ABNORMAL SEMANTIC NETWORK FOR "ANIMALS" BUT NOT "TOOLS" IN PATIENTS WITH ALZHEIMER'S DISEASE

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ABSTRACT

The effects of Alzheimer's disease (AD) on the organization of semantic knowledge (i.e., the semantic network) for living (e.g., animals) and non-living (e.g., tools) categories was examined. Multidimensional scaling and Pathfinder analyses of data from triadic comparison tasks showed that the semantic network for "animals", but not the network for "tools", was abnormal in patients with AD. Specifically, patients with AD tended to use a different primary dimension than control subjects for categorizing animals and their network was characterized by atypical associations between concepts. The differences in the integrity of the AD patients' networks for "animals" and "tools" was not likely to be an artifact of differences in the difficulty in identifying the stimuli in the two categories as all stimuli were identified on simple naming or matching tasks. These findings support the results of previous studies that have shown the presence of category-specific semantic deficits in patients with AD.

Key words: Alzheimer's disease; semantic memory; category specific deficits

INTRODUCTION

Neuropsychological studies of patients with relatively focal brain lesions (Hillis and Caramazza, 1991; McCarthy and Warrington, 1988; Warrington, 1981; Warrington and Shallice, 1984) and studies of normal individuals using positron emission tomography (PET; Damasio, Grabowski, Tranel et al., 1996; Martin, Haxby, Lalonde et al., 1995; Martin, Wiggs, Ungerleider et al., 1996; Tulving, Kapur, Craik et al., 1994) provide evidence of category specificity in the organization of semantic knowledge. One aspect of semantic knowledge where category specificity appears to be particularly evident is in the processing of information about animate (i.e., living) and inanimate (i.e., non-living) items. A number of investigators have described patients with bilateral damage to regions of the temporal lobe cortex who are selectively impaired on semantic memory tasks that probe for knowledge of living items (De Renzi and Lucchelli, 1994; Farah, McMullen and Meyer, 1991; Sartori and Job, 1988; Sheridan and Humphreys, 1993; Silveri and Gainotti, 1988; Warrington and Shallice, 1984), while others have described patients with cortical damage who show the opposite pattern of selectively impaired performance on semantic tasks that involve non-living items (Sacchett and Humphreys, 1992; Tippett, Glosser and Farah, 1996a; Warrington and McCarthy, 1983). This double dissociation was explicitly demonstrated by

Cortex, (2001) 37, 197-217

Hillis and Caramazza (1991) who found that two patients with bilateral damage in different regions of the temporal lobe cortex, P.S. and J.J., exhibited opposite selective deficits with living and non-living items on the same semantic tasks.

In light of these studies demonstrating category specific deficits in some patients with focal cortical damage, investigators recently began to explore whether or not Alzheimer's disease (AD), a disease that results in widespread damage in cortical association areas, may lead to similar category specific impairment of semantic knowledge. Category specificity is possible in patients with AD because some regions of the neocortex are affected before others in the early stages of the disease (Bancher, Braak, Fischer et al., 1993; Braak and Braak, 1991; DeLacoste and White, 1993). If relatively circumscribed cortical damage occurs in an area important for processing a specific type of information, then a category specific semantic deficit might be evident.

In an initial study that supported this possibility, Silveri and colleagues (Silveri, Daniele, Giustolisi et al., 1991) found that patients in the early stages of AD were impaired on tasks that required confrontation naming or recognition of verbal associations of living items, despite normal performance when the tasks were performed with non-living items. Similar instances of category specific semantic impairment in mildly demented patients with AD were subsequently reported by a number of investigators (Daum, Riesch, Sartori et al., 1996; Garrad, Patterson, Watson et al., 1998; Gonnerman, Andersen, Devlin et al., 1997; Mauri, Daum, Sartori et al., 1994; Montanes, Goldblum and Boller, 1995). These studies have demonstrated specific deficits for both living (Daum et al., 1996; Garrad et al., 1998; Gonnerman et al., 1997; Mauri et al., 1994; Montanes et al., 1995; Silveri et al., 1991) and non-living (Garrad et al., 1998; Gonnerman et al., 1997) items using a variety of semantic memory tasks, including confrontation naming, word-picture matching, and category classification.

Not all studies of mildly demented patients with AD have supported the possibility of category specificity in the semantic memory impairment of these patients. In contrast to the studies described above, a number of studies have found either no difference in the semantic memory test performance of AD patients with living and non-living categories, or a difference that appeared to be an artifact of the living category stimuli being more visually complex or less familiar than the non-living category stimuli (Cronin-Golomb, Keane, Kokodis et al., 1992; Gainotti, Di Betta and Silveri, 1996; Hodges, Salmon and Butters, 1992; Montanes et al., 1996; Tippett, Grossman and Farah, 1996b). As evidence of this latter possibility, Tippett and colleagues (Tippett et al., 1996b) were able to replicate the results of the study by Silveri and colleagues (Silveri et al., 1991) and demonstrate a selective impairment for living items in the confrontation naming performance of mildly demented patients with AD; however, this selective impairment was abolished when new stimulus sets that carefully controlled the naming difficulty of the living and non-living items were employed.

Given the conflicting findings concerning category specific deficits for knowledge of living and non-living items in patients with AD, the present study was designed to further explore this issue by examining the structure of their semantic knowledge (i.e., semantic network) in these two domains using multidimensional scaling (MDS; Davison, 1983; Romney, Shepard and Nerlove, 1972; Shepard, Romney and Nerlove, 1972) and graphic analysis (i.e., Pathfinder analysis; Dearholt and Schvaneveldt, 1990) techniques. These techniques are particularly sensitive to alterations in the organization and structure of semantic knowledge and have been previously used to examine the integrity of the semantic network for the category "animals" in patients with AD. A series of studies by Chan and colleagues has shown that mildly demented patients with AD possess an abnormally complex and chaotic network for "animals" that contains unnecessary connections and atypical strengths of association between concepts, shift the primary basis of the organization of their network from a conceptually abstract dimension (i.e., domesticity) to a more concrete dimension (i.e., size), and are less consistent than normal individuals in their use of a particular attribute for categorizing concepts in the network (Chan, Butters, Paulsen et al., 1993a; Chan, Butters and Salmon, 1997; Chan, Butters, Salmon et al., 1993b; Chan, Butters, Salmon et al., 1995a; Chan, Salmon, Butters et al., 1995b; also see Bonilla and Johnson, 1995).

