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Semantic relations and Alzheimer's disease: An early and disproportionate deficit in functional knowledge

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Abstract

This experiment explored knowledge of four types of semantic relations (superordinate category, part, property, and function) in Alzheimer's disease (AD) subjects and age- and education-matched controls. Moderate AD subjects showed the greatest disruption on functional relations, intermediate disruption on part and property relations, and the least disruption on category relations; mild AD subjects showed a similar pattern but significant deficits only on functions. We suggest that the disproportionate deficit on functions reflects a greater cognitive complexity of functions than other semantic relations that renders them more vulnerable either to disrupted processing or to structural degradation of the network of associations among semantic concepts. (*JINS*, 1995, *1*, 568–574.)

Keywords: Alzheimer's disease, Semantic memory

Introduction

Semantic memory refers to general knowledge, including knowledge about the relations among concepts. For example, semantic memory includes knowing that *scissors* are a kind of *tool* and that *scissors* are used for *cutting* things. Many recent studies of Alzheimer's disease (AD) patients attempt to characterize the impairments of semantic memory that are associated with this illness (e.g., Nebes, 1990, 1992; Gainotti, 1993). One question has been whether categories are preserved relative to other attributes (i.e., properties, parts, and functions). Warrington (1975) first suggested this possibility in a study of three patients with progressive dementia of undefined etiology. She found that these patients were able to answer "yes" or "no" questions (e.g., for *canary*: "Is it an *animal*?") and multiple choice questions (e.g., for *canary*: "Is it an *animal* or *not an animal*?") about the categories of pictured objects, but they were impaired on questions about the physical properties of objects (e.g., for *canary*: "Is it *bigger* than a *cat*?"). Similarly, Martin and Fedio (1983) found that AD patients were able to sort photographs into sets and produce appropriate category labels as well as make judgments about categorical relations (e.g., for *saw*: "Is it a *tool*?"). However, patients were less accurate in their judgments about perceptual and functional relations (e.g., "Does it have *moving parts*?"; "Is it *used to cut things*?"). Chertkow et al. (1989) asked AD patients to answer a series of forced-choice questions about line drawings with an accompanying label. Subjects were asked about each item's category (e.g., "Is it a *tool* or *clothing*?"), physical properties (e.g., for *saw*: "Is it *sharp* or *dull*?") and functional attributes (e.g., for *saw*: "Do you *cut things* with it or *lift* with it?"). They found that the patients and controls performed equally well (and near perfectly) on the superordinate question but the patients made more errors than elderly controls on questions about the perceptual and functional attributes of the items. Overall, the results of these studies have been used as support for the view that superordinate relations remain intact relative to other semantic attributes in AD patients.

On the other hand, evidence contradicting the idea that category relations are relatively preserved was reported by Nebes and Brady (1988). They had AD patients and matched controls judge whether or not several words were related to a line drawing of an object (e.g., *shirt*). Test words included the object's superordinate category (*cloth-*

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ing), a general associate (*tie*), a distinctive physical feature (*collar*), a function of the object (*wear*), and unrelated items (e.g., *guide*, *snow*, *bear*). There was no difference in response times when Nebes and Brady compared the combined response times of physical features and functions to the combined response times of categories and associates. Similarly, Funnell (1992) reported results from a case study in which the level of performance on semantic feature questions (Is a *stone soft*?) did not differ from that on semantic category questions (Is a *sparrow* a *bird*?).

More recently, Johnson et al. (1995) examined the effects of typicality on AD patients' judgments of four types of semantic relations: categories, parts, properties, and functions (e.g., Is this a kind of *dog*? – *collie*; Is this a part of a *bicycle*? – *basket*). Johnson et al. found that AD subjects, like elderly controls, showed typicality effects for all attributes; however, there was also some evidence that functions might be particularly difficult for AD subjects.

