Categorization of Novel Animals by Patients With Alzheimer’s Disease and Corticobasal Degeneration

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We taught a novel animal category by rule-based and similarity-based processes to participants with Alzheimer’s disease (AD), corticobasal degeneration (CBD), and healthy age-matched participants. Healthy participants successfully categorized by either process. AD patients’ rule-based categorization was impaired, while their similarity-based categorization resembled that of healthy participants. Correlations of AD patients’ performance with measures of executive functioning suggested a deficit in the cognitive resources necessary for engaging rule-based categorization. The contribution of limited executive resources to categorization difficulty in AD was further demonstrated in a second experiment in which features determining category membership were of lower salience. CBD patients were relatively impaired at similarity-based processing, suggesting that qualitatively distinct categorization processes can be selectively compromised in patients with focal neurodegenerative diseases. Moreover, AD patients’ impaired categorization correlated with performance on a measure of semantic memory, implicating this categorization deficit in AD patients’ semantic memory difficulty.

Keywords: Alzheimer’s disease, corticobasal degeneration, semantic, executive, categorization

Identifying an object entails placing it in a category (Smith, 1995). Hence, categorization is vital to semantic memory, our long-term knowledge of things and events. Categorization involves both knowledge about objects (e.g., their appearance and component features) and appropriately processing that knowledge (e.g., evaluating appearance and features). Although investigations of semantic memory have generally focused on stored semantic knowledge, process as well as content plays a role. Extensive evidence for semantic memory impairment in patients with neurodegenerative disease has been observed clinically as errors in naming, recognizing, or describing objects. Whereas researchers have attributed such impairment to degradation of semantic knowledge (Cappa et al., 1998; Chertkow & Bub, 1990; Devlin et al., 2002; Garrard, Patterson, Watson, & Hodges, 1998, 2001; Gonnnerman, Andersen, Devlin, Kempler, & Seidenberg, 1997; Montanes, Goldblum, & Boller, 1996; Moss & Tyler, 2000; Silveri, Daniele, Giustolisi, & Gainotti, 1991; Warrington, 1975), limited ability to apply a particular categorization process to intact knowledge could also impair semantic memory (Grossman et al., 2003; Koenig et al., 2006). In this study, we focus on the selective breakdown of categorization processes in patients with neurodegenerative disease and examine the implications of these deficits for the cognitive mechanisms that underlie semantic memory.

Similarity-based and rule-based categorization have been proposed as processes that contribute to forming concepts (Smith, Patalano, & Jonides, 1998). Similarity-based processing involves a relatively rapid perceptually based mental comparison with previously encountered exemplars or prototypes, whether actual or extracted from central tendencies (Ashby, Alfonso-Reese, Turken, & Waldron, 1998; Medin, Goldstone, & Gentner, 1993; Medin & Schaffer, 1978; Smith & Medin, 1981). This is presumably the default process for quick identification of objects. Rule-based processing assumes that some features have a special status in determining category membership (Smith, Langston, & Nisbett, 1992). This depends on executive resources such as selective attention, working memory, and inhibitory control to support discrete feature assessments and evaluate category membership criteria. This process presumably comes into play for ambiguous items (e.g., identifying whales as mammals rather than as fish) or for unfamiliar items for which there is no pre-established prototypical representation. The ability to appropriately employ both rule-based and similarity-based categorization thus seems particularly conducive to identifying the full range of items encountered in the course of daily life, and healthy individuals appear capable of implementing either process (Allen & Brooks, 1991; Grossman et al., 2003; Koenig et al., 2006; Patalano, Smith, Jonides, & Koepp, 2001; Rips, 1989; Sloman & Rips, 1998; Smith & Sloman, 1994).

In the current study, we investigated the processing components of semantic memory by teaching a novel category by similarity-based and rule-based processes to patients with Alzheimer’s disease (AD). Although the hallmark of AD is episodic memory impairment, semantic memory deficits are common (Cox, Bayles,
Trosset, 1996; Grossman et al., 1996; Grossman et al., 2006; Grossman, White-Devine, Robinson, Bissau, & D’Esposito, 1998). This may at least partially reflect rule-based categorization deficits stemming from executive resource limitations observed in AD (LaFleche & Albert, 1995; Patterson, Mack, Geldmacher, & Whitehouse, 1996): AD patients were impaired at using rule-based categorization in a study involving classification of familiar, briefly described objects (Grossman et al., 2003), consistent with their executive resource limitations. However, the use of familiar categories did not preclude an effect of degraded knowledge. Hence, in the present study we controlled content knowledge by presenting a novel semantic category. We anticipated that AD patients would have selective difficulty with rule-based categorization.

To further explore the role of categorization processes in semantic memory, we also assessed patients with corticobasal degeneration (CBD). In contrast to AD, both episodic and semantic memory are relatively preserved in CBD, a disease whose hallmark symptom is motor impairment (Mahapatra, Edwards, Schott, & Bhatia, 2004). CBD patients may also have executive resource limitations (Graham, Bak, & Hodges, 2003; Mahapatra et al., 2004). Of particular relevance to our inquiry into categorization is visuospatial impairment: CBD patients can be simulatanegous, that is, unable to attend to more than one object (or object part) at a time (Litvan, Goetz, & Lang, 2000; Mahapatra et al., 2004; Mendez, 2000; Pillon et al., 1995). Thus, they can be impaired at integrating parts to form a whole object, a limitation that could result in particular difficulty with similarity-based categorization and which can potentially contrast with patterns of spared and impaired categorization in AD.