Although there is considerable evidence of an alteration in the organization of knowledge in the category "animals" in mildly demented patients with AD, the status of their knowledge in other categories is largely unknown. In the present study, MDS and Pathfinder techniques were used to compare the organization of semantic knowledge for living (i.e., animals) and non-living (i.e., tools) items in these patients. Familiar items from each category were selected for study in order to insure that the items could be easily identified and named by the patients. In this way, any observed differences in the structure of the semantic networks could be attributed to category specific deficits rather than to an artifact arising from non-conceptual differences in the nature of the stimuli (i.e., naming difficulty) in the two categories. Semantic knowledge for the items in each category was also probed with a number of other commonly used measures (e.g., sorting by category, typicality ranking) to determine if the MDS and Pathfinder techniques would reveal category specific deficits that may not be apparent on other tests of semantic knowledge.

MATERIALS AND METHODS

Subjects

Nineteen patients with probable Alzheimer's disease (11 male, 8 female) and 19 normal control (NC) subjects (9 male, 10 female) participated in this study. The diagnosis of probable AD was made by a senior staff neurologist at the University of California, San Diego (UCSD) Alzheimer's Disease Research Center (ADRC) according to the criteria developed by the National Institute of Neurological and Communicative Disorders and Stroke (NINCDS) and the Alzheimer's Disease and Related Disorders Association (ADRDA; McKhann, Drachman, Folstein et al., 1984). To reduce the possibility of including subjects with multi-infarct dementia, patients with a score of 5 or greater on the modified Hachinski ischemia scale (Hachinski, Illiff, Zilhka et al., 1975; Rosen, Terry, Fuld et al., 1980) were excluded from the AD patient group.

Normal control subjects were either spouses of patients or volunteers obtained through newspaper advertisements. Subjects with a history of alcoholism, drug abuse, learning disabilities and serious neurological or psychiatric illness were excluded. As shown in Table

I, the AD patients did not differ significantly from the NC subjects in terms of age [t (36) = .01; n.s.] or education [t (36) = .42; n.s.]. However, the Dementia Rating Scale (DRS) scores (Mattis, 1976) of the AD patients were significantly lower than those of the NC subjects [t (36) = 114.55; p < .01]. As indicated by their DRS score (mean = 121), the AD patients were only mildly demented.

TABLE I

Mean and Standard Deviation (S.D.) of Age, Years of Education, and Dementia Rating Scale (DRS) Scores for the Normal Control (NC) Subjects and Patients with Alzheimer's disease (AD)

	NC (N = 19)		AD (N = 19)	
	Mean	S.D.	Mean	S.D.
Age	75	7.8	75	6.3
Education	16	2.7	16	2.8
Dementia Rating Scale	142	2.2	121	7.5

Stimuli

Pictures or the written name of the same 20 stimuli were used in all tasks. Ten of the stimuli were from the animal category (*lion*, *dog*, *cow*, *elephant*, *leopard*, *rhinoceros*, *pig*, *donkey*, *monkey*, and *rooster*). The animals chosen could be sorted on the basis of the three attributes that are commonly used in categorizing animals (Henley, 1969; Rips, Shoben and Smith, 1973); namely, *domesticity* (domestic vs. wild), *size* (big vs. small) and *predation* (meat-eater vs. plant-eater). Five of the stimuli (*dog, cow, lion, elephant* and *pig*) were relatively high frequency animals (i.e., a ranking above 10 in the Battig and Montague, 1969, category norms), while the others (*donkey, monkey, rhinoceros, leopard* and *rooster*) were low frequency animals (i.e., a ranking below 11 in the category norms).

The remaining ten stimuli constituted the tool category, and included both carpentry and sewing tools (*axe*, *scissors*, *hammer*, *button*, *knife*, *screwdriver*, *nail*, *saw*, *needle* and *thread*). These stimuli were chosen primarily because they had been used previously to examine the categorization abilities of fluent and non-fluent aphasic patients (McCleary, 1988). These aphasic patients, as well as normal individuals, categorized the tools by two primary attributes, namely *category* (carpentry vs. sewing tools) and *function* (tools for cutting vs. tools for attaching). Four of the tools (i.e., *hammer*, *saw*, *screwdriver* and *nail*) were among the 10 most frequent exemplars of the tool category (Battig and Montague, 1969).

Pictures of the ten animals and ten tools were drawn from the stimuli developed by Snodgrass and Vanderwart (1980). The pictures of the animals and tools were of a standard size (approximately 7 cm^2), and were mounted individually on 9 cm^2 pieces of cardboard.

The items from the animal and tool categories were not significantly different in terms of their frequency of occurrence in the language (Thorndike-Lorge), but differed significantly in Snodgrass and Vanderwort (1980) familiarity [t (18) = 3.40; p < .003] and visual complexity [t (18) = 7.93; p < .001] ratings. The tools (Mean = 3.42; s.d. = 0.60) had a higher average familiarity rating than the animals (Mean = 2.16; s.d. = 1.01), whereas the animals (Mean = 3.85; s.d. = 0.45) had a higher average visual complexity rating than the tools (Mean = 2.23; s.d. = 0.46).

Procedure

Each subject was tested individually during two 2-hour sessions that were separated by approximately 1 week. One session used only the animal stimuli and the other used only the tool stimuli. The order of administration of the two conditions was counterbalanced across the two sessions by random assignment within each group.

The following tasks were administered during each session, using the appropriate stimuli (i.e., animals or tools), in the order listed below:

Naming Task

The subject was shown the pictures of the ten stimuli, one at a time in a fixed random order, and asked to name them. The examiner recorded the subject's response, but did not provide feedback regarding accuracy. The stimuli were then presented again in the same manner and the subject was asked to name them again. Responses were again recorded, no feedback was provided, and the total number of stimuli (out of 10) that were correctly named on either trial was counted. If the subject was incorrect on both naming trials with a particular stimulus, that stimulus picture was shown again and the subject was asked to identify it in a multiple-choice format consisting of the correct stimulus name and two distractors from the same semantic category (presented verbally). If the subject was still unable to identify the stimulus, an error was recorded, he/she was told the stimulus name, and that stimulus was eliminated from the analysis of the triadic comparison task data. However, none of the participating subjects failed to identify all 10 stimuli in at least the multiple-choice component of the test.

Triadic Comparison Task

The triadic comparison task consisted of 120 trials that represented all possible permutations (i.e., orderings and combinations) of the 10 stimulus pictures taken three at a time. On each trial, three stimuli were presented in the form of an equilateral triangle on a single sheet of white paper (8.5 × 11 inches) and the subject was asked to choose from among the three the two that were most alike. No further instructions concerning the strategy to be used for grouping the stimuli were given. The subject's response was recorded by the examiner on an answer sheet. The 120 trials were presented in a fixed random order. A five minute rest break was provided after the first 60 trials.