Across these studies, then, the results do not show a consistent rank order of deficit for various attributes. Even if the results were entirely consistent, the conclusions would be equivocal for the following reasons: (1) The Warrington (1975) study tested patients who were not specifically diagnosed as having Alzheimer's disease (it was later reported that two of the three patients had Pick's disease on autopsy, see Hodges et al., 1992) and Funnell's (1992) study included only a single patient; (2) The Martin and Fedio (1983) study was briefly reported as a pilot study and little information was provided about the items used and the patients tested; (3) Neither Chertkow et al. (1989) nor Nebes and Brady (1988) report data separately for perceptual and function attributes; (4) In the Nebes and Brady study, the rationale for combining data for categories and associates is not clear; (5) The fact that the same concepts were tested repeatedly in the Chertkow et al., Martin and Fedio, and Nebes and Brady studies raises the question of whether or not performance was affected equally in the control and AD groups by priming. The repeated testing of the same concepts may have produced interference that fell differentially on different attributes in the Chertkow et al. and Martin and Fedio studies or produced facilitation that reduced potential differences between the response times for different attributes in the Nebes and Brady study; (6) The Johnson et al. study did not hold concept constant across attributes.

In short, it may be that AD produces greater or earlier disruption in some types of semantic attributes than others, but to date the evidence for this proposition is not strong. Thus, this experiment was designed to determine whether AD patients are disproportionately impaired on some aspects of semantic meaning relative to others. Subjects were asked to verify category membership, parts, properties, and functions for various concepts. Across subjects, a particular concept was tested in all four semantic conditions but each subject saw the concept only once.

Method

Subjects

Seventy-two subjects participated: 36 AD patients and 36 elderly controls. The patients were referred to us for testing by physicians and clinics in New Jersey and Pennsylvania (see Acknowledgments). The elderly controls, matched to the AD patients for age and education, were predominantly spouses of the patients. Five elderly controls were recruited from retirement communities in the Princeton area as controls for patients without spouses. For inclusion in the AD group, subjects had to be diagnosed as having probable Alzheimer's disease as defined by the National Institute of Neurological and Communicative Disorders and Stroke and the Alzheimer's Disease and Related Disorders Association (NINCDS–ADRDA) Work Group (McKhann et al., 1984) criteria. The AD patients were divided into 2 groups on the basis of their Mini–Mental Status Examination [(MMSE); Folstein et al., 1975] scores. Fifteen patients with MMSE scores between 4 and 18 were included in the moderately-to-severely impaired group and 21 patients with MMSE scores of 19 or greater were included in the mildly impaired group. Table 1 shows the demographic characteristics and MMSE scores for the groups. The groups did not differ in age or years of schooling. The moderately impaired patients had significantly lower MMSE scores than the mildly impaired patients, $F(1,34) = 51.45$, $MSE = 10.96$. MMSE scores were also obtained for the last 15 of the 36 elderly controls tested; the controls scored higher than the mild, $F(1,34) = 69.79$, $MSE = 4.67$, and moderate, $F(1,28) = 147.01$, $MSE = 10.19$, groups.

Materials and procedure

The materials consisted of 40 object names (e.g., *corn*, *saw*) and four attributes – category, part, property, and function – for each (e.g., for *saw*: its category is *tool*, its part is *teeth*, its property is *jagged*, and its function is *cutting*; for corn: the attributes were, respectively, crop, kernel, yellow, and eat). Each attribute set was then sub-

Table 1. Demographic and psychometric characteristics of the subject groups

	Moderate & severe AD ($N = 15$)	Mild AD ($N = 21$)	Elderly controls ($N = 36$)
Gender (F/M)	7/8	11/10	21/15
Age (yr)[a]	71.5 (2.2)	73.9 (1.5)	71.7 (1.4)
Education (yr)[a]	13.1 (.79)	13.8 (.93)	14.2 (.47)
MMSE (30 max.)[a]	14.4 (1.1)	22.4 (.54)	28.5 (.41)[b]

[a]Values are $M(SE)$.
[b]MMSE scores were available for 15 of the 36 elderly controls.

divided into four subsets of ten items. The subsets were equated for frequency (Francis & Kucera, 1982; see also Funnell & Sheridan, 1992), typicality,[1] and number of syllables. Each experimental list included a 10-item subset of items from each attribute, that is, categories, parts, properties, and functions. There were no significant differences in the average frequencies or typicality ratings of the four types of attributes in a particular list. Attribute subsets were tested in blocks and for each block, in addition to the 10 target items, there were 6 foils of the appropriate attribute type unrelated to any other concept on the list (e.g., for the category task, *guitar-reptile*). Like targets, foils used were equated across attributes for frequency (Francis & Kucera, 1982) and number of syllables. No subject was tested twice on the same concept. The different attributes for a given concept were counterbalanced across subjects as was the order in which the attributes were tested.

