Published in final edited form as:

Neuropsychologia. 2010 June ; 48(7): 1877–1885. doi:10.1016/j.neuropsychologia.2009.07.023.

Categorization of Novel Tools by Patients with Alzheimer's Disease: Category-Specific Content and Process

Phyllis Koenig¹, Edward E. Smith², and Murray Grossman¹

¹Dept. of Neurology, University of Pennsylvania School of Medicine

²Dept. of Psychology, Columbia University

Abstract

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

Keywords

Semantic; Memory; Similarity; Rule; Classification; Animals

Introduction

Semantic memory, our long-term knowledge about things and events, is frequently impaired in patients with neurological damage. Category-specific deficits, in which memory for some

© 2009 Elsevier Ltd. All rights reserved.

Please address correspondence to: Phyllis Koenig, Department of Neurology – 3 West Gates, University of Pennsylvania, 3400 Spruce Street, Philadelphia PA 19104-4283, Phone: 215-615-3427; fax: 215-349-8464; plkoenig@mail.med.upenn.edu.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Portions of this research were presented at the Academy of Aphasia annual meeting, Washington DC, 2007

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

A rich body of theories has developed to account for category-specific deficits in semantic memory. While some cases may be open to various explanations such as imbalanced frequency or familiarity of test items (Tippett et al, 1996), the most influential theories focus on aspects of category content and its interaction with the distribution of knowledge representation in the cortex. The sensory-motor theory (Martin et al, 2000; Martin & Chao, 2001) posits that semantic knowledge is stored in modality-specific cortical areas, and that various categories differ in their dependency on particular modalities. For instance, identification of living things is thought to depend primarily on visual-perceptual feature information such as shape, while identification of manufactured artifacts is thought to depend primarily on visual motion and action associated with function. Hence, category-specific deficits should arise in accordance with patterns of damage to and sparing of modality-specific brain regions in which feature knowledge is represented, such as visual or motor association cortex (Martin, 2007). The distributed theory (Taylor et al, 2007; Moss & Tyler, 2000; Tyler et al, 2000; Gonnerman, 1997) posits that representation of objects' composite features is distributed in a network throughout the cortex irrespective of modality. Category specificity reflects differing degrees of feature clustering and uniqueness among categories. Natural kinds, it is proposed, contain commonly-held and inter-correlated features; for instance, many animals have heads, eyes, ears, fur, and tails, allowing for loss of knowledge about any one animal's features to be compensated for by patterns of feature co-occurrence in other animals. Manufactured artifacts, on the other hand, tend to be defined by relatively unique features, such as a hammer's head or a saw's blade. Sparsely represented knowledge is more vulnerable to loss; category-specific deficits thus should be predicated on the extent of neurological damage.

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

that are misleading or irrelevant (e.g., wings rather than typical mammalian forelegs), and working memory to keep features in an active mental state while they are being assessed. Hence, we have posited that semantic memory impairment can reflect a loss of processing ability, in addition to loss of knowledge content.

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

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

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

Methods

Subjects

Twenty AD patients, 13 female and 7 male, participated. All were right-handed native speakers of English, except for one native Dutch speaker who was fluent in English. The patients were mildly impaired, with a mean MMSE score (Folstein et al, 1975) of 22.7 (± 3.6). Their mean age was 73.5 (± 7.6), and they had a mean of 13.5 (± 2.6) years of education. MMSE scores, age, and years of education did not differ from those of the AD patients who participated in the novel animal study (Koenig et al, 2007), $p > .23$ by t-test for all comparisons. AD patients' diagnoses were based on NINCDS-ADRDA criteria (McKhann et al, 1984), which include a progressive anterograde memory deficit associated with naming and language difficulty, visual impairment, and/or executive limitation. We excluded patients with other causes of dementia such as vascular disease or hydrocephalus, psychiatric disorders such as primary depression or psychosis, medical illnesses or metabolic conditions that may have resulted in progressive intellectual decline, and/or other medical conditions that may have an impact on cognitive performance. Twenty healthy seniors, all right-handed native speakers of English, mean age 70.8 (± 6.5), mean education 14.6 (± 2.5), also participated. The two participant groups were statistically equivalent in age, $t(38) = 1.40$, $p = .17$, ns, and in education, $t(38) = 1.10$, $p = .28$, ns. There were two experimental conditions, Similarity and Rule (described below). Most patients participated in both conditions; however, some participated in only one due to personal circumstances unrelated to their cognitive ability to perform the task, such as illness or moving from the area. All of the patients participated in the Similarity condition, and 17 participated in the Rule condition. Conditions were presented in counterbalanced order at least six weeks apart to ensure that exposure to one condition did not influence performance on the other. Healthy seniors participated in one condition only, as it was assumed that recollection of their experience in the first condition could influence their performance on the second, even after a several-week delay. Ten control subjects were randomly assigned to each condition.

Stimuli

Stimuli consisted of a set of realistic images of 64 novel tools, comprising all possible combinations of six features that each had two values, such as straight or bent handle, or curved or spiral tip. Examples of the tools can be seen in the sample training trial images displayed in Figure 1. Rankings of each feature's relative contribution to judgments of inter-item similarity were obtained by the same method employed for the animal stimuli, described in detail in Koenig et al, 2007: All possible pair-wise combinations of the 64 tools were created, yielding 1,024 unique pairs. A cohort of eight healthy young volunteers judged each pair for inter-item resemblance on a 1–7 Likert scale. These judgments served as data in a succession of multidimensional scaling analyses performed for one, two, three, four, five, and six features. With each of these successive analyses, a feature emerged as a determining factor in the resulting "similarity space." For instance, the one-dimension analyses divided the images into two clusters of tools primarily differentiated by having a straight or bent shaft; the two-dimension analyses generated four clusters primarily differentiated by the value of the shaft feature and the value of the handle feature, and so on.