The frequency (i.e., number of times) with which two stimuli were chosen as most alike across all trials in which they appeared together was calculated and served as an indicator of the degree of association (i.e., similarity or proximity) between the two stimuli. This resulted in a 10 × 10 half matrix that contained the frequency counts for each pair of stimuli. These data were subjected to the MDS and Pathfinder analyses.

Free-Recall Task

The subject was asked to recall the ten items that appeared in the previous triadic comparison task. The total number of items recalled and the number of intrusion errors (i.e., recalled items that did not appear in the triadic comparison task) were recorded.

Concept Identification Task

This task required the subject to match the printed names of the 10 stimuli (i.e., animal names or tool names) to the 10 pictures. First, the drawings of the 10 stimuli were placed in three rows in a fixed random order on a table in front of the subject. Then each stimulus name, printed on a card (3 × 1 inches), was handed to the subject and they were asked to match it with one of the drawings on the table. After the subject responded, the examiner placed the name of the stimulus under the chosen picture and recorded the response. No feedback regarding response accuracy was provided. The subject was allowed to move stimulus names from picture to picture (i.e., make corrections) throughout the test in order to make room for a new response on the current trial, but only their initial response with each stimulus was counted. The total number of correct responses was calculated and used as the dependent variable in subsequent analyses.

Sorting Task

The subject was asked to sort the pictures of the 10 stimuli on the basis of several different dimensions. For the animal category, the pictures were sorted three times; once each for the dimensions *size* (big or small), *predation* (carnivore or herbivore) and *domesticity* (wild or domestic). For the tool category, the pictures were sorted twice; once each for the dimensions *function* (attach or cut) and *category* (carpentry or sewing). The order of the sorts for each dimension within each category were randomly assigned.

In each sorting task, the two appropriate attributes for the tested dimension were written on separate index cards that were positioned on the table facing the subject. The subject was then given each stimulus picture, one at a time in a random order, and asked to place it below the attribute that best described it. For example, when sorting by *domesticity*, the labels *wild* and *domestic* were placed in front of the subject and they were asked to judge which one of the two labels better described each of the 10 animals (e.g., Is an *elephant* a *wild* or a *domestic* animal?). The stimulus picture remained where it was placed below the attribute label until all 10 had been sorted. The number of errors on each sorting trial was recorded.

Typicality Ranking Task

The ten pictures of the stimuli were placed on the table, and the subject was asked to choose the stimulus that was the best example of that category. The chosen picture was then taken away and the subject was asked again to choose the best example of the category from among the remaining pictures. This procedure was repeated until all 10 stimuli had been chosen. The order in which the items were selected was recorded and provided a rank order of the typicality of the stimuli within each category. The most frequent response at each rank across all subjects (e.g., the animal chosen the most often as the best example, the animal chosen most often as the second best example, and so on) was noted. In addition, the number of subjects that ranked each stimulus at a given level (e.g., the number of subjects who choose *hammer* as the best example, the number who choose *hammer* as the second best example, and so on) was calculated. This latter procedure resulted in 10 frequency scores (one at each ranking level) for each stimulus.

Statistical Analyses

The proximity data derived from the triadic comparison task were analyzed by the Individual Difference Scaling Analysis (INDSCAL; Carroll and Chang, 1970) and by the Pathfinder analysis (Dearholt and Schvaneveldt, 1990). These analyses are scaling procedures designed to systematically construct a graphic representation of the organization of knowledge in some domain based upon empirically derived concept proximity data. The resulting models embed the concepts under study in a coordinate space or a network where the distances between points are assumed to reflect the psychological proximity between the respective items. The INDSCAL procedure will also reveal the dimensions underlying the organization of semantic knowledge within the model. The generated models are sometimes referred to as cognitive maps or semantic networks (Collins and Loftus, 1975; Collins and Quillian, 1969).

INDSCAL Analysis

INDSCAL, an MDS method developed by Carroll and Chang (1970), provides two measures of the goodness-of-fit of the MDS solution. The first is the percentage of variance in the proximity data (R^2) that can be accounted for by the analysis. This R^2 measure reflects the coherence within the proximity data. For example, if a subject indicates that concepts A and B are more similar than concepts A and C, and concepts A and C are more similar than concepts B and C, then concepts A and B must be more similar than concepts B and C. Violations of this assumption results in a poorly fit solution, a low R^2 value, and indicates that the subject has difficulty differentiating among the concepts. Thus, the higher the R^2 value, the more intact the structure of the subject's semantic knowledge.

The second goodness-of-fit measure generated through the INDSCAL procedure is the Stress Value (Kruskal and Wish, 1978). This value measures the accuracy, in terms of error, of the MDS solution in representing the proximity data. The higher the Stress Value, the worse the fit of the MDS solution. Because it is assumed that a better fit of the MDS solution is possible when the structure of semantic knowledge is intact, the Stress Value may reflect the integrity of the structure of semantic knowledge.

The INDSCAL procedure also produces a Weight Index which is a measure of the tendency of a subject to utilize each of the various dimensions obtained with the INDSCAL analysis in categorizing concepts. Thus, the Weight Index, ranging from 0 to 1, represents the saliency of each dimension for an individual subject as compared to all other subjects. The higher the Weight Index for a dimension, the more important that dimension is in categorizing concepts for that subject.

Pathfinder Analysis

Pathfinder analysis (Dearholt and Schvaneveldt, 1990) generates a network representation of the concepts within a given domain. A Pathfinder network consists of a set of nodes, with each node representing a single concept. Concepts are connected within the network by links which have various lengths that represent their strength of association as determined by the proximity data. Concepts with a low strength of association are represented by a long link, and concepts with a high strength of association are represented by a short link. Two concepts will be directly connected in the network only if the length of their direct link is shorter than the sum of the links that indirectly connect them through other concepts in the network.

The structural similarity between two Pathfinder networks can be examined by calculating the Closeness measure developed by Goldsmith and Davenport (1990). This measure, also called the Similarity Index, describes the extent to which the same concept in two networks is surrounded by the same neighboring concepts. To compute the Similarity Index, the neighboring concepts (i.e., directly connected concepts) for each concept in the two graphs are listed and compared. A quotient is then calculated for each concept by dividing the number of neighboring concepts common to both networks by the total number of neighboring concepts in the two networks. For example, if the neighboring concepts of Concept A in network 1 are B and C, and the neighboring concepts of Concept A in network 2 are B and D, there are a total of three neighboring concepts (i.e., B, C, D), but only one common neighboring concept (i.e., B) for Concept A in both networks. Therefore, the quotient for Concept A would be 1/3 or .33. The Similarity Index for the two networks is obtained by averaging the quotients of all concepts. The value of the Similarity Index can range from 0.0 for totally dissimilar graphs to 1.0 for identical graphs.