We used a novel category in order to control the nature and familiarity of the requisite knowledge needed for the task, and thus isolate the effects of processing deficits. Many previous studies with AD patients used meaningless categories such as artificial grammars (Knowlton, Ramus, & Squire, 1992; Reber, Martinez, & Weitnraub, 2003) and dot patterns (Keri et al., 1999), raising questions about the generalizability of the findings to semantically meaningful categories. Our stimuli were realistic illustrations of biologically plausible novel animals, intended to capture some of the qualities of semantically meaningful categories. For Experiment 1, we formed a category based on the most salient features. The category was constructed so that members were likely to be perceived as resembling each other, and our categorization rules were consistent with this perceived resemblance. We expected AD patients to have difficulty using rules while being able to learn the novel category by a process involving similarity to a central tendency. In addition, we correlated AD patients’ categorization performance results with semantic and executive assessment tasks in order to elucidate links between categorization processing deficits and semantic memory for familiar items. In contrast, we expected the CBD patients’ visuospatial deficit to cause difficulty in performing the overall comparisons necessary for similarity-based categorization. For Experiment 2, we further examined the role of executive functions in category learning by forming a category that excluded the most salient features and included the least salient ones. Thus, processing the category structure required executive resources such as selective attention and inhibitory control even during similarity-based learning. We expected the AD

**Participants**

Eighteen AD patients, 8 CBD patients, and 20 healthy age- and education-matched individuals participated. The patients were mildly to moderately demented according to the Mini-Mental State Exam (MMSE; Folstein, Folstein, & McHugh, 1975), and were matched in their dementia severity. All participants were right-handed native speakers of English, except for one AD patient who had been a fluent speaker throughout adulthood, but whose native language was Dutch. The diagnosis of the AD patients was based on criteria from the National Institute of Neurological and Communicative Diseases and Stroke/Alzheimer’s Disease and Related Disorders Association (NINCDS–ADRDA; McKhann et al., 1984). These criteria include a progressive anterograde memory deficit early in the disease process, associated with naming and language difficulty, visual impairment, and/or executive limitation. CBD patients were given a clinical diagnosis based on clinical–pathological studies reported in the literature (Forman et al., 2006; Litvan et al., 2001; Murray et al., in press; Riley et al., 1990; Rinne, Lee, Thompson, & Marsden, 1994). These patients had evidence for apraxia, naming difficulty, visual perceptual–spatial difficulty, cortical sensory loss, and/or other features of a parietal disorder, such as acalculia with an asymmetric extrapyramidal disorder (e.g., myoclonus, dystonia, alien hand syndrome, rigidity) but little resting tremor. We excluded patients with other causes of dementia such as vascular disease orhydrocephalus, 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. Some of the patients were taking medications at the time of testing, such as acetylcholinesterase inhibitors or serotonin-specific reuptake inhibitors, as needed clinically, but none of these medications were sedating or known to have an impact on semantic memory. Demographic information, MMSE score means, and assessment measures of episodic memory and visuospatial processing are provided in Table 1.

The two experimental conditions, rule and similarity, are described below. Most patients participated in both conditions in counterbalanced order at least 1 month apart to avoid contaminating the different learning conditions. Healthy individuals participated in one randomly assigned condition. Rule condition participants included 14 AD patients and 7 CBD patients. All of the 18 AD and 8 CBD patients participated in the similarity condition.

**Stimuli**

We created a set of 64 realistic images of biologically plausible novel animals, representing all possible combinations of six binary features. Each feature’s relative contribution to subjective assessments of resemblance among the animals was ascertained via multidimensional scaling analyses, for one through six dimensions, performed on similarity judgments of all possible animal
Table 1
Participant Demographic and Neuropsychological Testing Information

<table>
<thead>
<tr>
<th>Participant group</th>
<th>Gender</th>
<th>Age (M, SD)</th>
<th>Years of Education (M, SD)</th>
<th>MMSE (M, SD)</th>
<th>Recall (M, SD)</th>
<th>Recognition (M, SD)</th>
<th>Visual construction (M, SD)</th>
<th>Spatial location (M, SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy participants</td>
<td>7 m, 13 f</td>
<td>68.2 (6.2)</td>
<td>15.1 (2.5)</td>
<td>29.0 (1.9)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AD patients</td>
<td>8 m, 10 f</td>
<td>69.5 (6.9)</td>
<td>14.8 (3.5)</td>
<td>23.2 (4.1)</td>
<td>0.4 (0.7)</td>
<td>13.9 (2.7)</td>
<td>9.4 (1.6)</td>
<td>6.9 (1.7)</td>
</tr>
<tr>
<td>CBD patients</td>
<td>3 m, 5 f</td>
<td>64.5 (4.0)</td>
<td>13.8 (2.0)</td>
<td>20.7 (5.4)</td>
<td>1.5 (0.9)</td>
<td>17.3 (1.7)</td>
<td>4.8 (3.1)</td>
<td>15.9 (9.9)</td>
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<tr>
<td>Healthy participants</td>
<td>8 m, 10 f</td>
<td>73.2 (8.1)</td>
<td>14.3 (2.0)</td>
<td>29.1 (0.9)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AD patients</td>
<td>8 m, 11 f</td>
<td>70.9 (9.1)</td>
<td>14.1 (2.7)</td>
<td>21.3 (9.2)</td>
<td>0.6 (1.0)</td>
<td>13.5 (2.9)</td>
<td>9.1 (1.7)</td>
<td>8.4 (2.5)</td>
</tr>
<tr>
<td>CBD patients</td>
<td>5 m, 4 f</td>
<td>70.1 (10.8)</td>
<td>14.2 (3.4)</td>
<td>20.1 (6.5)</td>
<td>2.1 (1.9)</td>
<td>17.5 (1.5)</td>
<td>6.0 (2.3)</td>
<td>12.9 (6.9)</td>
</tr>
</tbody>
</table>

Note. AD = Alzheimer’s disease; CBD = corticobasal degeneration. Recall and recognition assessments involved word lists, with maximum scores of 10 (all words correctly recalled) and 20 (10 words from list recognized and 10 foils rejected), respectively. Visual construction involved copying overlapping geometric figures, with a maximum correct score of 11. Spatial location involved reproducing a dot within a rectangle, with scores measuring error in centimeters; hence, higher score indicates higher error rate.