Each trial began with the experimenter reading a question aloud, (e.g., "Is this a category for *saw*?"). Then a word appeared in the middle of a computer screen (e.g., *tool*), activating a timer. The subject responded to the question by answering "yes" or "no" and the experimenter pressed a key on the keyboard to record the subject's response and response time and advanced to the next trial. We did not have subjects press buttons or speak into a voice key in order to eliminate extra task requirements (keeping track of which button is which; inhibiting irrelevant vocalizations such as coughing or clearing throat) that might create a greater cognitive burden on AD patients than controls. Moreover, the primary dependent variable was accuracy. However, we recorded the time from the appearance of the word on the screen to the experimenter's keypress. Although these times include an experimenter factor contributing to absolute response times, we were not particularly interested in absolute response times (AD patients generally respond more slowly than controls) but rather in any potential interaction of attribute with subject group.

Results

Subsequent comparisons following the analyses of variance (ANOVAs) reported below were made using the Tukey–Kramer test to compare groups or the Tukey Honestly-Significant-Difference (HSD) test to compare attributes. Unless otherwise indicated, results are significant at $p < .05$ or better.

The mean proportion of correct responses to targets minus the proportion of incorrect responses to foils (i.e., hits-false positives) are shown in Figure 1. The data were analyzed as a 3 (Group: elderly controls, milds, and moderates) × 4 (Attribute: categories, parts, properties, and functions) ANOVA. There was a main effect of group, $F(2,71) = 31.62$, $MSE = .07$. Subsequent comparisons indicated that moderately impaired patients (.60), mildly impaired patients (.80), and elderly controls (.93) were significantly different from each other. In addition, there was a main effect of attribute type, $F(3,213) = 13.21$, $MSE = .02$; functions (.69) were harder than categories (.84), parts (.79), or properties (.79). More important, as is evident from Figure 1, attribute type interacted with group, $F(6,213) = 3.27$, $MSE = .02$. Subsequent analyses revealed that moderates made significantly more errors than milds and elderly controls on all attributes. The only significant difference between the milds and elderly controls was for the functions. In short, moderates were impaired on all attributes, but most impaired on functions and least on categories. Mild AD patients showed the same general pattern, but were significantly impaired on functions only.

The median response times (RTs) in seconds for targets are shown in Figure 2. There was a main effect of group, $F(2,69) = 13.61$, $MSE = 2.78$; moderately impaired patients (2.30) were significantly slower than mildly impaired patients (1.49) and elderly controls (.98). The difference between the milds and elderly controls was