In the present study, the degree of similarity of each AD patient's semantic network generated through the Pathfinder analysis was compared to a standard network that was generated based upon the average proximity data of all of the NC subjects. This procedure resulted in a Similarity Index for each AD patient that quantified the degree of similarity between their network and that of the NC subjects. The higher the Similarity Index for an AD patient, the closer to normal their semantic network.

RESULTS

Naming Task

The AD patients were able to correctly name, on at least one of the two naming attempts, an average of 9.1 (s.d. = 1.25) of the animals and 9.0 (s.d. = 1.18) of the tools presented in this task. The NC subjects correctly named an average of 9.9 (s.d. = .23) of the animals and 9.9 (s.d. = .23) of the tools. Because of the near perfect performance of the NC subjects, these data were analyzed with non-parametric procedures. Mann-Whitney U-tests revealed that the AD patients' naming scores were significantly lower than those of the NC subjects in both the animal ($p < .01$) and tool ($p < .01$) categories. It should be noted, however, that the magnitude of these differences were quite small (approximately 9%), and were comparable for the tool and animal categories.

As mentioned previously, all of the AD patients and NC subjects were able to identify all 10 animals and 10 tools in the multiple-choice component of this task.

Triadic Comparison Task

The proximity data obtained from the triadic comparison tasks were analyzed with INDSCAL. The data of the AD patients and NC subjects were analyzed separately to generate cognitive maps that represent the organization of concepts within the animal and tool domains. The cognitive maps of the tool domain for the two groups are presented in Figure 1. As can be seen, the cognitive maps were essentially identical, with the tool concepts clearly organized in a very similar way along the dimensions of *function* and *category*. For both groups, *category* was the dominant dimension used to categorize tools. Comparable clusters of concepts are evident throughout the cognitive map.

The cognitive maps of AD patients and NC subjects in the animal domain, shown in Figure 2, were also similar, but appear to be less similar than for the tool domain. Two dimensions, *domesticity* and *size*, were clearly revealed in the cognitive maps of the animal domain for both AD patients and NC subjects, and for both groups *domesticity* was the dominant dimension used to categorize the animals. Although the concepts were clustered in a similar way throughout most of the cognitive map, the two maps did slightly diverge in some respects. For example, *rhinoceros* appeared to be less closely associated with *lion* and *leopard* in the AD patients' cognitive map than in that of the NC subjects.

The cognitive maps generated by INDSCAL are based on data that are averaged across subjects which results in a smoothing of the data and a minimization of individual variability (Ashby, Maddox and Lee, 1994). Thus, some of the difference in two cognitive maps may be minimized and difficult to visualize. In order to better observe differences in the semantic networks of two groups, the quantitative measures derived from the INDSCAL analyses were directly compared.

Differences in the semantic networks of the NC subjects and AD patients were further examined by directly comparing the R^2, Stress Value, and Weight Index measures obtained for each subject from the INDSCAL analyses. To insure that these data were appropriate for parametric analyses, tests for skewness, kurtosis and homogeneity of variance were carried out separately for the animal and tool conditions. These tests revealed that a significant deviation from a normal distribution was evident only for the R^2 measure in the animal condition for the NC subjects, and that there was homogeneity of variance for all measures except the R^2 value in the animal condition. All other distributions and circumstances were appropriate for parametric statistical analyses. Because of the non-normal distribution of the R^2 value in the animal condition for NC subjects, analyses involving this measure were performed with both raw and log-transformed data. The results of these analyses were essentially identical, so only the results obtained with the raw data are reported.