Pairs. Four features were revealed as discernibly affecting similarity judgments. A category was created on the basis of those four features, that is, snout, legs, color, and neck; these are referred to as “contributing” features. A prototype animal was chosen at random. Twenty designated category members matched the prototype in at least three contributing features. The 24 low-distortion items matched the prototype in exactly two contributing features; the 20 high-distortion items matched the prototype in no more than one contributing feature. The two noncontributing features (teeth and tail) served as irrelevant, “distractor” features and were equally represented within each of these three stimulus types.

Training items were 40 unique pairs created from one each of eight members and eight high-distortion items. The pairs were arranged such that each member and high-distortion item appeared once within every eight contiguous trials, and particular combinations of contributing features and distractor features were equally represented and distributed in no discernible pattern. The pairs occupied the lower half of the presentation computer screen in each of two training conditions, described below.

Procedure

Training. Procedures for both training conditions involved sequential presentation of the same training item pairs. In the rule condition, the stimulus displays included captioned outlines of the four contributing features. Participants were told that an animal called a crutter had to have any three of the four features, and were asked to indicate which animal in each pair was a crutter in accordance with the “at least three of four features” rule. In the similarity condition, the stimulus displays included the prototype. Participants were told that the prototype was an animal called a crutter and were asked to indicate which animal in each pair was also crutter based on its overall resemblance to the sample crutter. Figure 1 shows sample training-trial images. Participants had up to 15 s to respond by key press, and the experimenter provided feedback. All participants saw at least the first 16 pairs, that is, they were exposed to each member and each high-distortion training item minimally twice. If a participant chose correctly for at least seven out of eight succeeding contiguous pairs, training ended; otherwise, all 40 pairs were shown. Responses and reaction times (RTs) were recorded.

Testing. Testing was identical for both conditions. Participants saw a sequential presentation of the entire set of 64 animals in a fixed pseudo-random order in which items of any one stimulus type appeared no more than three times contiguously and judged whether each was a crutter. Participants were provided with “reminder” cards showing the features or the prototype to ensure that difficulties in categorization could not simply be attributed to episodic memory deficits. The use of memory aids of this type is an established technique for assessing cognitive processes in participants with impaired episodic memory (Oscar-Berman & Samuels, 1977). Identical reminder cards and test stimuli were used in the similarity conditions in Experiments 1 and 2, yet systematically different responses to the test items were elicited, demonstrating that the patients were not simply relying on the reminder cards at test. Participants had up to 15 s to respond by key press, and no feedback was provided. Responses and RTs were recorded.

Tasks Assessing Executive Function, Memory, and Semantic Impairment

Patients were assessed on three standard tests measuring executive function: the Stroop task; generation of words beginning with f, a, and s; and reverse digit span. Patients’ memory for recently encountered items was assessed with a validated, 10-word supra-span recall-and-recognition list-learning test (Welsh, Butters, Hughes, Mohs, & Heyman, 1991). Semantic impairment was assessed with the semantic decision task (Grossman et al., 1996): Patients indicated whether 48 familiar items, presented in blocked sequences of pictures and of printed words, belong to a target category. The items include equal numbers of category targets and foils, and the latter, in turn, contain equal numbers of items that are related or unrelated to the target category. For the target category vegetable, related foils are fruits, and unrelated foils are tools and furniture. For the target category tools, related foils are furniture, and unrelated foils are fruits and vegetables. Judgments require
Figure 1. Training trial examples, Experiment 1.
categorization processes analogous to those being assessed in the current study: Similarity-based categorization should suffice for distinguishing an unrelated foil target from a target (e.g., deciding that a hammer is not a vegetable) because the foil is so unlike any exemplar of the target category. However, rule-based categorization is presumably needed to distinguish between a target and a perceptually similar related foil (e.g., selecting diagnostic features, such as “grows on trees,” in deciding that an apple is not a vegetable).

Results

Training performance measures included the number of trials needed to reach our learning criterion and reaction times for responses. Test measures included membership judgments, RTs for correct responses to members, and correlation of performance with assessments of executive function, memory, and semantic competence. Reported effect sizes are partial eta squared values for analyses of variance (ANOVAs) and Cohen’s d values for t tests.

Training

Across conditions, healthy participants required the least number of trials, and CBD patients required the most, as confirmed by an ANOVA with a main effect of group, F(2, 61) = 10.40, p < .001, η² = .25, and a Group × Condition interaction, F(2, 61) = 6.66, p < .05, η² = .18. AD patients required more trials for the rule-based condition, and CBD patients required more trials for the similarity-based condition. The mean numbers of training trials required to learn the category are shown in Figure 2; RTs are shown in Table 2. Subsequent comparisons are by t test.

Healthy participants required only the set minimum of trials in the rule condition, and close to the minimum in the similarity condition. These ceiling effects precluded reliable statistical comparisons of these means. Healthy participants’ RTs did not differ across conditions.

AD patients required significantly more trials in the rule condition than in the similarity condition, t(30) = 2.05, p < .05, d = .71. They did not differ from healthy participants in the number of trials required for similarity training but required significantly more trials than did healthy participants for rule training, t(22) = 2.81, p = .01, d = 1.26. AD patients’ RTs were significantly greater for rule-based training relative to similarity-based training, t(28) = 4.10, p < .001, d = 1.51.

In contrast to the AD patients, CBD patients required significantly more trials for similarity-based than for rule-based training, t(13) = 2.33, p < .05, d = 1.21, and significantly more trials for similarity training than required by healthy participants, t(16) = 5.25, p < .001, d = 2.36, and by AD patients, t(24) = 4.42, p < .001, d = 1.76. CBD patients also required significantly more trials for rule-based training than did healthy participants, t(15) = 3.04, p < .01, d = 1.34, but an equivalent number to that of AD patients. RTs for CBD patients were essentially identical across conditions.