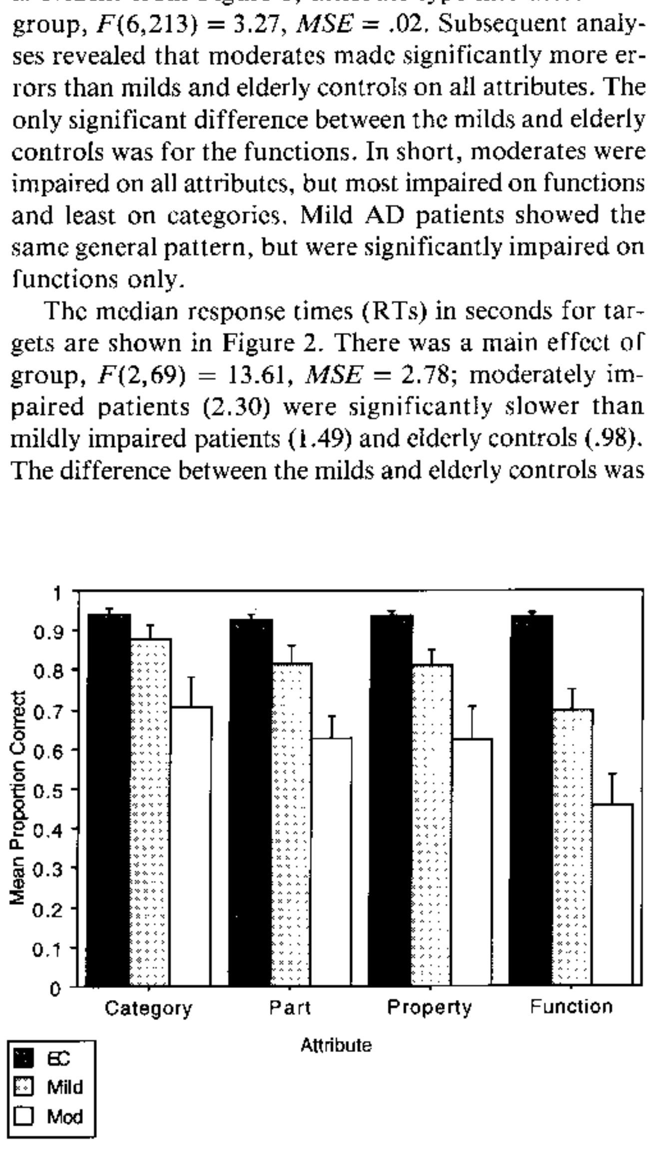

Fig. 1. Mean proportion correct to targets minus mean proportion incorrect to foils. Error bar indicates standard error of the means indicated by error bars.

[1] In order to equate typicality across lists in each experiment, we obtained typicality ratings from young adult subjects for all of the attributes used in this experiment. Each subject was asked to rate how likely an attribute for a concept came to mind on a scale of 1 to 5 where 1 is not at all likely and 5 is very likely. For example, for categories of concepts, subjects read the following instructions, "for each concept below (on the left in bold), rate how likely the category (on the right) is to come to mind when you think of a category for the concept. Please use the full range of the scale when making your decisions and circle only one number." Each concept-attribute relation was rated by approximately 30 (range = 27 to 32) subjects. The overall mean rating for items used was 3.59. For comparison, this is between the average for medium and high typical items in Johnson, et al., 1995. Details are available from the authors.

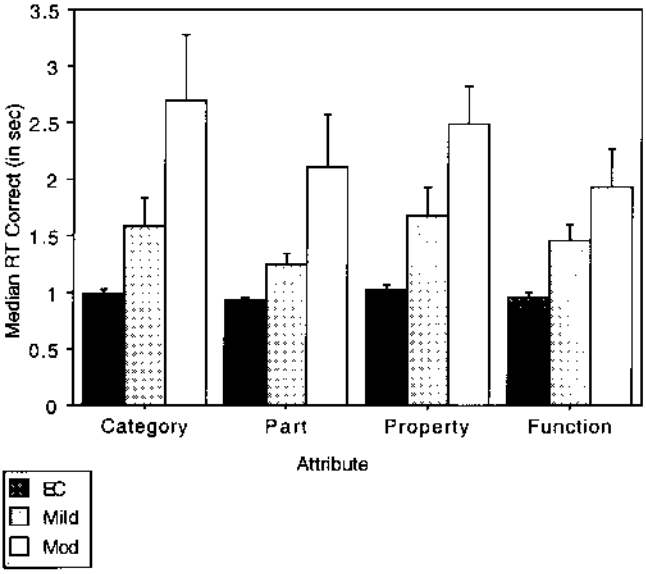

Fig. 2. Median time in s for correct responses to targets. Error bar indicates standard error of the mean.

not significant. The main effect of attribute, $F(3,207) = 8.79$, $MSE = .22$, indicates that subjects were generally slower in responding to categories (1.75) and properties (1.73) than parts (1.43) and functions (1.45). In addition, attribute type interacted with group, $F(6,207) = 3.09$, $MSE = .22$. Subsequent analyses revealed that moderates were slower than milds and elderly controls when responding to all types of attributes. Milds were significantly slower than elderly controls when responding to properties.

Within-subject tests on all four attributes of the same concepts

Accuracy

Thirty of the subjects (15 elderly controls, and 11 mild and 4 moderate AD patients) were given 3 test lists in addition to the first included in the analyses above. The time between tests ranged approximately 15–30 min, during which subjects were engaged in other tasks. Across the four lists, for each subject each concept was tested for all four attributes: category, part, property, and function. The mean proportion correct responses to targets minus the mean proportion incorrect responses to foils (hits-false positives) collapsed across all four tests are shown in Figure 3. The general pattern was similar to the pattern observed when the analysis was limited to Test 1 as reported above (see Figure 1).