The mean R^2, Stress value, and Weight Indexes for the first and second

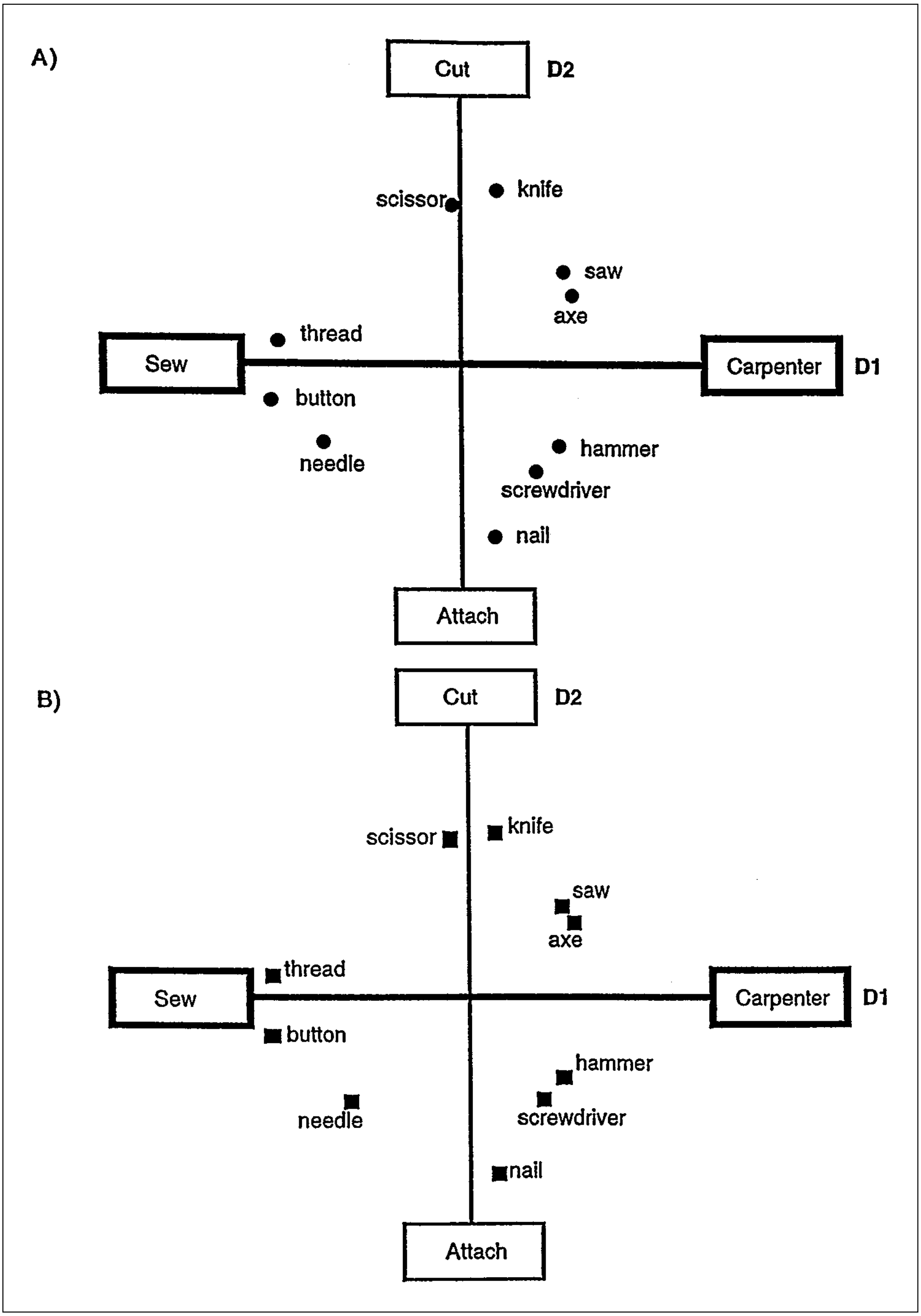

Fig. 1 – *The cognitive maps derived through multidimensional scaling analyses for 19 normal control (NC) subjects (A) and 19 patients with Alzheimer's disease (B). The cognitive maps represent the organization of the concepts in the category "Tools". The dominant dimension used to categorize concepts is presented in bold.*

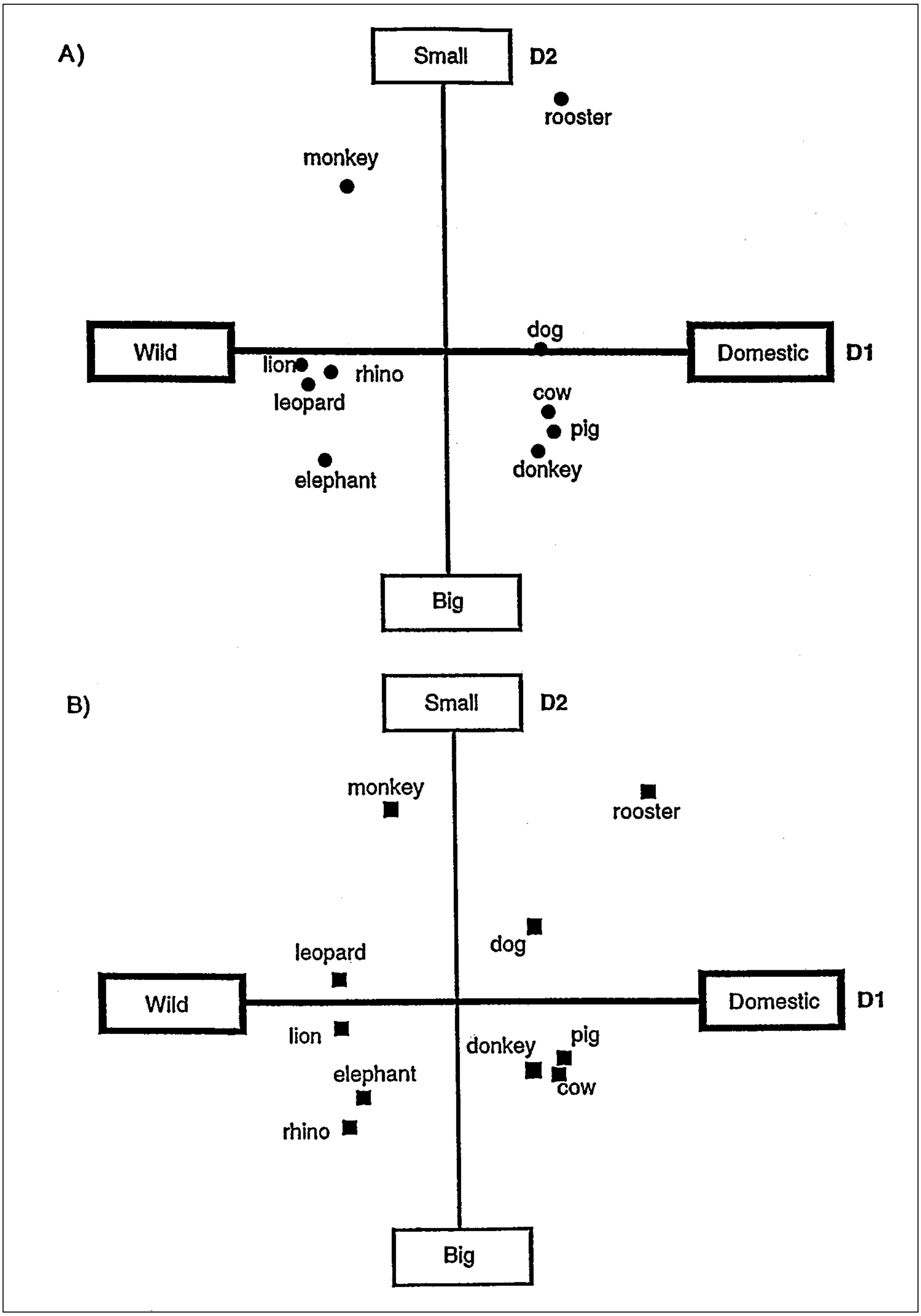

Fig. 2 – *The cognitive maps derived through multidimensional scaling analyses for 19 normal control (NC) subjects (A) and 19 patients with Alzheimer's disease (B). The cognitive maps represent the organization of the concepts in the category "Animals". The dominant dimension used to categorize concepts is presented in bold.*

dimensions obtained by the AD patients and NC subjects in the tool and animal conditions are shown in Table II. A Group (NC vs. AD) × Condition (animate vs. inanimate) repeated measures analysis of variance (ANOVA) of the R^2 measure revealed a significant main effect of Group [F (1, 36) = 11.72; $p < .01$] and a significant Group × Condition interaction effect [F (1, 36) = 8.41; $p < .01$]. The effect of Condition was not significant [F (1, 36) = .57; n.s.]. Post-hoc t-tests (two-tailed) were used to further examine the nature of the interaction effect. The results of these tests indicated that the R^2 value for the cognitive map of the animal domain was significantly lower than that for the tool domain for the AD patients [t (18) = 2.24; $p < .05$], whereas the R^2 values of the two cognitive maps did not differ significantly for the NC subjects [t (18) = 1.89; n.s.]. Furthermore, the R^2 of the cognitive map of the AD patients was significantly lower than that of NC subjects in the animal condition [t (36) = 3.64; $p < .01$], but not in the tool condition [t (36) = .51; n.s.].