Test

We calculated the percentage by which participants endorsed each stimulus type as a category member. These scores are summarized in Figure 3; latencies for correctly judging members are summarized in Table 2. Successful rule-based and similarity-based categorization should yield characteristically distinct judgment profiles: For rule-based judgments, members must be endorsed as such, whereas both low-distortion and high-distortion items must be considered nonmembers. For similarity-based judgments, endorsements should reflect an item’s degree of resemblance to the prototype such that low-distortion items would be endorsed about half of the time. We used repeated measure ANOVAs to compare between-condition and between-group performance. We used t tests to compare corresponding scores across groups and conditions.

Healthy participants. Healthy participants’ judgments show the expected categorically bounded response pattern for rule-based categorization and a graded response pattern for similarity-based categorization. Overall learning was demonstrated by a main effect of stimulus type across conditions, F(2, 36) = 227.71, p < .001, η² = .93. Between-condition differences were confirmed by a main effect of condition, F(1, 18) = 5.94, p < .05, η² = .25, and a Stimulus Type × Condition interaction, F(2, 36) = 31.51, p < .001, η² = .64. Healthy participants’ scores differed across the two conditions for all three stimulus types; members received a higher endorsement score, and low- and high-distortion items received lower ones, in the rule condition relative to the similarity condi-
tion. These differences all reached significance in t tests: \( t(18) = 4.81, p < .001, d = 2.15 \), for comparisons between members; \( t(18) = 4.97, p < .001, d = 2.22 \), for comparisons between low-distortion items; and \( t(18) = 3.37, p < .01, d = 1.51 \), for comparisons between high-distortion items. The longer RTs for rule-based relative to similarity-based endorsements of members approached significance, \( t(18) = 2.02, p < .06, d = 0.90 \), consistent with the greater processing demands of rule-based judgments.

**Alzheimer’s disease patients.** In contrast to the healthy participants, AD patients showed a graded response pattern for both similarity- and rule-based conditions. Category learning overall was demonstrated by a main effect of stimulus type, \( F(2, 60) = 101.81, p < .001, \eta^2 = .77 \); however, there was neither a main effect of condition, \( F(1, 30) = 2.04, ns, \eta^2 = .06 \), nor a Stimulus Type \( \times \) Condition interaction, \( F(2, 60) = 2.16, ns, \eta^2 = .07 \). AD patients’ similarity-based performance was essentially identical to that of healthy participants; analyses revealed neither a main effect of group, \( F(1, 26) = 0.21, ns, \eta^2 = .01 \), nor a Group \( \times \) Stimulus Type interaction, \( F(1, 26) = 0.99, ns, \eta^2 = .04 \). In contrast, AD patients’ rule-based performance was less accurate than that of healthy participants, as revealed by a marginal main effect of group, \( F(1, 22) = 3.43, p < .08, \eta^2 = .14 \), and a Group \( \times \) Stimulus Type interaction, \( F(2, 44) = 16.81, p < .001, \eta^2 = .43 \). Rule scores were less accurate than those of healthy participants for all stimulus types: for members, \( t(22) = 4.15, p < .001, d = 1.84 \); for low-distortion, \( t(22) = 2.99, p < .01, d = 1.24 \); for high-distortion, \( t(22) = 3.55, p < .005, d = 1.59 \). AD patients took significantly longer to correctly respond to members in the rule-based condition relative to the similarity-based condition, \( t(30) = 4.94, p < .001, d = 1.76 \).

Correlations of AD patients’ categorization performance with neuropsychological measures are summarized in Table 3. Each measure of executive function correlated significantly with rule performance, but not with similarity performance, emphasizing the role of limited executive resources in AD patients’ rule-based categorization deficit. None of the recall and recognition measures correlated with performance in either condition, suggesting that competence in either of the categorization tasks was not a function of episodic memory.

AD patients’ performance in the semantic decision task also correlated very highly with their rule-based categorization performance (Table 3). To examine the relationship between rule use and semantic memory, we analyzed the responses of two subgroups of AD patients: those who scored at or above the median in the semantic decision task (high scorers, \( n = 7 \)) and those who scored below (low scorers, \( n = 6 \)). The results are presented in Figure 4. An ANOVA confirms that the high and low scorers performed equivalently in the similarity condition: There was no effect of scorer (high vs. low), \( F(1, 16) = 0.06, ns, \eta^2 = .00 \), nor a Scorer \( \times \) Stimulus Type interaction, \( F(2, 32) = 0.40, ns, \eta^2 = .02 \). However, the high and low scorers’ judgments were distinctly different in the rule condition, suggesting particular difficulty with rule use by those AD patients who did poorly on the semantic decision task and relatively spared rule use by the higher scoring group. There was a main effect of scorer (high vs. low), \( F(1, 12) = 32.57, p < .001, \eta^2 = .73 \), and a Scorer \( \times \) Stimulus Type interaction, \( F(2, 24) = 11.97, p < .001, \eta^2 = .50 \). In addition, the low scorers in the rule condition performed equivalently to the entire group of AD patients in the similarity condition; there was no effect of condition, \( F(1, 23) = 0.18, ns, \eta^2 = .01 \), nor a Condition \( \times \) Stimulus Type interaction, \( F(2, 46) = 2.09, ns, \eta^2 = .08 \).

**Corticobasal degeneration patients.** CBD patients showed difficulty with similarity-based as well as with rule-based categorization. Like the AD patients, CBD patients’ performance showed a main effect of stimulus type, \( F(2, 26) = 26.68, p < .001, \eta^2 = .67 \), and neither an effect of condition, \( F(1, 13) = 0.08, ns, \eta^2 = .01 \), nor a Condition \( \times \) Stimulus Type interaction, \( F(2, 26) = 1.24, ns, \eta^2 = .04 \). In addition, CBD patients’ scores for the three stimulus types did not differ across the two conditions. Like the AD patients, CBD patients’ rule scores differed from those of the healthy participants, as revealed in a Group \( \times \) Stimulus Type interaction, \( F(2, 30) = 14.57, p < .001, \eta^2 = .49 \). However, unlike the AD patients, CBD patients’ similarity scores differed from those of the healthy participants as well, as revealed in a Group \( \times \) Stimulus Type interaction that neared significance, \( F(2, 32) = 2.61, p < .09, \eta^2 = .14 \), reflecting significantly lower scores for members (\( d = 1.12 \)). Table 2 shows that, in contrast to those of the AD patients, CBD patients’ RTs were essentially equivalent across the two conditions.