Subsequent analysis of the accuracy data was performed to determine how subjects' errors were distributed across concepts; that is, of the four attributes for each concept, how many attributes were correctly verified. If concepts degrade as a "package" we would expect AD patients to have a bimodal distribution in which they either

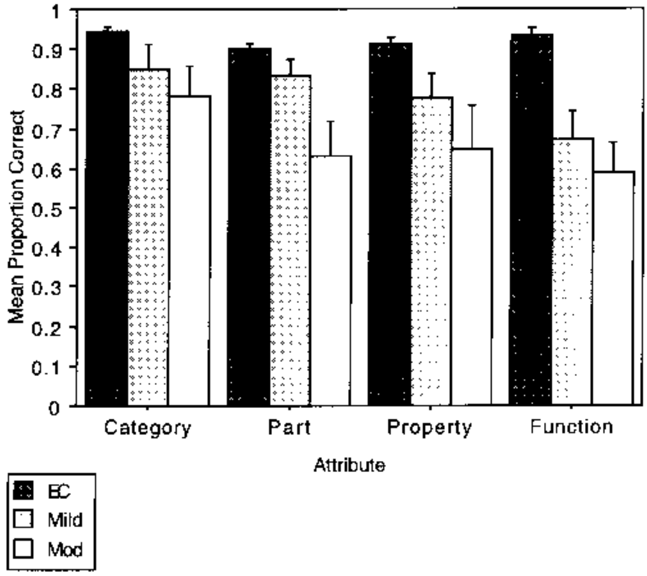

Fig. 3. Mean proportion correct to targets minus mean proportion incorrect to foils, collapsed across 4 trials (within-subjects analysis). Error bar indicates standard error of the mean.

got all four attributes correct for a concept or no attributes correct. As evident from Figure 4, however, even for moderates it was rare that no attributes (or even only one) were correct (see also Bayles et al., 1991).

Median response times

The median response times, in seconds, for correct responses to targets collapsed across the four tests are shown in Figure 5. The general pattern is similar to that

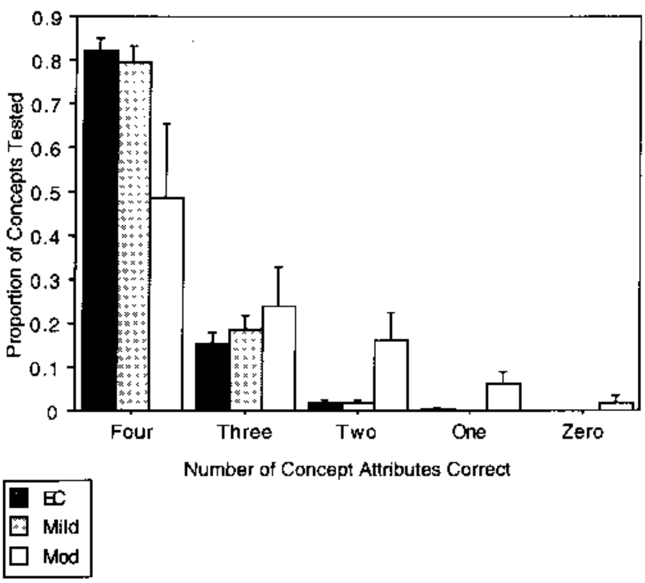

Fig. 4. Mean proportion of concepts for which 4, 3, 2, 1, and 0 attributes were correct (within-subjects analysis). Error bar indicates standard error of the mean.

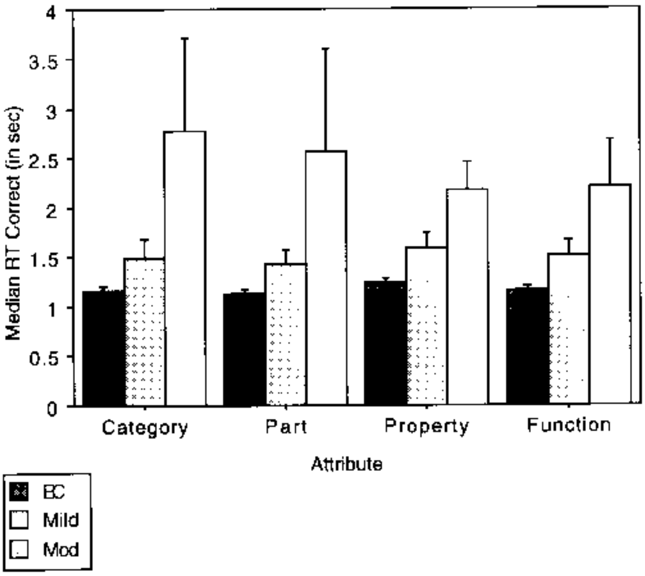

Fig. 5. Median correct response times (in s) for targets (within-subjects analysis). Error bar indicates standard error of the mean.