TABLE II

Mean and Standard Deviation (S.D.) of the R^2, Stress-Value and Weight Index (WI) of Dimension 1 (D1) and Dimension 2 (D2) Obtained from the Multidimensional Scaling Analyses with the Tool and Animal Categories for Normal Control (NC) Subjects and Patients with Alzheimer's Disease (AD)

	NC (N = 19)		AD (N = 19)	
	Mean	S.D.	Mean	S.D.
Tool Category				
R^2	.85	.08	.84	.10
Stress-Value	.17	.05	.16	.05
WI of D1 (Category)	.87	.07	.85	.07
WI of D2 (Function)	.32	.13	.28	.13
Animal Category				
R^2	.92	.11	.73	.19
Stress-Value	.11	.08	.24	.09
WI of D1 (Domesticity)	.86	.18	.61	.22
WI of D2 (Size)	.29	.22	.50	.26

A Group (NC vs. AD) × Condition (animate vs. inanimate) repeated measures ANOVA of the Stress value measure revealed significant Group [F (1, 36) = 17.34; $p < .01$] and Group × Condition interaction effects [F (1, 36) = 14.01; $p < .01$]. The effect of Condition was not significant [F (1, 36) = .49; n.s.]. Post-hoc t-tests revealed that the Stress values for the animal and tool conditions did not differ significantly for the NC subjects [t (18) = 2.03; n.s.], but the stress value for animals was significantly higher than that for tools in the AD patients [t (18) = 3.34; $p < .01$]. In addition, the Stress value of the AD patients was significantly higher than that of the NC subjects in the animal condition [t (36) = 4.5; $p < .01$], but not in the tool condition [t (36) = .47; n.s.]. These results, in conjunction with those obtained with the R^2 measure, suggest that the cognitive maps of the AD patients and NC subjects are very similar in the tool domain, but that the AD patients' cognitive map in the animal domain significantly deviates from that of the NC subjects.

The importance that subjects attributed to the various dimensions they used in categorizing stimuli within the tool and animal domains, or the saliency of the dimensions, was reflected in the Weight Index measure derived for each dimension by the INDSCAL procedure. Because the dimensions that were revealed by the MDS analysis are idiosyncratic to the particular category being examined, separate Group (NC vs. AD) × Dimension (dimension 1 vs. dimension 2) repeated measure ANOVAs were performed for the animal and tool categories. The results of this analysis in the animate category revealed significant Dimension [F (1, 36) = 21.21; p < .01] and Group × Dimension interaction [F (1, 36) = 9.83; p < .01] effects. The effect of Group was not significant [F (1, 36) = .99; n.s.]. Post-hoc t-tests indicated that the Weight Index of dimension 1 was significantly higher for the NC subjects than for the AD patients [t (36) = 3.62; p < .01], while the Weight Index of dimension 2 was significantly higher for the AD patients than for the NC subjects [t (36) = 2.53; p < .01]. In addition, the Weight Index of dimension 1 was significantly higher than that of dimension 2 for the NC subjects [t (18) = 5.65; p < .01], but these two Weight Indexes were not significantly different for the AD patients [t (18) = 1.00; n.s.]. These results indicate that the primary dimension used to classify animals (i.e., *domesticity*) was more salient for the NC subjects than for the AD patients, and that the AD patients attributed more importance than the NC subjects to the secondary dimension (i.e., *size*). These results are consistent with previously reported results (Chan et al., 1993b, 1995a, 1995b) in showing that while NC subjects strongly focus on an abstract conceptual attribute (i.e., *domesticity*) in categorizing animals, AD patients are more likely than NC subjects to additionally rely on a concrete perceptual attribute such as *size*.

The Group (NC vs. AD) × Dimension (dimension 1 vs. dimension 2) repeated measure ANOVAs performed with the Weight Indexes from the tool category revealed a significant main effect of Dimension [F (1, 36) = 365.56; p < .01], but no significant Group [F (1, 36) = .27; n.s.] or Group × Dimension interaction [F (1, 36) = 1.15; n.s.] effects. The main effect of Dimension was due to significantly higher Weight Indexes for the *category* dimension than for the *function* dimension across groups [t (36) = 19.08; p < .001]. These results suggest that the cognitive maps of AD patients and NC subjects for the tool category are essentially normal, with both groups relying predominantly on the *category* dimension when categorizing tools.

The degree of similarity between each AD patient’s semantic network as derived by the Pathfinder analysis and the standard network derived from the pooled data of the NC subjects was reflected in the Similarity Index. Separate Similarity Indexes were generated for the animal and tool categories for each AD patient. A t-test revealed that the AD patients’ Similarity Indexes for the tool category [mean = .75, s.d. = .06] were, on average, significantly higher than those for the animal category [mean = .68; s.d. = .08; t(18) = 54.82; p < .01]. Thus, the AD patients deviated more from the NC subjects when categorizing animals than when categorizing tools.

Free Recall Task

The mean number of items from the tool and animal categories that were recalled by the AD patients and NC subjects are shown in Table III. A Group (NC vs. AD) × Condition (animals vs. tools) repeated measures ANOVA revealed a significant main effect of Group [F (1, 36) = 102.38; p < .001], but no significant Condition [F (1, 36) = .61; n.s.] or Group × Condition interaction [F (1, 36) = .95; n.s.] effects. These results indicate that the AD patients recalled fewer items than the NC subjects in both the tool and animal conditions, and that their recall was comparably poor in both conditions.

The number of intrusion errors (i.e., incorrectly recalling an item that did not appear in the previous tasks) and perseverative errors (i.e., repeating an item that had already been recalled) produced by the two groups during the free recall task are also presented in Table III. Because of the small number of these errors, these data were analyzed with non-parametric procedures. Mann-Whitney U-tests revealed that patients with AD committed significantly more intrusion errors than the NC subjects in both the animal [p < .01] and tool [p < .01] conditions. The AD patients committed significantly more perseverative errors than the NC subjects in the animal condition [p < .01], but did not significantly differ from the NC subjects in the tool condition.

TABLE III

Mean and Standard Deviation (S.D.) of the Number of Correct Responses, Intrusion Errors, and Perseverative Errors Produced in the Tool and Animal Category Conditions of the Free-Recall Task by the Normal Control (NC) Subjects and Patients with Alzheimer's Disease (AD)

	NC (N = 19)		AD (N = 19)	
	Mean	S.D.	Mean	S.D.
Tool Category				
Number of Correct Responses	9.2	0.9	4.6	1.9
Number of Intrusion Errors	0.7	0.9	5.5	2.0
Number of Perseverative Errors	0.2	0.4	0.4	1.0
Animal Category				
Number of Correct Responses	9.2	1.1	5.1	2.1
Number of Intrusion Errors	0.7	1.1	4.9	1.9
Number of Perseverative Errors	0.0	0.0	0.6	1.0

Concept Identification Task

All of the NC subjects and AD patients achieved 100% accuracy in matching the pictures of the animal and tool stimuli with their correct written name.