Detailed inspection of CBD patients’ response patterns underlined their difficulty with attending to more than an individual

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**Table 2**

**Mean Response Reaction Times (in Milliseconds) During Training and Test for Endorsed Members**

<table>
<thead>
<tr>
<th>Participant group</th>
<th>Rule</th>
<th>Similarity</th>
<th>Rule</th>
<th>Similarity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Training</td>
<td>Test</td>
<td>Training</td>
<td>Test</td>
</tr>
<tr>
<td></td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
</tr>
<tr>
<td>Healthy older participants</td>
<td>7,160 (495)</td>
<td>5,551 (754)</td>
<td>4,077 (251)</td>
<td>7,404 (788)</td>
</tr>
<tr>
<td>AD patients</td>
<td>10,049 (402)</td>
<td>8,280 (369)</td>
<td>7,004 (371)</td>
<td>5,209 (504)</td>
</tr>
<tr>
<td>CBD patients</td>
<td>10,046 (355)</td>
<td>9,913 (712)</td>
<td>7,404 (788)</td>
<td>7,240 (722)</td>
</tr>
</tbody>
</table>

**Experiment 1**

<table>
<thead>
<tr>
<th>Participant group</th>
<th>Rule</th>
<th>Similarity</th>
<th>Rule</th>
<th>Similarity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Training</td>
<td>Test</td>
<td>Training</td>
<td>Test</td>
</tr>
<tr>
<td></td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
</tr>
<tr>
<td>Healthy older participants</td>
<td>7,252 (498)</td>
<td>6,568 (460)</td>
<td>4,277 (356)</td>
<td>3,106 (457)</td>
</tr>
<tr>
<td>AD patients</td>
<td>9,452 (383)</td>
<td>7,152 (404)</td>
<td>7,132 (437)</td>
<td>4,207 (397)</td>
</tr>
<tr>
<td>CBD patients</td>
<td>8,924 (603)</td>
<td>9,027 (737)</td>
<td>5,662 (1,221)</td>
<td>5,536 (446)</td>
</tr>
</tbody>
</table>

**Note.** AD = Alzheimer’s disease; CBD = corticobasal degeneration.
stimulus feature and, hence, their particular difficulty with similarity-based processing. Five CBD patients in the similarity condition, or 63%, and 3 patients in the rule condition, or 43%, focused on a single feature, that is, they endorsed most items containing a particular feature variant and rejected essentially all items lacking it. Whereas most of these patients focused on a contributing feature, one patient in the similarity condition focused on a distractor feature. The 3 patients in the rule condition all showed the same feature preference (the leg feature), as did one of the patients in the similarity condition. This suggests that this feature was most easily attended to by the CBD patients, even though it was not the highest contributor to inter-item resemblance in judgments by healthy individuals. We examined the endorsement scores for groups of CBD patients who did and did not focus on a single feature; performance profiles are summarized in Figure 5. Although there were too few patients for reliable statistical analyses, the scores are suggestive: The “feature-focus” subgroups performed equivalently across conditions, with scores conforming to the apparent “similarity-based” gradation that automatically occurs with this strategy. The judgments of CBD patients who did not focus on a single feature allowed an assessment of performance when not clouded by the perceptual attraction to an individual feature. These CBD patients demonstrated reasonable rule-based categorization, endorsing most members while rejecting most low- and high-distortion items. By comparison, CBD patients who did not focus on a single feature were quite impaired in their similarity-based categorization performance, exhibiting an endorsement pattern across stimuli that was nearly flat.

Because CBD patients’ performance was strongly influenced by the tendency to focus on an individual feature, mean performance scores masked the actual categorization strategies that these patients used, and thus overall accuracy was not a straightforward indication of successful categorization by the processes of interest in either condition for this patient group. Hence, correlations with assessment measures comparable to those reported for the AD patients would not be informative.

Summary. Healthy participants successfully used qualitatively distinct processes in our two categorization conditions, both during training and at test. AD patients demonstrated impaired rule-based processing and intact similarity-based categorization. Rule-based training posed a significant challenge for these patients, both in relation to their own similarity-based training and in relation to rule-based training for healthy participants. At test, AD patients’ selective rule-based deficit was evident in their inaccurate judgments and longer latencies. Significant correlations between rule-based categorization and performance on executive measures emphasized the role of limited executive resources in AD patients’ categorization deficit. Correlations between rule-based categorization and the semantic decision task implicated AD patients’ categorization difficulty in their semantic impairment for familiar objects. CBD patients’ judgments were impaired in both processing conditions, with a particular disadvantage for the overall comparisons necessary for similarity-based processing. CBD patients required more trials during similarity-based learning. CBD patients’ difficulty in perceiving objects in their entirety also appeared to interfere with similarity-based categorization at test: About half of the CBD patients used a strategy focusing on a single feature, utilizing the same approach as their counterparts in the rule condition. Moreover, patients whose performance was not clouded

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**Figure 3.** Mean (and standard error) endorsement of stimuli during Experiment 1 test for each group. AD = Alzheimer’s disease; CBD = corticobasal degeneration; Dist. = distortion.
by focusing on a single feature seemed to have relatively preserved rule-based processing but highly impaired similarity-based processing.

