	-3.34 $\pm$ 4.3	-3.85 $\pm$ 3.5	-

NOTE

* z-score based on performance of 25 age- and education-matched controls. A z-score of -2.32 differs from controls at the p<0.01 level.

[†] two patient groups significantly different.

TABLE 2

STIMULUS OBJECT NAMES

STIMULUS
human
cat
squirrel
robin
cobra
frog
spider
flower
comet
robot
computer
doll
bike

TABLE 3MEAN $\pm$ S.D. GROUP RATINGS IN EACH OF FOUR CONDITIONS*

CONDITION premise $\rightarrow$ conclusion	CONTROL	AD	SD
NK $\rightarrow$ NK	2.82 $\pm$ 0.68	2.50 $\pm$ 0.49	3.13 $\pm$ 0.60
AR $\rightarrow$ AR	2.31 $\pm$ 0.70	2.28 $\pm$ 0.79	2.53 $\pm$ 0.78
NK $\rightarrow$ AR	1.35 $\pm$ 0.47	1.58 $\pm$ 0.41	2.07 $\pm$ 0.84
AR $\rightarrow$ NK	1.48 $\pm$ 0.52	1.83 $\pm$ 0.48	2.14 $\pm$ 0.78

NOTE

* These scores reflect generalization judgments on a Likert scale (range 1–5), where 5 is “very likely.” AR = artifact, NK = natural kind

TABLE 4

GROUP MEAN RATINGS FOR EACH PAIR OF OBJECTS IN AN ARGUMENT

CONTROLS													
PREMISE OBJECT	CONCLUSION OBJECT												
	Human	Cat	Squirrel	Robin	Cobra	Frog	Spider	Flower	Comet	Robot	Computer	Doll	Bike
Human		3.56	3.06	2.81	2.75	3.25	2.88	2.25	1.63	1.25	1.25	1.25	1.38
Cat	3.31		3.19	3.06	3.19	3.25	2.94	2.06	1.38	1.50	1.50	1.31	1.31
Squirrel	3.25	3.31		3.13	3.13	3.44	3.06	1.88	1.56	1.31	1.25	1.25	1.25
Robin	3.19	2.88	3.00		2.75	3.25	2.94	1.69	1.38	1.38	1.25	1.31	1.25
Cobra	2.75	3.00	2.88	2.88		3.38	3.25	1.88	1.38	1.38	1.25	1.31	1.44
Frog	3.13	3.13	3.44	2.94	3.25		3.00	1.88	1.44	1.50	1.38	1.31	1.31
Spider	2.81	3.00	3.00	2.75	3.25	3.25		2.38	1.25	1.63	1.25	1.25	1.38
Flower	1.69	2.06	1.81	2.06	2.13	2.69	2.06		1.31	1.25	1.25	1.38	1.56
Comet	1.69	1.75	1.56	1.56	1.44	1.56	1.88	1.56		1.69	1.81	1.81	1.88
Robot	1.50	1.63	1.44	1.44	1.25	1.75	1.38	1.50	1.63		2.88	2.38	3.13
Computer	1.63	1.56	1.31	1.25	1.44	1.38	1.31	1.81	2.00	3.38		1.75	3.38
Doll	1.44	1.31	1.25	1.44	1.38	1.44	1.31	1.81	1.69	2.31	2.38		2.25
Bike	1.63	1.94	1.25	1.25	1.31	1.44	1.63	1.25	1.56	3.19	2.75	2.31	
SD PATIENTS													
PREMISE OBJECT	CONCLUSION OBJECT												
	Human	Cat	Squirrel	Robin	Cobra	Frog	Spider	Flower	Comet	Robot	Computer	Doll	Bike
Human		3.89	3.56	3.67	3.67	2.78	2.44	2.89	1.67	2.33	2.22	2.22	2.11
Cat	3.67		3.56	2.89	3.33	3.00	4.11	2.67	2.33	2.00	2.00	1.78	1.89
Squirrel	3.11	3.89		3.11	3.44	2.78	2.67	3.11	2.44	2.89	1.78	2.33	2.11
Robin	3.00	3.67	2.67		2.44	3.56	3.22	2.78	1.44	2.33	1.89	2.33	1.33
Cobra	3.11	3.78	3.33	3.11		3.33	3.33	3.11	2.44	2.89	2.22	2.56	1.67
Frog	3.44	3.56	3.89	3.22	3.56		2.67	3.11	2.33	2.22	1.78	1.89	1.67
Spider	2.33	3.00	3.44	2.67	2.67	3.67		2.33	1.67	2.11	1.56	1.78	2.00
Flower	2.22	3.00	2.89	3.56	2.44	2.78	2.33		2.56	2.44	1.78	1.56	2.22
Comet	2.33	1.89	2.22	2.11	2.11	2.44	2.33	1.67		2.67	2.22	1.67	2.89
Robot	2.56	1.67	2.78	2.33	2.33	2.33	2.22	2.56	2.89		3.22	2.22	3.11
Computer	2.78	1.89	1.89	1.89	2.00	2.00	2.33	1.78	2.67	2.89		2.11	3.00
Doll	1.89	2.44	2.33	2.11	1.78	1.89	1.78	2.78	1.67	2.00	2.67		2.44
Bike	1.78	1.78	2.33	2.00	1.56	2.11	2.00	2.56	2.44	2.78	2.22	2.89	
AD PATIENTS													
PREMISE OBJECT	CONCLUSION OBJECT												
	Human	Cat	Squirrel	Robin	Cobra	Frog	Spider	Flower	Comet	Robot	Computer	Doll	Bike
Human		3.27	2.82	2.64	2.45	2.91	2.18	2.09	1.55	1.45	1.64	1.45	1.36
Cat	2.55		3.45	2.82	2.82	2.64	2.45	2.73	2.27	2.09	1.45	1.45	1.27
Squirrel	2.91	3.18		2.82	2.82	3.09	1.82	2.09	1.55	1.45	1.55	1.73	1.73
Robin	2.36	2.00	3.27		2.18	2.27	2.55	1.82	2.09	1.55	1.73	1.36	1.64
Cobra	2.36	2.91	2.64	2.09		3.09	2.73	1.73	1.64	1.73	2.00	1.36	1.27
Frog	2.09	2.45	2.55	2.45	3.00		3.00	1.55	1.73	1.55	1.64	1.36	1.55
Spider	1.82	2.45	2.27	2.64	3.00	2.64		2.73	1.45	1.55	1.36	1.73	1.45
Flower	1.91	2.18	2.27	2.09	2.00	2.27	2.00		1.45	1.27	1.55	1.45	1.55
Comet	1.73	1.73	1.82	1.91	1.91	2.09	1.73	1.91		2.09	2.09	1.36	1.82
Robot	2.27	1.55	1.64	2.09	1.64	1.91	1.64	2.09	2.27		3.18	2.18	2.55
Computer	1.91	1.45	1.64	1.73	1.91	2.00	1.73	1.82	1.64	3.27		2.00	3.09
Doll	2.55	1.18	1.55	2.09	1.82	2.00	1.91	2.55	2.09	2.64	1.82		2.36
Bike	2.00	1.91	1.73	1.82	1.64	1.27	1.73	1.55	2.09	2.55	2.18	2.36	