The resulting R^2 measures for the analyses indicated that each successive dimension accounts for an approximately equal increase in contribution to the resemblance judgments, with the analysis for all six dimensions accounting for 77%. This suggests that judged resemblance among novel tools primarily reflects the number of feature values that the items have in common. This contrasts with the novel animal stimuli analyses, in which successive additions of dimensions to the MDS analyses accounted for an uneven increase in contribution to the resemblance judgments: Adding dimensions had a negligible effect beyond the first two dimensions until at least five dimensions were included, with the six-dimension analyses

accounting for less than 62% of the resemblance judgments. As described in Koenig et al, 2007, it seems that resemblance among the novel animals relies relatively more on the presence of particular diagnostic features, with judged resemblance increasing further only when nearly all feature values are shared. The R^2 results for the six successive MDS analyses for the tool and animal stimuli are listed in Table 1. To test for distinctions in the patterns of results between tools and animals, we calculated the difference between the R^2 value of each successive pair of MDS analyses within each stimulus set (i.e., R^2 for 2 dimensions minus R^2 for 1 dimension, R^2 for 3 dimensions minus R^2 for 2 dimensions, etc.), yielding successively-ordered five-point data sets (one set each for tools and for animals) that capture the patterns of R^2 increase with successively added dimensions. We then performed a Pearson correlation on the two data sets. No correlation was found, $r=.10(8)$, $p>.85$, two-tailed, confirming that the patterns of increase in R^2 as the number of analyzed dimensions increase are not comparable across the tool and animal stimulus sets.

To construct the tool category, we used the four highest-ranked features, that is, those that emerged in the first four of the six sequential multi-dimensional scaling analyses, hereafter referred to as “contributing” features. The remaining two features served as “distractor” features. A value (e.g., straight handle, spiral tip) was chosen at random for each contributing feature. A category prototype contained the chosen value, hereafter referred to as the “prototypic” value, for all four contributing features. Thus, there were four prototypes, each with a different combination of distractor feature values. Category MEMBERS contained the prototypic value of at least three contributing features. There were 20 such items, including the four prototypes. LOW DISTORTION items, of which there were 24, contained the prototypic value of exactly two contributing features, and the 20 HIGH DISTORTION items contained maximally one. The distractor feature values were evenly distributed throughout the stimulus set. Eight non-prototype MEMBERS (i.e., items with exactly three prototypic contributing features) and eight HIGH DISTORTION items were used in the training session. All prototypic feature values were equally represented among the training MEMBERS, and the opposite values were equally represented among the HIGH DISTORTION training items. The training items were formed into 40 unique MEMBER-HIGH DISTORTION pairs for sequential presentation in the training session. The sequence was ordered such that features and combinations of features were evenly represented throughout the presentation, and appeared in no discernible pattern.

Procedure

Training—There were two training conditions, Similarity-based and Rule-based, followed by an identical test session, presented on a laptop computer. Both training conditions utilized the identical sequence of paired items presented in the lower half of the computer screen, with a condition-specific display in the upper half that remained the same throughout the training session. For Similarity-based training, the upper half displayed a prototype, chosen at random from among the four possible prototypes (see Figure 1A). Prior to beginning the training session, participants were told that they would be seeing a tool called a *trell*, along with pairs of tools, one of which was also a *trell* and one of which was not, and that their task was to judge which tool in the pair was a *trell* based on its resemblance to the example (i.e., the presented prototype). For Rule-based training, the upper half of the screen displayed monochromatic sketches of the four requisite contributing feature values with descriptive verbal captions such as “straight handle” (see Figure 1B). Prior to beginning the training session, participants were told that a tool called a *trell* had to have at least three out of four specified features, and that they would be seeing pairs of tools, one of which was also a *trell* and one of which was not. Their task was to judge which tool in the pair was a *trell* based on its adherence to the at-least-three-features rule. Participants in both conditions were initially shown a printed image of the first training trial to acquaint them with the screen display before

training and data collection began. Trials were self-paced within 15 seconds. Participants indicated their choices by right or left key presses, corresponding to the position of the item on the screen. At each trial, the experimenter briefly indicated whether the participant had chosen correctly. All participants performed the first 16 trials, entailing exposure to each MEMBER and HIGH DISTORTION training item twice. If a participant did not judge at least seven of the last eight trials in this initial period correctly, then training continued beyond 16 trials until seven out of eight contiguous trials were judged correctly, or until the end of the 40-trial sequence. Judgments and latencies were recorded. All participants except one patient in the Rule condition met the learning criterion within the 40-trial training session. Although narrowly missing the criterion (the patient did correctly respond to six out of eight contiguous trials), the patient demonstrated learning by doubling his accuracy rate in the second half of the training session relative to the first. Moreover, the patient's subsequent test performance approximated the group mean, suggesting the effect of his training was comparable to that of the other patients.