Sorting Task

The mean number of errors committed by the AD patients and NC subjects on the various sorting tasks are presented in Table IV. Because very few errors were made by either group, these data were analyzed with non-parametric procedures. Mann-Whitney U-tests revealed that the AD patients made significantly more sorting errors than the NC subjects when sorting tools by the *category* dimension (p < .05), but not when sorting by the *function* dimension. In the animal category, the AD patients made significantly more errors than the NC subjects when sorting by the *predation* dimension (p < .01), but not when sorting by the *domesticity* or *size* dimensions.

TABLE IV

Mean and Standard Deviation (S.D.) of the Number of Errors Committed in the Tool and Animal Category Conditions of the Sorting Task by Normal Control (NC) Subjects and Patients with Alzheimer's Disease (AD)

	NC (N = 19)		AD (N = 19)	
	Mean	S.D.	Mean	S.D.
Tool Category Dimension				
Category	0.05	0.23	0.79	1.13
Function	0.21	0.16	0.74	0.26
Animal Category Dimension				
Domesticity	0.21	0.54	0.57	1.02
Size	0.21	0.42	0.47	0.70
Predation	1.31	0.58	2.53	1.58

Typicality Ranking Task

The group rankings of the tool and animal concepts as representative exemplars of their category are shown separately for the AD patients and NC subjects in Table V. The rankings are based on the number of subjects who chose a particular concept at a given rank. For example, if more subjects chose

TABLE V

The Rankings of the Tool and Animal Concepts as the Most Representative Exemplar of Their Category by the Normal Control (NC) Subjects and Patients with Alzheimer's Disease (AD). Designated Concepts Received the Same Ranking [++] by NC subjects and AD Patients, or Differed by Only One Rank Level [+]

	NC	AD	
Tool Category			
Ranking			
1	hammer	hammer	++
2	saw	screwdriver	+
3	screwdriver	saw	+
4	axe	axe	++
5	scissors	nail	+
6	knife	scissors	+
7	needle	knife	+
8	nail	needle	
9	thread	thread	++
10	button	button	++
Animal Category			
Ranking			
1	dog	dog	++
2	cow	donkey	
3	lion	elephant	+
4	elephant	lion	+
5	pig	monkey	
6	donkey	leopard	
7	monkey	cow	
8	rhinoceros	pig	+
9	leopard	rhinoceros	
10	rooster	rooster	++

dog than any other concept as the best exemplar of the animal category, that concept received a ranking of 1. If more subjects chose *cow* than any other concept as the second best animal exemplar, that concept received a ranking of 2, and so on.

Comparison of the rankings of the tool and animal stimuli made by the AD patients and NC subjects showed that the groups' rankings were more similar for the tool category than for the animal category. In the tool category, four exemplars (*hammer, axe, thread* and *button*) were ranked the same by AD patients and NC subjects, and five additional exemplars were within one rank for the two groups. In the animal category, by contrast, only two stimuli (*dog* and *rooster*) were ranked the same by the patient and control groups, and only three additional exemplars (*lion, rhinoceros,* and *elephant*) were within one rank for the two groups.

To further analyze the typicality ranking data, the number of subjects that ranked each stimulus at a given level (e.g., the number of subjects who choose *hammer* as the best example, the number who choose *hammer* as the second best example, and so on) was calculated. This latter procedure resulted in 10 frequency scores (one at each ranking level) for each stimulus. The frequency scores of each concept for NC subjects were then correlated with those of AD patients. For example, the following frequency distributions were obtained for the AD patients and NC subjects for the concept *hammer*:

Typicality Rank:	1	2	3	4	5	6	7	8	9	10
AD Patients:	18	0	1	0	0	0	0	0	0	0
NC Subjects:	13	6	0	0	0	0	0	0	0	0

The correlation coefficient (Pearson r) comparing these two distributions was .80.

This procedure resulted in 10 correlation coefficients for the *animal* category and 10 for the *tool* category. The magnitude of the correlation coefficients obtained for the tool and animal categories were then compared with a t-test (two-tailed). The results showed that there was a significantly higher degree of correlation between the rankings of the AD patients and the NC subjects for the tool category [mean $r = .63$; s.d. = .40] than for the animal category [mean $r = .31$; s.d. = .37] [$t(18) = 1.87$; $p < .05$].

DISCUSSION

The results of the present study indicate that the organization of semantic knowledge in the category "animals" is disrupted in mildly demented patients with AD at a time when the organization of their knowledge in the category "tools" is essentially intact. This differential impairment was evident in the patients' performance on the triadic comparison tasks which required them to group exemplars within the categories on the basis of their various attributes. Multidimensional analyses of the data from these tasks showed that the model of the AD patients' semantic network (or cognitive map) for "animals" was altered compared to that of NC subjects in terms of measures of goodness-of-fit (i.e., R^2 and Stress Value) and the weight placed upon various attributes used to categorize exemplars. In particular, patients with AD placed equal weight (as measured by the Weight Index) on the attributes of *domesticity* and *size* when categorizing animals, while NC subjects placed significantly greater weight on the *domesticity* attribute than on the *size* attribute. The models of the semantic network for “tools”, in contrast, were similar for AD patients and NC subjects. The measures of goodness-of-fit for the models generated for the patients and controls were not significantly different, and both groups placed significantly greater weight on the *category* attribute than on the *function* attribute when categorizing tools.

Additional analyses showed that the degree of similarity in the semantic networks of AD patients and NC subjects, as measured by the Similarity Index, was significantly less for the “animal” category than for the “tool” category, as were the correlations between the AD patients’ and control subjects’ rankings of the typicality of the exemplars in each category. Taken together, these results suggest that category specificity is present in the semantic memory deficit exhibited by these patients with AD. The observed disruption of the organization of knowledge in the “animal” category, but not the “tool” category is consistent with a number of previous studies that have shown that mildly demented patients with AD exhibit greater impairment on semantic memory tests with living than with non-living items (Daum et al., 1996; Garrad et al., 1998; Mauri et al., 1994; Montanes et al., 1995; Silveri et al., 1991).

Although some previous demonstrations of category specific semantic deficits in patients with AD are possibly attributable to an artifact of the living category stimuli being more visually complex or less familiar than the non-living category stimuli (Tippett et al., 1996b), this explanation is not likely to apply to the present results. While visual complexity and familiarity are known to have an impact upon the ability to name a given item, it is not clear that these factors would have a negative impact on the ability to categorize the item once it had been successfully identified. All of the items in both categories were identified by the patients with AD in the Concept Identification Task, and although the stimuli in the “tool” category were more familiar and less visually complex than those in the “animal” category, the patients were only very mildly impaired in their ability to name or sort the items and their performance was equivalent for both categories. It is also unlikely that the differential performance with the two categories can be attributed to one category being inherently more complex than the other. In both cases, the optimal model developed with multidimensional scaling techniques had a two dimensional solution.