obtained in the analysis of Test 1 data alone (see Figure 2). Figure 6 shows the median response times to targets for each of the four tests, collapsed across type of attribute. From Figure 6, overall response times of moderates decreased to a level closer to that of milds and elderly controls at Test 2 but then increased again on Tests 3 and 4.

Although the small number of moderate AD subjects that were tested on all 4 attributes of each concept make the conclusions tentative, the accuracy data are consistent with those from Test 1 data. AD patients had particular difficulty verifying functional relations. In addition, categorical relations were relatively intact even in moderately impaired AD patients. Furthermore, the response time data for subjects tested four times on each category suggested that moderate AD patients may be subject to both facilitation and interference effects when the same concept is repeatedly tested. Moderates responded more quickly on Test 2 than Test 1; however, response times increased again on Tests 3 and 4. Although these data are suggestive, we cannot make any strong conclusions about the exact form of the relation between response time and test because the time was not held constant between pairs of adjacent tests. Also, the rise in response time from Test 2 to Tests 3 and 4 could reflect dissipation of facilitation or a general fatigue effect rather than increasing interference.

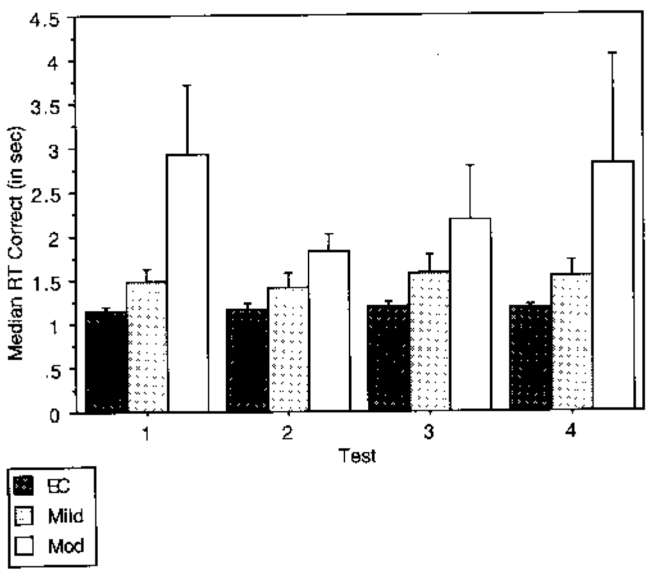

Fig. 6. Median correct response times (in s) for targets (within-subjects analysis). Error bar indicates standard error of the mean.

Discussion

Previous studies of attribute knowledge in AD patients suggested that categorical knowledge might be preserved relative to knowledge of other attributes. Limitations to these previous studies include small sample (Funnell, 1992), unspecified etiology of patients tested (Warrington, 1975), limited information about the items and procedures involved (Martin & Fedio, 1983), repeated testing of the same concepts (Nebes & Brady, 1988; Chertkow et al., 1989), combining results across different types of attributes (Nebes & Brady, 1988; Chertkow et al., 1989), or not holding concepts constant across attributes (Johnson et al., 1995). Therefore, the present experiment was designed to determine whether AD patients are equally disrupted on several types of attribute knowledge (category, part, property, and function).

The accuracy data clearly demonstrate that moderately impaired patients show preserved performance on categorical relations relative to other attributes, consistent with conclusions reached by Warrington (1975), Martin and Fedio (1983), and Chertkow et al. (1989). Furthermore, consistent with Johnson et al. (1995), we found that both moderate and mild AD patients showed a disproportionate disruption of functional relations. These findings were obtained comparing different attributes of the same concepts and with frequency levels of the words designating the attributes equated across attribute condition. The overall pattern of disruption shown in Figure 1 suggests a systematic progression in semantic memory deficits; functions are disrupted initially in the mild stage of AD, followed by parts and properties and, lastly, categorical information as the disease progresses. That is, broad category knowledge is more available than more specific, differentiating or distinguishing information (Warrington, 1975; Schwartz et al., 1979).