Test—Testing followed training, and was identical for both conditions. Participants were told that they would be seeing more pictures of tools, some of which would be *trells* and some of which would not be, and that they were to indicate whether each tool was a *trell*, in accordance with how they were trained; that is, following similarity-based training, judgments were to be based on a test item's resemblance to the training sample, and following rule-based training, judgments were to be determined by a test item's adherence to the defining rule. Participants were presented with the entire set of 64 individual tools in a sequence, semi-randomly ordered such that no items of any one type (e.g., MEMBERS) appeared more than three times consecutively. A condition-appropriate memory prompt consisting of a printed image of either the training prototype (to show what a *trell* "could look like") or of the four requisite contributing features (to show the four features of which a *trell* "must have at least three") was available to subjects throughout the test session. This established means of prompting amnesic patients' memories without otherwise influencing their decision-making processes (Oscar-Berman & Samuels, 1977) was used to ensure that AD patients' judgment patterns reflected categorization processes, rather than their ability to explicitly recall their training experience. We have demonstrated elsewhere (Koenig et al 2007) that participants' judgments at test reflect their training experience, rather than comparisons between test items and the memory prompt image. Trials were self-paced within 15 seconds, and choices were indicated by a right-hand key press for endorsements and a left-hand key press for rejections. No feedback was provided. Responses and reaction times were recorded.

Psychometric measures—We assessed AD patients' performance on psychometric tests of recognition and executive function, such as working memory, selective attention, and inhibitory control, for comparison with their test performance on the tool categorization task. Recognition of recently encountered items was assessed via a validated 10-item list of studied words (Welsh et al, 1991). Executive function was measured by the standard Reverse Digit Span task and the Stroop Task.

Results and Discussion

Training

We assessed the number of training trials needed to reach our learning criterion beyond the requisite 16, along with reaction times. These data are presented in Table 2. Healthy seniors required minimal additional trials and did not differ across conditions, $t(17)=-.85$, $p=.41$, ns. The trend towards relatively longer latencies for rule-based training did not reach significance, $t(17)=1.82$, $p<.09$. Thus, healthy seniors appeared competent in both training processes. AD patients' number of trials did not differ reliably across conditions, $t(34)=-.86$, $p=.40$. Their

longer latency for the Rule condition relative to the Similarity condition was significant, $t(35) = 2.14$, $p = .04$. Between subject groups, the greater number of trials in the rule condition for AD patients relative to the healthy seniors was reliable, $t(24) = 2.12$, $p < .05$, while the trend towards relatively more trials for patients in the Similarity condition did not reach significance, $t(27) = 1.76$, $p = .09$. Latencies were longer for AD patients relative to healthy seniors in both the Similarity and Rule conditions; $t(27) = 4.17$, $p < .0001$, and $t(24) = 2.89$, $p = .008$, respectively. Thus, AD patients showed some indication that rule-based training was more challenging than similarity-based training.

There are both parallels and contrasts with the results reported in our novel animal categorization study. As in the novel animal study, healthy seniors in the current study required minimal trials for both processing conditions with trends towards longer latencies in the Rule condition, and AD patients had longer latencies in the Rule condition relative to their performance in the Similarity condition and required more trials in the Rule condition relative to healthy seniors. Thus, with this new stimulus set of novel tools, we continue to observe competence in both categorization training conditions in healthy subjects, and greater difficulty, particularly in rule-based category learning, for AD patients. However, while AD patients required more trials for rule-based training relative to similarity-based in the novel animal study, in the current novel tool study the number of training trials required by AD patients for similarity-based training was equivalent to that required for training with rules. This suggests that AD patients were somewhat challenged by similarity-based learning of novel tools, in contrast with their essentially normal performance with similarity-based learning of novel animals.

Test

Endorsements—We assessed categorization by calculating the percentage of endorsements of MEMBERS, LOW DISTORTION items, and HIGH DISTORTION items. Successful similarity-based categorization judgments would reflect items' resemblance to the prototype, with most MEMBERS being endorsed, most HIGH DISTORTION items being rejected, and LOW DISTORTION items—which bear equal resemblance to MEMBERS and HIGH DISTORTION items—endorsed about half the time. In contrast to this graded pattern, successful rule-based categorization would reflect the sharply-defined category boundary, with all MEMBERS endorsed, and both LOW and HIGH DISTORTION rejected. We looked for these process-specific endorsement patterns, and we also assessed reaction times for responses to MEMBERS.

Healthy seniors' endorsement patterns are shown in Figure 2A. Category learning is evident in both conditions; MEMBERS were generally endorsed, and HIGH DISTORTION items were generally rejected. A repeated-measure ANOVA including both conditions showed a main effect of stimulus type, $F(2,36) = 194.10$, $p < .0001$, and no effect of condition, $F(1,18) = 1.27$, $p > .25$, ns. As expected, responses differed characteristically across the two conditions, indicating that healthy seniors could successfully employ either categorization process. This is apparent in the contrasting shapes of the slopes shown in the figure, and was captured by a condition $\times$ stimulus type interaction, $F(2,36) = 10.64$, $p < .0001$. Healthy seniors endorsed MEMBERS to a greater extent, $t(18) = 2.71$, $p < .05$, and LOW DISTORTION items to a lesser extent, $t(18) = 2.51$, $p < .05$, in the Rule condition relative to the Similarity condition. Mean reaction times for MEMBERS of 2977 ms (± 509) in the Rule condition were significantly slower than those of 2083 ms (± 1004) in the Similarity condition, $t(18) = 2.51$, $p < .05$, consistent with the claim that rule-based processing is more effortful and resource-demanding.

AD patients also demonstrated learning, as shown in Figure 2B; there was a main effect of stimulus type, $F(2,70) = 177.68$, $p < .0001$. However, in contrast with the healthy seniors, their endorsements followed essentially identical graded patterns in both processing conditions;

there was neither an effect of condition, $F(1,35)=.34$, $p=.56$, ns, nor a condition $\times$ stimulus type interaction, $F(2,70)=.94$, $p>.39$, ns. The mean reaction time of 5812 ms (± 2289) in the Rule condition did not differ reliably from that of 4712 ms (± 1935) in the Similarity condition, $t(35)=1.58$, $p=.12$. These observations of endorsement patterns thus far generally mirror our reported findings in the novel animal categorization study, with one exception: In the novel animal study, AD patients' shorter RTs for judging MEMBERS in the Similarity condition relative to the Rule condition were reliable and robust.