Experiment 2

The category used in Experiment 1 involved subjectively salient features. Classification, however, does not always fit as smoothly with perceived resemblance: Salient but misleading features must sometimes be overridden, as in classifying penguins as birds despite their upright posture and swift underwater swimming. Learning to categorize unfamiliar items can entail overcoming initial attentional preferences, such as a novice gardener first classifying flowers by color and, only later, with experience, attending to petal structure. We designed Experiment 2 to place greater demands on selective attention and inhibitory control by

![Figure 4](image1.png)

*Figure 4.* Mean (and standard error) performance of Alzheimer’s disease subgroups (high vs. low semantic decision scorers) in Experiment 1. Dist. = distortion.

![Figure 5](image2.png)

*Figure 5.* Mean (and standard error) performance of corticobasal degeneration subgroups (feature focus vs. no feature focus) in Experiment 1. Dist. = distortion.

### Table 3

<table>
<thead>
<tr>
<th>Experimental condition</th>
<th>Semantic decision overall accuracy</th>
<th>Semantic decision–related foils Stroop</th>
<th>Reverse digit span</th>
<th>f. a. s category naming fluency</th>
<th>Episodic memory recognition</th>
<th>Episodic memory recall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rule</td>
<td>.84**</td>
<td>.65*</td>
<td>.79**</td>
<td>.56*</td>
<td>.68**</td>
<td>-.39</td>
</tr>
<tr>
<td>Similarity</td>
<td>-.01</td>
<td>-.25</td>
<td>.41</td>
<td>.33</td>
<td>.08</td>
<td>.33</td>
</tr>
</tbody>
</table>

* p < .05. ** p < .01.
using the four least salient of the six variable features, such that categorization involved directing attention toward the two least salient features and away from the two most salient ones.

We expected this change in feature salience to affect our two categorization processing conditions differently and thus to have distinctive consequences for performance among the participant groups. Rule-based training involved examining items for discrete features that are presented in isolation, making it possible to perform the task analytically and without forming complete exemplar representations. While the six features contribute unequally to resemblance assessments, pilot studies suggest that they are all readily discernible by healthy individuals. Rule-based categorization of our stimuli, therefore, should be relatively unaffected by the change in the category’s feature salience. Hence, we expected healthy participants’ rule-based judgment profiles for the two experiments to be comparable. We also did not expect a change in AD patients’ rule-based categorization.

Similarity-based categorization is inherently tied to perceived salience. Hence, although we assumed that healthy participants could learn the less salient category by a similarity-based process, we anticipated a modest increase in difficulty because of the greater requirement in selective attention to less salient features. We expected AD patients’ similarity-based performance to be impaired with this low-salience target, reflecting this patient group’s limitations in executive resources. For CBD patients, we anticipated continued reliance on strategies focusing on a single feature.

Method

Participants

Twenty AD patients, 9 CBD patients, and 18 healthy age- and education-matched individuals participated. The diagnoses of the patients and their criteria for inclusion and exclusion were the same as in Experiment 1. Demographic information, MMSE score means, and measures of episodic memory and visuospatial processing are provided in Table 1.

As in Experiment 1, there were two experimental conditions, rule-based and similarity-based, and participants participated in one or both conditions in counterbalanced order, at least 1 month apart. Rule condition data included 15 AD patients, 1 of whom participated in that condition only, 6 CBD patients, and 9 healthy participants. Similarity condition data included 18 AD patients, 3 of whom participated in that condition only, 9 CBD patients, and 9 healthy participants.

Stimuli

Stimuli were the same set of 64 novel animals used in Experiment 1, with the same animal serving as the prototype, and with membership determined by matches on at least three of four designated features. Unlike Experiment 1, the contributing features were those four identified as being the least salient. Two of these features had also served as contributing features in Experiment 1, whereas the remaining two had served as distractor features in Experiment 1. Two features that had served as contributing features in Experiment 1, and which had contributed most strongly to the previously described resemblance-based assessments, served as distractor features in Experiment 2. We refer to the category in Experiment 2 as the “discordant” category and the category in Experiment 1 as the “concordant” category.

Procedure

Experiment 2 differed from Experiment 1 only in the features designated as contributing or noncontributing to the category, and thus in the particular stimulus items designated as members, low-distortion items, and high-distortion items. Hence, as in Experiment 1, there were separate rule-based and similarity-based training conditions followed by a single test procedure. Participants in the rule-based training condition were shown captioned outlines of the set of four features that constituted the categorization rule in Experiment 2 and were instructed as they had been in Experiment 1. Participants in the similarity-based training condition were shown the identical “example crutter” (i.e., the prototype) as were participants in Experiment 1. The test session was identical to that in Experiment 1 except for the reordering of three items to avoid more than three sequential trials of any one item type.

Results

Training

The numbers of training trials needed to reach the learning criterion by each group in each condition are shown in Figure 2; RTs are shown in Table 2. As in Experiment 1, healthy participants required the least number of training trials, and CBD patients required the most. These differences are captured in the ANOVA’s main effect of group, $F(2, 59) = 10.80, p < .001, \eta^2 = .27$. The results differ from Experiment 1 in that both patient groups required approximately the same number of training trials across conditions: Unlike Experiment 1, there was no Group x Condition interaction, $F(2, 59) = 1.16, ns, \eta^2 = .04$. Subsequent comparisons are by $t$ test.

Healthy participants required essentially the equivalent number of trials for rule-based training in Experiment 2 as in Experiment 1. The greater number of trials required for training by similarity in Experiment 2 than in Experiment 1 did not reach significance. Healthy participants also took marginally longer to respond in the rule condition relative to the similarity condition, $t(16) = 1.78, p = .09, d = .84$. AD patients required essentially as many trials for training by similarity as for training by rule in Experiment 2, although they again took significantly longer to respond during the rule condition, $t(32) = 3.25, p < .01, d = 1.11$. In addition, AD patients required marginally more trials for similarity-based training in Experiment 2 than in Experiment 1, $t(32) = 1.68, p = .10, d = .57$, and had significantly greater latencies for similarity-based training in Experiment 2 than in Experiment 1, $t(32) = 2.06, p < .05, d = .71$. CBD patients required as many trials for training by rule as for training by similarity, and their RTs were essentially identical across conditions. They required significantly more training trials for rule-based training in Experiment 2 than in Experiment 1, $t(11) = 2.28, p < .05, d = 1.25$.