Further evidence that the observed category specific semantic deficits are not simply due to differences in the familiarity, visual complexity, or representativeness of the stimuli used in the two categories is provided by an examination of the performance of individual subjects. Although the AD patients as a group exhibited an impaired semantic network for the “animal” category but not the “tool” category, the opposite relationship was occasionally observed. For example, when the R^2 values and the primary Weight Indexes for each patient with AD were converted to z-scores based upon the mean and standard deviations of the NC group, at least one patient obtained z-scores of – 2.55 and – 1.67, respectively, for the “tool” category and – 0.40 and 0.42, respectively, for the “animal” category. If there were strong inherent differences in the representativeness of the items in each category, this opposite pattern of category specificity would not be expected to occur.

Taken together, these three lines of converging evidence (i.e., intact identification of all items in both categories; optimal two-dimensional solutions for both categories; inter-individual dissociations in the impaired semantic network) strongly suggest that the present results were not simply an artifact of the living category stimuli being more visually complex or less familiar than the non-living category stimuli. However, the possibility that these stimulus properties played some role in the present results cannot be completely ruled out. Replication of the present study with a wider variety of categories and category exemplars is warranted, both to confirm the differential impact of AD on “living” and “non-living” categories of semantic knowledge and to explore the possibility of additional fractionations of semantic knowledge in these patients.

The neuropsychological basis of category specific deficits in semantic memory for living and non-living objects has been attributed to differential damage to neural systems underlying the representation of perceptual and functional attributes of stimuli (Warrington and McCarthy, 1987; Saffran and Schwartz, 1994; Garrad et al., 1998; Martin et al., 1996; but see Gonnerman et al., 1997 for an alternative position). According to this point of view, living objects are distinguished from one another primarily on the basis of perceptual attributes (e.g., size, color) and this visual semantic knowledge is mediated by posterior brain regions (i.e., temporolimbic cortex). Non-living objects, in contrast, are distinguished from one another primarily in terms of functional attributes and this conceptual semantic knowledge is mediated by anterior brain regions (i.e., frontoparietal cortex). Early in the course of AD, these cortical areas may be differentially affected by the disease and a category specific deficit may result. Consistent with this notion, there is some evidence to suggest that the pathological changes of Alzheimer’s disease progress from the medial temporal lobe region (e.g., entorhinal cortex, hippocampus) to the more posterior association cortex, and then to the more anterior association cortex (Bancher et al., 1993; Braak and Braak, 1991). Primary sensory and motor cortices and most subcortical structures are spared (Braak and Braak, 1991). The relationship between this proposed progression of AD pathology (as measured by functional and structural brain imaging) and the progression of semantic memory deficits for living and nonliving categories would be an ideal topic for future longitudinal studies.

The specific deficit in the “animal” category exhibited by the mildly demented patients with AD in the present study suggests that the posterior cortices involved in processing visual semantic knowledge are more affected by the disease than are the anterior cortical regions involved in processing conceptual semantic knowledge. This interpretation of the results, however, appears to be at odds with the finding that the basis of the organization of the "animal" network shifts from primary reliance upon an abstract conceptual dimension (i.e., domesticity) in normal individuals to equal reliance upon a conceptual dimension and a more concrete perceptual dimension (i.e., size) in the patients with AD. If the processing of visual semantic information is specifically impaired in AD, why would the patients appear to increase the weight they place upon a perceptual dimension in organizing their knowledge?

It may be the case that visual semantic knowledge is typically used when attempting to make subtle distinctions between animals (e.g., stripes distinguish a tiger from a leopard) rather than when attempting to group animals on the basis of certain broad features (e.g., a tiger and leopard are both wild animals). If visual semantic knowledge is degraded in patients with AD, however, subtle distinctions may no longer be recognized and the physical characteristics of animals may be limited to large and salient features such as big and small. When the potential use of visual semantic knowledge is simplified in this way, it may gain additional weight for grouping animals along these salient dimensions and play a greater role in the organization of knowledge within the category. This shift in the weight placed upon a physical aspect of the stimuli may also be facilitated by the relative preservation of the primary visual cortex in the occipital lobe of patients with AD. Martin et al. (1996) showed that a region of the left medial occipital lobe that is involved in the earliest stages of visual processing was activated in normal individuals when naming pictured animals, but not when naming pictured tools.

Despite the differences in the integrity of the organization of their knowledge for the concepts "animals" and "tools", the patients with AD were similarly impaired on free recall tasks for items from both categories. The insensitivity of their performance on the episodic memory tasks to differences in the status of semantic knowledge is consistent with previous studies that have shown that there is a reduction in the interaction between semantic and episodic memory in patients with AD. A number of studies have shown, for example, that AD patients have a deficient ability to perform semantic encoding during episodic memory tasks (Dalla Barba and Goldblum, 1996; Goldblum, Gomez, Dalla Barba et al., 1998) and that the provision of semantic support in the form of categorically organizable material or semantic retrieval cues is much less effective for patients with AD than for normal elderly individuals (for review, see Backman and Herlitz, 1996; Backman and Small, 1998). Given this lack of interaction between the two systems, it is not surprising that the patients with AD exhibited a general episodic memory deficit that affected both categories equally.

The results of the present study also have important implications concerning the underlying nature of the deficit in semantic memory exhibited by patients with AD. While some investigators suggest that patients with AD suffer a breakdown in the organization of semantic knowledge (Butters, Granholm, Salmon et al., 1987; Chertkow and Bub, 1990; Hodges et al., 1992; Martin and Fedio, 1983; Salmon, Heindel and Lange, 1999), others propose that their semantic knowledge remains essentially intact but is less accessible because of a general retrieval deficit (Nebes, 1992; Nebes and Halligan, 1999). Although the present study did not directly address these two hypotheses, it is not clear why a general retrieval deficit would affect one category (i.e., *animals*) and not another (i.e., *tools*). Thus, the alteration of the AD patients' semantic network for "animals" revealed with the triadic comparison task suggests that a breakdown in the organization of knowledge has occurred.

Acknowledgement. The late Dr. Nelson Butters contributed importantly to the conceptual development of this study. The study was supported, in part, by NIA grants AG-05131 and AG-12963, an Alzheimer Research Center of California (ARCC) grant from the State of California, and a Summer Research grant from the Chinese University of Hong Kong.

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(*Received 25 July 2000, reviewed 29 September 2000, revised 16 October 2000; accepted 26 October 2000*)