We compared performance across groups within each processing condition. AD patients were less accurate at rule-based categorization of novel tools than were healthy seniors. In an ANOVA showing a main effect of stimulus type, $F(2,50)=140.47$, $p<.0001$, and no effect of subject group, $F(1,25)=.15$, $p=.70$, ns, this between-group difference was captured by a stimulus type $\times$ group interaction, $F(2,50)=5.71$, $p=.006$. T-tests revealed that AD patients endorsed MEMBERS significantly less often than did healthy seniors, $t(25)=2.71$, $p<.05$. Again, this observation is comparable to the results of the animal study, in which AD patients were impaired at rule-based categorization relative to healthy seniors.

AD patients and healthy seniors also differed in endorsement patterns following Similarity-based training, with the AD patients' pattern exhibiting a relatively shallower slope. In an ANOVA showing a main effect of stimulus type, $F(2,56)=278.0$, $p<.0001$, and no effect of subject group, $F(1,28)=1.07$, $p=.31$, the between-group difference was captured by a stimulus type $\times$ group interaction, $F(2,56)=4.16$, $p=.02$. This interaction reflects overall differences in the endorsement patterns of the two participant groups, as none of the individual stimulus types differed reliably across groups (although AD patients' scores for MEMBERS were marginally lower than those of healthy seniors, $t(28)=1.69$, $p=.10$). This between-group difference in endorsements contrasts with the results of the novel animal study, in which healthy seniors and AD patients in the Similarity condition performed essentially identically.

In sum, the test results suggest that while healthy seniors can successfully use either similarity-based or rule-based categorization processes to acquire a category of novel tools as readily as they can with novel animals, AD patients were somewhat challenged by the novel tool category. As expected, AD patients showed impaired rule-based processing in categorizing the novel tools, consistent with deficits observed in the novel animal study. However, while we previously reported unimpaired performance by AD patients for similarity-based categorization of novel animals, this was not the case with their performance in the analogous condition with novel tools; the slope of their performance profile was significantly shallower relative to healthy seniors. Moreover, their speed at judging novel tool MEMBERS in the Similarity condition was not reliably faster than in the Rule condition, consistent with the loss of the advantage for similarity-based processing previously demonstrated with novel animals.

Feature preferences—We ascertained whether participants based categorization judgments on the presence of a particular feature value in a test item. While endorsement scores characteristic of successful rule-based categorization indicate correct application of the three-out-of-four-features rule, assessing endorsement scores alone may be insufficient for revealing the bases for categorization decisions in the Similarity condition: The graded profile characteristic of successful similarity-based categorization can also be achieved by focusing on an individual contributing feature, because any contributing prototypic feature value is present in most MEMBERS and in half the LOW DISTORTION items, and absent in most HIGH DISTORTION items.

To assess instances of feature bias, we first calculated each participant's "preference score" for each of the six features by determining the participant's rate of endorsement for items containing each of the two variants and calculating the difference. For example, a participant

who endorsed 70% of spiral-tipped items and 50% of curve-tipped items would have a preference score of 20 for the “tip” feature. If the same participant endorsed 60% of the straight-handled tools and 60% of the bent-handled tools, the preference score for the “handle” feature would be zero, and the participant’s categorization judgments would thus appear to be more influenced by the kind of tip the tool had than by the kind of handle. We also performed analogous analyses on the endorsement data from our prior novel animal study. A participant was considered to have a single-feature bias if the preference score for any one feature exceeded the preference scores for each of the remaining five features by a minimum of 25. We chose this threshold because it exceeded the largest standard deviation of the mean preference score range for any condition within the novel tool and novel animal data sets. Hence, a preference score for any one feature that exceeded scores for all other features by that amount was a fairly stringent criterion of single-feature bias.

We divided participants in each condition into those who exhibited a single-feature bias and those who did not, and performed sign tests in each condition. The percentages of feature-bias participants are displayed in Figure 3. No healthy seniors (shown in Figure 3A) favored a single feature in the Rule condition for either novel tools or novel animals, a significant distinction by sign test, $p=.002$. This was to be expected, as the rules required that the four contributing features be regarded equally in categorization judgments. However, participants in the Similarity condition, although instructed to base their judgments on general resemblance, were free to attend to particular features as they chose, whether deliberately or not. At least half of the healthy seniors exhibited a feature bias when categorizing by similarity for both the tool and the animal stimulus sets. The sign tests confirmed that healthy seniors were essentially evenly divided between those who favored a single feature and those who did not within each stimuli set, as these groups did not differ significantly, $p=1.00$, ns, and $p=.34$, ns, for the tool and animal studies, respectively. In short, healthy seniors were primarily affected by the type of process, regardless of content: they adhered to the rules under rule-based processing, and about half of them spontaneously favored a feature of choice under similarity-based processing, regardless of whether they are categorizing novel tools or novel animals. In contrast, the AD patients were primarily affected by the type of content, often focusing on a single feature when categorizing novel animals, but not novel tools, in either categorization condition (Figure 3B): For categorizing novel animals, there was no reliable difference between the number of patients who did or did not exhibit a single-feature bias, $p=.82$ and $p=.42$ for Similarity and Rule, respectively. In contrast, significantly fewer AD patients exhibited a single-feature bias than not when categorizing novel tools regardless of categorization condition, $p=.01$ and $p=.002$ for Similarity and Rule, respectively.