Test

Endorsement scores are summarized in Figure 6; latencies for correctly judging members are summarized in Table 2. Analyses are analogous to those performed in Experiment 1. In addition, we examined judgments of items in Experiment 2 according to
whether they shared salient features with the prototype, in order to further assess the role of selective attention and inhibitory control. Eleven members were “salient members”; these had at least three salient features, that is, the two most salient of the four contributing features along with one salient distractor feature. Nine members were “nonsalient members,” whose contributing features included no more than two salient features and contained no salient distractor features. We examined responses to these items plus nine “salient nonmembers,” that is, items that had at least three salient features but were not members of the discordant category because most of their salient features served as distractor features for this category.

Healthy participants. Healthy participants showed distinct patterns of response for rule- and similarity-based conditions while demonstrating somewhat greater difficulty for the similarity condition in Experiment 2 relative to Experiment 1. Overall learning was demonstrated by a main effect of stimulus type, $F(2, 32) = 149.32, p < .001, \eta^2 = .90$. Between-conditions differences were confirmed by a main effect of condition, $F(1, 26) = 20.18, p < .001, \eta^2 = .46$, and a Stimulus $\times$ Condition interaction, $F(2, 32) = 40.93, p < .001, \eta^2 = .72$. Judgment patterns were essentially identical for rule-based processing across Experiments 1 and 2, as confirmed by an ANOVA showing no effect of experiment, $F(1, 17) = 0.21, ns, \eta^2 = .01$. However, responses for the similarity conditions across Experiments 1 and 2 differed slightly, as demonstrated by a main effect of experiment that neared significance, $F(1, 17) = 4.18, p < .06, \eta^2 = .20$. Healthy participants in Experiment 2 were less likely to reject nonmembers than in Experiment 1: $t$ tests revealed endorsement scores that were significantly higher for low-distortion items, $t(16) = 2.58, p < .05, d = 1.19$, and marginally so for high-distortion items, $t(17) = 1.91, p = .07, d = .88$. This reflected healthy participants’ tendency to overendorse salient nonmembers in the similarity condition: These items were endorsed at chance levels, that is, 55%, whereas in Experiment 1, only 29% of nonmembers were endorsed, differing from chance ($p = .05$). Healthy participants took significantly longer to correctly respond to members in the rule-based condition relative to the similarity-based condition in Experiment 2, $t(16) = 2.55, p < .05, d = 1.20$. Latencies for corresponding conditions across experiments did not differ.

Alzheimer’s disease patients. AD patients’ categorization deficit was not limited to the rule-based condition in Experiment 2 but also included some difficulty with the similarity condition. For AD patients, overall learning in Experiment 2 was demonstrated by a main effect of stimulus type, $F(2, 62) = 73.36, p < .001, \eta^2 = .70$. AD patients’ performance revealed no main effect of condition, $F(1, 31) = 1.45, ns, \eta^2 = .05$, but there was a Stimulus Type $\times$ Condition interaction, $F(2, 62) = 8.22, p = .001, \eta^2 = .21$, reflecting the flatter slope of the similarity-based judgments. AD patients’ similarity-based profile in Experiment 2 was also flatter than the corresponding condition in Experiment 1, as revealed by an Experiment $\times$ Stimulus Type interaction, $F(2, 68) = 3.15, p < .05, \eta^2 = .09$. Results from $t$ tests revealed that this interaction derived from the lower endorsement scores for members during similarity-based performance in Experiment 2, $t(34) = 2.50, p < .05, d = .83$. In contrast to Experiment 1, AD patients’ similarity-based scores were also significantly less accurate for members than those of healthy participants, $t(25) = 2.16, p < .05, d = .91$. As predicted, rule-based performance was essentially the same across experiments in AD, showing neither a main effect of experiment,

Figure 6. Mean and standard error endorsement of stimuli during Experiment 2 test for each group. AD = Alzheimer’s disease; CBD = cortico-basal degeneration; Dist. = distortion.
ments of the subset of members with salient features along with chance responses to the subset of members without salient features. Many CBD patients again used a feature-focus strategy for both categorization conditions. Longer latencies in Experiment 2 and more trials needed to complete similarity-based training relative to Experiment 1, along with the ‘preferred’ focal feature revealed in Experiment 1 no longer being a diagnostic option, suggest that the less salient features posed difficulties for this patient group.

Discussion

The current study was designed to link categorization processes with semantic memory by assessing similarity- and rule-based learning of a semantically meaningful novel category in patients with AD and correlating performance with semantic classification of familiar objects. The categorization processes were investigated further by assessments of performance by patients with cortico-basal degeneration. The qualitative distinctions between the two categorization processes were evident in the performance of healthy older participants: Following similarity-based training, these individuals’ membership endorsements reflected items’ resemblance to the prototype; following rule-based training, their endorsements honored the category boundary imposed by the rules. The executive resource demands of rule-based processing were evident in the longer latencies for rule-based relative to similarity-based judgments.