Why might deficits in functional knowledge show up early and remain disproportionately disrupted as AD progresses? There are several possibilities worth considering for why, among the more differentiating attributes, functions would be the most vulnerable (Johnson et al., 1995).

One alternative is suggested by ideas proposed by Tversky and Hemenway (1984) and Roy and Square (1985). Tversky and Hemenway suggested that functions of objects are apprehended *via* salient or essential parts of objects. Similarly, Roy and Square suggested that perceptual features (i.e., parts and properties) of objects serve to activate the procedures associated with functional knowledge. These views imply that parts and properties are more basic than functions and that knowledge of parts and properties is essential to knowledge of functions. If knowledge of functions is accessed through knowledge of parts and properties, then it follows that activation of functional knowledge depends on activation of parts and properties. Because they are "farther away," more activation or more processing operations would be required to activate functional knowledge than to activate other attributes of a concept.

Another possibility is that functions are more cognitively complex than parts and properties because parts and properties define concepts as entities whereas functions generally reflect potential relations (e.g., actions expressed as verbs) among different concepts or entities. In effect, it takes more concepts to instantiate a function than it does to instantiate a part or a property. For example, the fact that a *saw* has *teeth* is part of the basic definition of a saw; the fact that a saw can be used for *cutting* requires knowledge of the parts and properties of other concepts – entities with which saws might interact (e.g., *lumber*, *trees*, etc.). That is, functions require general knowledge beyond knowledge of individual objects (Miller, 1991). Again, more activation or more processing operations would be required to access and maintain the concepts necessary for completing the relation in the case of functions than of other attributes. A related possibility is that as more relevant concepts are activated, more irrelevant concepts are activated as well, increasing the demands for selection and, perhaps, inhibition.

In short, in normal semantic processing, relative to other attributes, functions may require (1) more or longer lasting stimulus-driven activation; (2) more agenda-controlled, strategic, or reflective processes for keeping concepts active (*refreshing*, *rehearsing)* or for *retrieving* related information (e.g., Johnson, 1992); or (3) more inhibition of irrelevant concepts (e.g., Hasher & Zacks, 1988). One or more of these factors would not necessarily be reflected in accuracy or response times of cognitively intact subjects on tasks that are well within their processing capabilities. However, stresses on the cognitive system (e.g., from brain damage) may reveal differences in processing requirements that are not otherwise obvious. There have been proposals about disruption of cognitive processing arising from AD that correspond to each of these possibilities. AD may reduce levels of semantic activation (e.g., Milberg et al., 1995), disrupt self-initiated or reflective cognitive processes (e.g., Nebes et al., 1984; Hartman, 1991; Bonilla & Johnson, 1995); and/or disrupt inhibitory processes (e.g., Balota & Duchek, 1991). Thus, disrupted processing views could accommodate a disproportionate deficit in functional knowledge in AD patients.

However, the present results alone do not rule out the possibility that critical cognitive processes are intact but the semantic structure is degrading (e.g., Chan et al., 1993). For example, if on average more concepts are required to compute the meaning of functions than other semantic relations, then the degradation of any associations within the network would, by chance, fall disproportionately on functions. Nevertheless, the present results, along with other findings (e.g., Johnson et al., 1995) indicate that if the semantic network is degrading, it is doing so in a manner that maintains many of the systematic typicality relations among concepts characteristic of an intact semantic system and at the same time produces marked impairment of functional knowledge relative to other attributes.

In summary, the present results indicate that AD does not result in a random loss of entire concepts (see Figure 4), nor a random loss of attributes across concepts. Rather, there appears to be a regular progression to the deficit that maintains a consistent relative rank order of difficulty of attributes (categories, properties and parts, functions) as the disease progresses (see Figure 1). AD patients also show typicality effects for each of the semantic attributes investigated here (Johnson et al., 1995). Thus, AD appears to be a disease that, at least in its earlier stages, results in *systematic deficits* rather than a *disordering* of knowledge, and in which more cognitively complex semantic relations are more vulnerable to the disease process.

Acknowledgments

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