We assessed whether feature biases contributed to categorization success by determining the percentage of biased participants whose categorization accuracy was at or above median performance. Although the numbers of participants are insufficient for reliable statistical analyses, the patterns are suggestive: While focusing on a feature was neither necessary for nor a guarantee of categorization success, biased participants in the Similarity condition seemed to fare better. In the Similarity condition, 5 of the 7 (71%) biased healthy elderly participants categorizing novel animals and 3 of the 5 (60%) categorizing novel tools were successful at or above the median point, as were the 6 out of the 8 (75%) biased AD patients categorizing novel animals and the 3 of the 4 (75%) categorizing novel tools. In contrast, all 5 of the biased AD patients categorizing novel animals in the Rule condition scored below the median, as did 1 of the 2 biased AD patients categorizing novel tools in the Rule condition, as these participants tended to erroneously endorse items that contained the favored feature without meeting the at-least-three-features rule.

Correlations with psychometric measures—As in the novel animal study, we correlated AD patients’ accuracy at categorizing novel tools, as measured by their appropriate

endorsements and rejections, with their performance on psychometric tests (described earlier) assessing recognition and executive function. We were particularly interested in these cognitive faculties for several reasons: First, episodic memory loss is the hallmark of Alzheimer's disease, and thus could potentially affect the results of any study involving AD patients. Second, executive functions are necessary for rule-based processing. In particular, the Reverse Digit Span test assesses working memory, a resource needed to evaluate and retain several individual features as required by our rule-based categorization task, and the Stroop task requires selective attention and inhibitory control, resources needed to focus on particular features while ignoring others that might be salient but are irrelevant to the task at hand. Third, in the novel animal study these executive resource measures correlated only with AD patient's rule-based performance, and episodic memory measures correlated with neither rule- nor similarity-based performance. Thus, by comparing the correlation patterns across the tool and animal studies, we could observe whether categorization processing demands remained stable as content changed.

Correlation results are summarized in Table 3. AD patients' scores on a standard assessment of recognition memory correlated with their success at categorizing novel tools by either categorization processing condition, while there was no significant correlation between the assessments of preserved executive resources and categorization success in either condition. Consistent with AD patients' profoundly impaired episodic memory, there is no evidence that AD patients, at test, were able to recall the specific tools seen repeatedly during training: endorsements of "old" MEMBERS at test (i.e., items previously seen during training) did not differ from endorsements of "new" MEMBERS items (i.e., comparable non-prototype MEMBERS seen for the first time at test) in either processing condition, $t(16)=1.18$, $p=.26$, ns, and $t(16)=.57$, $p=.58$, for Similarity and Rule, respectively. Rather, the recognition task correlation suggests that patients' success at categorizing the novel tools is facilitated by accrued familiarity with the general appearance of the tool category members, comparable to the gist memory that AD patients have been shown to develop for semantic categories over repeated trials despite their inability to recall specific items (Budson et al, 2000).

The pattern of correlations for categorizing novel tools are quite different from those previously reported for the novel animal study (see Table 2): AD patients' Reverse Digit Span and Stroop task success both correlated with accuracy at rule-based categorization of novel animals, while their recognition did not correlate with performance in either categorization condition.

General Discussion

Semantic memory involves both content knowledge and integrative processes such as categorization. While recent theories of semantic memory, generally intended to account for category-specific deficits, have emphasized category content, our view has emphasized the need for both content and process, and we have argued in previous reports that processing deficits can contribute to semantic impairment observed in neurologically impaired patient populations (Grossman et al, 2003; Koenig et al, 2007). The present study examines content and process interactions: We taught AD patients and their healthy counterparts a category of novel tools by similarity- and rule-based processes, and compared patterns of performance with those found in our previous study involving categorization of novel animals (Koenig et al, 2007). As the two studies employed identical procedures and comparably-constructed novel object categories, we attribute differences in performance to characteristics of the tool and animal stimuli, and to those characteristics' interaction with the categorization processes.

Healthy seniors were able to successfully employ both similarity-based and rule-based processes in categorizing our novel tools; they endorsed items according to degree of prototypicality following similarity-based training, and according to a requisite-features rule

following rule-based training. Longer response latencies in the Rule condition during test suggest that rule-based categorization was more effortful than similarity-based, in keeping with the executive resource demands of employing rules and the relative automaticity of similarity assessments. The healthy seniors' behavior thus parallels the results of our novel animal study, and is consistent with other observations of healthy adults' ability to appropriately employ either categorization process. A closer look at the strategies driving category endorsements confirms that the healthy seniors applied a particular process regardless of category content: Roughly half of the healthy seniors were biased towards the presence of a single feature in their membership endorsements under similarity-based processing whether categorizing novel tools or novel animals, and all the healthy seniors considered all requisite features equally under rule-based processing.

AD patients were able to learn to categorize our set of complex novel tools, reliably endorsing MEMBERS and rejecting HIGH DISTORTION items in both processing conditions, but their performance profiles reflected the graded pattern characteristic of similarity-based judgments in the Rule as well as in the Similarity condition. The impaired ability to categorize according to rules is consistent with the results of our novel animal study. However, AD patients were somewhat impaired in categorizing novel tools following similarity-based training as well. This contrasts with the results of the novel animal study, in which AD patients matched the healthy seniors' success in categorizing by similarity, and where fewer training trials and robustly faster reaction times relative to rule-based processing demonstrated their facility with this task. In addition to poorer performance relative to the healthy seniors, there were other indications that categorizing novel tools by similarity was particularly challenging for the patients: Unlike the novel animal study, AD patients categorizing tools needed as many trials during similarity-based training as during rule-based training to reach the set learning criterion, and their judgment latencies for endorsing tool category MEMBERS at test following similarity-based training were not reliably faster than those following rule-based training.