AD patients had significant rule-based categorization difficulty. This patient group required more training trials and had longer response times, relative to their own performance in the similarity-based condition and relative to the rule-based performance of healthy participants. Rule-based categorization at test was significantly impaired, showing a graded performance pattern rather than the sharp distinction between members and nonmembers seen in healthy participants. Residual use of rule-based categorization at test was seen only for those AD patients who did well in the semantic decision assessment task. This is consistent with individual patient analyses that show semantic memory difficulty in a subgroup of AD patients (Garrard et al., 1998; Grossman et al., 1996, 2006). The semantic decision task compares classification of familiar items that vary in their relatedness with a target category and is designed to elicit categorization processes analogous to those explicitly used in the current study. We believe that intact feature knowledge includes information that is required for category membership (e.g., lettuce has leaves) as well as information that is characteristically descriptive but not essential (e.g., lettuce is green). We presume that individuals who successfully use rules to categorize familiar objects can evaluate features for their potential to contribute to object meaning and select ones that are appropriate. The AD patients who did poorly on the semantic decision task had difficulty only with related foils, that is, items that share features with the target category but do not belong to it and, hence, presumably require rule-based processing for feature assessment (Grossman et al., 2006). The strong correlation between AD patients’ performance on a task involving rule-based processing of known objects and their explicit rule-based categorization of our novel stimuli suggests that a comparable ability to use rule-based categorization underlies performance in both tasks. By comparison, AD patients’ performance following similarity-based training in Experiment 1 was equivalent to that of healthy
participants. AD patients’ success at rejecting unrelated foils on the semantic decision task suggests that sufficient object knowledge is retained for using similarity-based processes to distinguish among familiar but unrelated categories. Although we cannot rule out some degraded feature knowledge in AD (Chertkow et al., 1990; Garrard et al., 1998; Garrard et al., 2001; Gonnerman et al., 1997; Montanes, Goldblum & Boller, 1995; Montanes et al., 1996; Silveri et al., 1991), the observations in the present study suggest that a rule-based categorization deficit also contributes to AD patients’ semantic memory difficulty.

The correlations between AD patients’ rule-based categorization difficulty and their performance on tests of executive function support the view that a limitation of executive resources such as working memory, inhibitory control, and selective attention contribute to their deficit with rule-based processing. The feature salience manipulation in Experiment 2 introduced the need for executive resources such as selective attention and inhibitory control in similarity-based categorization: Successful categorization required overcoming initial attentional tendencies and learning, over the course of training, to redirect that attention to features of lesser salience. The decreased accuracy in judging the discordant category following similarity-based training, reflecting selective difficulty in endorsing members with nonsalient features and rejecting nonmembers with salient features, further demonstrates the role of deficits in selective attention and inhibitory control in AD, and supports our view of the role of limited executive resources in their semantic memory impairment. Moreover, AD patients’ episodic memory impairment, that is, the hallmark symptom of AD, showed no correlation with performance in either categorization condition, suggesting that semantic memory impairment in AD is relatively independent of episodic memory deficits, at least in the mild-to-moderate stage of the disease.

CBD patients also had impaired categorization, but their performance pattern differed from that of AD patients. Approximately half of the CBD patients focused on an individual feature at test, that is, they used a simplified rule regardless of the preceding training condition. In the similarity-based condition, judgments resulting from this strategy superficially approximated successful similarity-based categorization. CBD patients who did not use this strategy showed no evidence of successful similarity-based categorization. CBD patients who did not use this strategy showed no evidence of successful similarity-based categorization, although they honored the category boundary in the rule-based condition in Experiment 1. CBD patients thus appear to have difficulty making overall resemblance comparisons, which interfered with their similarity-based categorization. This was most apparent in Experiment 1, in which more training trials, and more time per trial, were required for similarity-based training relative to rule-based training. The presentation of features in isolation during the rule condition presumably facilitated attending to individual features, but as the training display in the similarity condition did not provide this advantage, responses were slower and less accurate. Hence, this patient group’s impaired categorization seems likely to be at least partly related to the visuospatial difficulty, including simultanagnosia, that is characteristic of their disease. Additional work is needed to determine the basis for CBD patients’ impaired rule-based processing with less salient features in Experiment 2, although the pattern of particular feature preferences suggests that the contributing features in the discordant category may have been more difficult for these patients to isolate. For instance, the CBD patients who attended to a single feature in the rule condition in Experiment 1 all focused on the same feature, as did a patient in the similarity condition in each experiment. However, this feature was not a contributing feature option in Experiment 2 and, hence, successful categorization of the discordant category required attending to a feature other than the “preferred” one. Moreover, as the CBD patients generally favored larger features (i.e., the legs and tail) rather than the feature shown to be most salient to healthy participants (i.e., the head), it is possible that purely perceptual aspects of the stimuli had a greater influence on this patient group.

We have proposed a link between categorization processes and semantic memory impairment in AD, namely, that intact similarity-based processing will support much of semantic memory while deficits in rule-based processing will impair categorization of items whose classification requires specific feature assessments. In contrast with AD, semantic memory is generally preserved in CBD. While CBD patients were impaired at our novel animal categorization task, their intact ability to use at least a simplified rule could presumably compensate for their deficit in similarity-based categorization and, hence, support semantic memory: For instance, a patient who cannot integrate the various features of celery into a unified whole could still classify it as a vegetable by its individual features such as green color, stalks, or leaves.

Distinctions between rule-based and similarity-based processes have long been debated, with some investigators proposing unified views (e.g., Nosofsky & Johansen, 2000; Nosofsky & Palmeri, 1998; Nosofsky, Palmeri, & McKinnley, 1994; Pothos, 2005). Our observation of different categorization profiles in AD and CBD is more consistent with multiple categorization processes that can be selectively impaired in patients with focal neurodegenerative diseases (see also Koenig et al., 2006). Functional neuroimaging studies are also consistent with the view that rule-based and similarity-based categorization are qualitatively distinct (Grossman et al., 2002; Koenig et al., 2005; Patalano et al., 2001). Indeed, the contrasting loci of cortical atrophy in patients with AD and CBD parallel the areas recruited by healthy participants successfully performing each form of categorization (Grossman et al., 2002; Koenig et al., 2005): Prefrontal cortex (supporting executive resources) is affected in AD (Arnold, Hyman, Florry, Damasio, & van Hoesen, 1991; Grossman et al., 2004) and was recruited by healthy participants during rule-based categorization judgments; inferior parietal cortex (supporting feature configuration) is affected in CBD (Boeve et al., 1999; Grossman et al., 2004; Murray et al., in press) and was recruited by healthy participants during similarity-based categorization judgments. Thus, we conclude that qualitatively distinct categorization processes, supported by distinct cortical networks, contribute to semantic memory.

References
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