In contrast with the healthy seniors, AD patients adopted content-specific, rather than process-specific, strategies. When categorizing novel animals, AD patients were as likely as not to focus on a single feature regardless of the processing condition, while only a small minority of AD patients did so when categorizing novel tools in either processing condition. Focusing on a particular feature appeared to provide a performance advantage in similarity-based categorization judgments for healthy seniors and for AD patients, perhaps enabling feature-biased participants to bootstrap their way to a mental representation of the unfamiliar stimulus materials. The prevalence of this approach apparently contributed to the AD patients' success as a group in similarity-based categorization of novel animals, in which AD patients performed equivalently to their healthy counterparts. AD patients generally did not favor individual features when categorizing novel tools, and their group performance was less accurate than that of healthy seniors.

What can account for these contrasting content-governed approaches in the AD patients' performance, and why were AD patients unable to match the healthy seniors in categorizing the novel tools following similarity-based training? Although the novel tool and novel animal categories are alike in being composed of six variable features, our feature assessment studies suggest that there is relative diagnostic equality among the tool features but varying levels of diagnostic strength among the animal features. We have argued elsewhere (Koenig & Grossman, 2007) that the imbalance among the novel animal features is primarily determined by semantic rather than perceptual salience, reflecting general knowledge about animate beings that participants bring even to these unfamiliar creatures: Even imaginary animals, if biologically plausible, have constraints on the forms of their features (e.g., the features labeled "legs" must be recognizable as such in shape, number, etc.), on those features' relative spatial positions, and on their function. A learner comes to our categorization task already knowing

that the animal's head is more diagnostic of "species" than its tail and expects its head and tail to be located at opposite ends of a body that has legs underneath. During training, then, the learner acquires category exemplars that conform to familiar structures and readily cohere into a meaningful whole. Further support for this view is provided by our previous work (Koenig et al, 2007): We taught AD patients and healthy seniors a novel animal category created from the same stimulus set and using the same particular item as the prototypic example, but we structured the category with the two most salient features assigned the roles of distractor rather than contributing features, while the two least salient features were included among the four designated contributing features. This manipulation only affected similarity-based processing: While healthy seniors were able to learn to correctly endorse category members, they incorrectly endorsed non-members that contained a salient distractor feature. AD patients were even more affected, reliably endorsing members that contained salient features (whether contributing or distractor), and otherwise performing at chance.

Compared with the novel animals, the novel tool features' forms, proportions, and relative spatial positions are relatively unconstrained, even with the requirements of a recognizable handle and function-entailing parts. Acquiring our tool category involves learning patterns of arbitrary shapes almost from scratch, rather than learning variants of forms that are like those already represented in semantic memory, and thus puts greater demand on episodic memory than does acquiring the novel animal features. This would put the AD patients at a particular disadvantage in learning the novel tool features. We find support for this view in the correlations between the AD patients' recognition memory and their success at categorizing the novel tools by either categorization process, while no such correlation was found in the novel animal study. It appears that the patients' memory-based difficulty in acquiring the tool features cost them the opportunity, in the Rule condition, to apply what residual executive resources they possessed, as the trends towards correlations between executive ability and categorizing tools by rules did not reach significance, in contrast with the novel animal study. Furthermore, we posit that attending to a salient feature in either category helped participants bootstrap their way to a representation of the item as a whole—but if the tool features are harder for the AD patients to acquire, then patients are less able to take advantage of this mode of learning the tool category. Indeed, healthy seniors were often influenced by the presence of an individual feature in their similarity-based membership endorsements of both novel tools and novel animals, but AD patients were only able to adopt this strategy with the novel animals. There is evidence that AD patients, like healthy seniors, retain some level of the "picture superiority effect" that enhances recognition for pictorial over verbal material, thought to result from the richness and distinctiveness of visual presentations compared with verbal labels (Ally et al, 2009). It is consistent with that finding that the semantic knowledge associated with the novel animals and the diagnostic salience of particular features enriched the animal images so that they were more memorable than the tool images, even for patients with profoundly impaired recall.

In sum, we have shown that novel tools and novel animals elicit identical category judgment strategies in healthy seniors, yet somewhat different category judgment strategies in patients with Alzheimer's disease. Furthermore, for the AD patients, content and process interact: While AD patients are impaired at rule-based categorization regardless of category content, they are selectively challenged by the tool category when attempting to categorize by a similarity-based process because of the burden on recognition memory imposed by the relatively arbitrary features of the novel tools. Our results suggest that existing theories of semantic memory are unlikely to entirely explain category-specific deficits. The sensory-motor theory posits that representations of animals primarily contain visually-based perceptual features like shape and color while tool features are tied to function-related action and visually-perceived motion, with category-specific deficits reflecting damage to relevant modality-specific brain regions. However, even though our tools and animals were presented in identical

protocols consisting of series of static images, which presumably resulted in similar modes of representation for both newly-acquired categories, AD patients were selectively impaired in the tool category. This suggests that differences in representation reflecting modality-specific knowledge acquisition does not entirely account for patterns of impairment, as selective impairment can apparently occur within a specific modality of representation. The distributed theory cites contrasting patterns of feature co-occurrence and uniqueness across categories as the cause of category-specific deficits. Our tool and animal categories were deliberately designed to contain equal numbers of variable features, with identical patterns of feature uniqueness and co-occurrence, yet AD patients were selectively impaired in acquiring the tool category, suggesting that sparse versus redundant representation of clustered features does not entirely account for patterns of impairment.

Although we have demonstrated content-specific distinctions in AD patients' acquisition of novel categories that cannot be completely accounted for by prevailing theories of category-specific deficits, still our results do not provide a straightforward account of such deficits in semantic memory—that is, we would not predict, on the basis of our findings, that memory-impaired patients would necessarily have a greater semantic memory deficit for man-made objects than for natural kinds. Our presentation of both the tool and the animal categories in series of static images may run counter to real-world differences in exposure to, and hence knowledge of, contrasting categories. For instance, participants could not observe our novel tools in use, and thus lacked the sensory-motor input and resulting knowledge of the kind that may support semantic memory for tools. In addition, the deliberate balance in number of features across our novel categories may violate typical real-world distinctions between categories of man-made objects and natural kinds that could contribute to their semantic representation. For instance, the degree of feature overlap among our category exemplars may be more common among natural kinds than among man-made objects, and our multi-featured tools, unlike many familiar carpenters' tools, lack a unique defining feature. Furthermore, difficulties in learning novel items, albeit realistic ones, may not be fully analogous to semantic memory deficits for familiar items, and thus our findings may speak more to the learnability of categories of natural kinds versus manufactured artifacts than to the retention of previously-held semantic knowledge. Finally, our results must be interpreted with some caution because different AD patients participated in the novel tool and novel animal studies, and hence variability in cognitive impairment and/or semantic knowledge among patients across groups could potentially contribute to the between-study performance distinctions. With these caveats in mind, however, our results suggest that there are content-specific distinctions in how an object's component features are regarded, which in turn differentially affect the processes by which those features are integrated. Category-specific deficits in neurologically impaired patients may thus reflect interactions between the varying demands of categorization processes and representation of content knowledge.

Acknowledgments

This research was carried out at the Dept. of Neurology, University of Pennsylvania School of Medicine

This work was supported by grants from NIH (AG15116, NS44266, and AG17586)

References

- Allen SW, Brooks LR. Specializing the operation of an explicit rule. *Journal of Experimental Psychology: General* 1991;120:3–17.
- Ally BA, Gold CA, Budson AE. The picture superiority effect in patients with Alzheimer's disease and Mild Cognitive Impairment. *Neuropsychologia* 2009;47:595–598. [PubMed: 18992266]
- Ashby FG, Alfonso-Reese LA, Turken U, Waldron EM. A neuropsychological theory of multiple systems in category learning. *Psychological Review* 1998;105:442–481. [PubMed: 9697427]

- Budson AE, Daffner KR, Desikan R, Schacter DL. When false recognition is unopposed by true recognition: Gist-based memory distortion in Alzheimer's disease. *Neuropsychology* 2000;14:277–287. [PubMed: 10791867]
- Cappa SF, Binetti G, Pezzini A, Padovani A, Rozzini L, Trabucchi M. Object and action naming in Alzheimer's disease and Fronto-temporal dementia. *Neurology* 1998;50:351–355. [PubMed: 9484352]
- Caramazza A, Shelton JR. Domain-specific knowledge systems in the brain: The animate-inanimate distinction. *Journal of Cognitive Neuroscience* 1998;10:1–34. [PubMed: 9526080]
- Farah MJ, McClelland JL. A computational model of semantic impairment: modality specificity and emergent category specificity. *Journal of Experimental Psychology: General* 1991;120:339–357. [PubMed: 1837294]
- Folstein MF, Folstein SF, McHugh PR. "Mini Mental State." A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research* 1975;12:189–198. [PubMed: 1202204]
- Gainotti, G. Locus of lesion in semantic disorders. In: Hart, J.; Kraut, MA., editors. *Neural Basis of Semantic Memory*. Cambridge: Cambridge University Press; 2007. p. 28-61.
- Garrard P, Lambon Ralph MA, Watson PC, Powis J, Patterson K, Hodges JR. Longitudinal profiles of semantic impairment for living and nonliving concepts in dementia of the Alzheimer's type. *Journal of Cognitive Neuroscience* 2001;13:892–909. [PubMed: 11595093]
- Garrard P, Patterson K, Watson PC, Hodges JR. Category specific semantic loss in dementia of Alzheimer's type: Functional-anatomic correlations from cross-sectional analyses. *Brain* 1998;121:633–646. [PubMed: 9577390]
- Gonnerman LM, Andersen ES, Devlin JT, Kempler D, Seidenberg MS. Double dissociation of semantic categories in Alzheimer's disease. *Brain and Language* 1997;57:254–279. [PubMed: 9126416]
- Grossman M, Smith EE, Koenig P, Glosser G, Rhee J, Dennis K. Categorization of object descriptions in Alzheimer's disease and frontotemporal dementia: Limitation in rule-based processing. *Cognitive, Affective, and Behavioral Neuroscience* 2003;3(2):120–132.
- Koenig P, Smith EE, Grossman G. Semantic categorisation of novel objects in frontotemporal dementia. *Cognitive Neuropsychology* 2006;23:541–562.
- Koenig, P.; Grossman, M. Process and content in semantic memory. In: Hart, J.; Kraut, MA., editors. *Neural Basis of Semantic Memory*. Cambridge: Cambridge University Press; 2007. p. 247-264.
- Koenig P, Smith EE, Grossman M, Glosser G, Moore P. Categorization of novel animals by patients with Alzheimer's disease and corticobasal degeneration. *Neuropsychology* 2007;21:193–206. [PubMed: 17402819]
- LaFleche D, Albert MS. Executive function deficits in mild Alzheimer's disease. *Neuropsychology* 1995;9:313–320.
- Martin A. The representation of object concepts in the brain. *Annual Review of Psychology* 2007;58:25–45.
- Martin A, Chao LL. Semantic memory and the brain: structure and processes. *Current Opinion in Neurobiology* 2001;11:194–201. [PubMed: 11301239]
- Martin, A.; Ungerleider, LG.; Haxby, JV. Category-specificity and the brain; the sensory/motor model of semantic representations of objects. In: Gazzaniga, MS., editor. *The Cognitive Neurosciences*. Cambridge, MA: MIT Press; 2000. p. 1023-1037.
- McKhann G, Drachman D, Folstein M, Katzman R, Price D, Stadlan EM. Clinical diagnosis of Alzheimer's disease: Report on the NINCDS-ADRDA work group under the auspices of the Department of Health and Human Services Task Force on Alzheimer's disease. *Neurology* 1984;34:939–944. [PubMed: 6610841]
- Medin DL, Goldstone RL, Gentner D. Respects for similarity. *Psychological Review* 1993;100:254–278.
- Medin DL, Schaffer MM. A context theory of classification learning. *Psychological Review* 1978;85:207–238.
- Moss HE, Tyler LK. A progressive category-specific deficit for non-living things. *Neuropsychologia* 2000;38:60–82. [PubMed: 10617292]
- Oscar-Berman M, Samuels I. Stimulus preference and memory factors in Korsakoff's syndrome. *Neuropsychologia* 1977;vol. 15(1):99–106. [PubMed: 831157]

- Patalano A, Smith EE, Jonides J, Koeppel R. PET evidence for multiple strategies of categorization. *Cognitive, Affective, and Behavioral Neuroscience* 2001;1:360–370.
- Patterson MB, Mack JL, Geldmacher DS, Whitehouse PJ. Executive functions and Alzheimer's disease: Problems and prospects. *European Journal of Neurology* 1996;3:5–15.
- Perry RJ, Hodges JR. Attention and executive deficits in Alzheimer's disease: A critical review. *Brain* 1999;122:383–404. [PubMed: 10094249]
- Pothos EM. The rules versus similarity distinction. *Behavioral and Brain Sciences* 2005;28:1–14. [PubMed: 16047456]
- Silveri MC, Daniele A, Giustolisi L, Gainotti G. Dissociation between living and nonliving things in dementia of the Alzheimer type. *Neurology* 1991;41:545–546. [PubMed: 2011254]
- Smith, EE.; Medin, DL. *Categories and concepts*. 1 ed.. Cambridge: Harvard University Press; 1981.
- Smith EE, Langston C, Nisbett RE. The case for rules in reasoning. *Cognitive Science* 1992;16:1–40.
- Smith EE, Patalano AL, Jonides J. Alternative strategies of categorization. *Cognition* 1998;65:167–196. [PubMed: 9557382]
- Smith EE, Sloman SA. Similarity- versus rule-based categorization. *Memory and Cognition* 1994;22:377–386.
- Taylor, KI.; Moss, HE.; Tyler, LK. The conceptual structure account: A cognitive model of semantic memory and its neural instantiation. In: Hart, J.; Kraut, MA., editors. *Neural Basis of Semantic Memory*. Cambridge: Cambridge University Press; 2007. p. 265-301.
- Tippett LJ, Grossman M, Farah MJ. The semantic memory impairment of Alzheimer's disease: Category-specific? *Cortex* 1996;32:143–153. [PubMed: 8697745]
- Tyler LK, Moss HE, Durrant-Peatfield MR, Levy JP. Conceptual structure and the structure of concepts: a distributed account of category-specific deficits. *Brain and Language* 2000;75:195–231. [PubMed: 11049666]
- Warrington EK, Shallice T. Category specific semantic impairments. *Brain* 1984;107:829–854. [PubMed: 6206910]
- Welsh KA, Butters N, Hughes JP, Mohs RC, Heyman A. Detection of abnormal memory decline in mild cases of Alzheimer's disease using CERAD neuropsychological measures. *Archives of Neurology* 1992;48:278–281. [PubMed: 2001185]

1A

Similarity-based Training Trial

2A

Rule-based Training Trial

Figure 1.

2 A

2 B

Figure 2.
% Endorsement of Novel Tools by Healthy Seniors and AD Patients

3 A

3 B

Figure 3.
Feature Preference Biases During Similarity- and Rule-Based Categorization of Tools and Animals

Table 1

Multi-dimensional Scaling Analyses of Judged Inter-Item Resemblance for 1 through 6 Dimensions

MDS Index (R^2)		
# of Dimensions	Novel Tools	Novel Animals
1	.23	.16
2	.30	.27
3	.39	.32
4	.52	.34
5	.65	.55
6	.77	.62

Table 2

Mean (SD) Training Results

GROUP	Training Results			
	Similarity		Rule	
	# of trials	RT in ms	# of trials	RT in ms
Healthy Seniors	1.2 (2.9)	5087 (1927)	0.3 (1.0)	6681 (1888)
Alzheimer's	5.2 (6.7)	7910 (1630)	7.6 (10.1)	9361 (2409)

Table 3

Pearson Correlations of accuracy with Neuropsychological Measures

NOVEL TOOLS					
Similarity			Rules		
Recognition	RevDigit	Stroop	Recognition	RevDigit	Stroop
.52 *	.22	.30	.50 *	.29	.40
NOVEL ANIMALS					
Similarity			Rules		
Recognition	RevDigit	Stroop	Recognition	RevDigit	Stroop
.33	.33	.41	-.39	.56 *	.79**

* p<.05, two-tailed

* p<.01, two-tailed