Loss of Distinctive Features and a Broader Pattern of Priming in Alzheimer's Disease

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Abstract

The results of two experiments supported the contention that patients with Alzheimer's disease (AD) suffer from a relative loss of the semantic features that distinguish concepts from one another and that the representations of pairs of concepts consequently share a larger proportion of their associated features in AD than in normal aging (Martin, 1992). In the first experiment, AD patients listed fewer features for a set of concepts than normal older adults and were more deficient at listing features if the features were distinctive to particular concepts than if they were shared by multiple concepts. In the second experiment, AD patients showed on-line priming at levels of relatedness at which normal older adults did not.

Alzheimer's disease (AD) is the most common neurodegenerative disorder affecting persons over 65 years of age. The disease is associated with progressive cortical, limbic, and subcortical brain damage (Shimamura, Salmon, Squire, and Butters, 1987). It is a dementing disorder affecting all domains of intellectual functioning.

Memory problems are among the first as well as the most disabling of the cognitive deficits that occur in AD. Episodic memory is disrupted early in the course of the disease (Kazniak, Poon, & Riege, 1986).

Semantic memory is also disrupted in AD. AD patients are impaired on a variety of tasks that depend on semantic information. For example, AD patients have difficulty accessing words (Kempler, Curtiss, & Jackson, 1987), producing word associations (Gewirth, Shindler, & Hier, 1984), retrieving members of semantic categories (Martin & Fedio, 1983; Salmon, Heindel, & Lange, 1999; Troester, Fields, Testa, Paul, Blanco, Hames, Salmon, & Beatty, 1998), naming objects (Kirshner, Webb, & Kelly, 1984; LaBarge, Balota, Storandt, & Smith, 1992), and verifying the semantic attributes of concepts (Grober, Buschke, Kawas, & Fuld, 1985; Johnson, Hermann, & Bonilla, 1995). When AD patients make similarity judgments with respect to concepts from certain categories (e.g."animal"), graphical representations of the judgment data are often systematically different from the representations of data from normal older adults (Chan, Butters, & Salmon, 1997; Chan, Butters, Salmon, & McGuire, 1993; Chan, Salmon, &Butters, 1998; Chan, Salmon, & De la Pena, 2001; but see Ober & Shenaut, 1999).

Two major hypotheses have been proposed to account for the semantic memory deficits of AD patients. According to the *degraded access hypothesis,* AD patients are impaired in accessing semantic knowledge (Nebes, Martin, & Horn, 1984). Semantic knowledge remains intact in these

patients, but they are unable to retrieve the knowledge in an efficient and effective manner. According to the *degraded store hypothesis*, semantic knowledge is actually lost in AD patients. No amount of retrieval support will allow the knowledge to be expressed. It is gone (Martin, 1992).

A number of kinds of data have been put forward in support of the degraded access and degraded store hypotheses. For example, inconsistency of responding on tests of semantic knowledge has been taken as support for the degraded access hypothesis (Knotec, Bayles, & Kazniac, 1990). On the other hand, greater deficiency in one kind of knowledge than another (as in knowledge of certain categories but not others) has been taken as support for the degraded store position (Fung, Chertkow, & Templeman, 2000).

Although the degraded access and degraded store hypotheses have both been supported in past work, the weight of the evidence has tended to favor the latter hypothesis. The present study sought to explore one particularly well-specified version of that hypothesis. Martin's (Martin, 1992; Parasuraman & Martin, 1994) version of the degraded store hypothesis starts from the assumption that concepts are represented mentally in terms of semantic features. This assumption is common to much recent work on concept processing, especially work undertaken within the neural network framework (McRae, de Sa, Seidenberg, 1997; Devlin, Gonnerman, Anderson, & Seidenberg, 1998; Tippett, McAuliffe, & Farah, 1995). Given this assumption, Martin proposes that AD patients are deficient in knowledge of the features that determine the mental representations of concepts and especially deficient in knowledge of the features that distinguish particular concepts from one another. Features are lost as a consequence of pathology in the neural substrate of semantic memory. Features that are distinctive to particular concepts are especially susceptible to loss because they enjoy less representational redundancy than features that are shared by multiple concepts. The loss of distinctive features in AD has

important consequences for the mental representation of concepts. The proportion of the features associated with a given pair of concepts that are shared by the two concepts (as opposed to being distinctive to either) is larger in AD than in normal aging.

The plausibility of Martin's account has been demonstrated through neural network modeling (Tippett, et al., 1995). In addition, a certain amount of empirical evidence has been cited in support of the account. The relevant evidence would benefit from reinforcement, however. The present study sought to do this.

As evidence that AD patients are deficient in knowledge of semantic features, and especially deficient in knowledge of distinctive features, Martin has noted that AD patients, when asked to identify common objects, often produce the names of the superordinate categories to which these objects belong, and, when performing picture-sorting and definition tasks, often demonstrate a disproportionate preservation of superordinate knowledge (Fedio & Martin, 1983; Hodges, Salmon, & Butters, 1992). These patterns of spared knowledge are rather indirect evidence, however, of deficiency in knowledge of distinctive features. The present study sought to provide more direct evidence on this score.

As evidence that pairs of concepts share a larger proportion of their associated features in AD than in normal aging, Martin has cited data from on-line priming tasks. In these tasks, participants perform cognitive operations with respect to pairs of stimuli in close succession. For example, participants might make lexical decisions with respect to verbal stimuli, deciding for each whether it is a legal constituent of some language. Priming occurs if a target stimulus is processed more quickly when it follows a related stimulus than when it follows a neutral stimulus (in the case of a lexical decision, the neutral stimulus might be 'XXXX', Neely, 1991). In fact, two kinds of on-line priming have been distinguished. *Automatic* priming is relatively fast acting, involves neither awareness nor intention, and is

associated with no cost when the target stimulus follows an unrelated stimulus – that is, the target stimulus is processed no more slowly when it follows an unrelated stimulus than when it follows a neutral stimulus. *Strategic* priming is relatively slow-acting, involves awareness and intention, and is associated with a cost when the target stimulus follows an unrelated stimulus – that is, the target stimulus is processed more slowly when it follows an unrelated stimulus than when it follows a neutral stimulus (Neely, 1991).

As evidence that pairs of concepts share a larger proportion of their associated features in AD than in normal aging, Martin has cited the fact that AD patients often show *hyperpriming* in on-line priming tasks involving verbal stimuli – that is, AD patients often show more priming than normal older adults for a given pair of stimuli (Balota & Duchek, 1991; Hartman, 1991; Margolin, 1987; Martin, 1992; Nebes, Brady, & Huff, 1989). Martin's argument is based on the assumption that on-line priming reflects a process of spreading activation. When the prime stimulus is processed, its mental representation is activated. Activation then spreads to the mental representation of the target stimulus, rendering it more available for cognitive processing. Martin assumes, further, that hyperpriming is explained as follows: 1) The greater the number of features shared by representations A and B, the greater the amount of activation spreading from A to B when A is activated. 2) The greater the amount of activation present in a representation, the more quickly its associated stimulus is processed. Given these assumptions, and the premise that pairs of concepts share a larger proportion of their associated features in AD than in normal aging, it follows that hyperpriming should occur for AD patients.

As further support for Martin's position, several studies have shown relationships between the occurrence of hyperpriming and the loss of feature knowledge (Chertkow, Bub, & Seidenberg, 1989; Giffard, et al., 2001, 2002). In Giffard et al.'s (2001) study, AD patients were divided into two groups

on the basis of their performance on a task that tapped knowledge of the distinguishing features of concepts. The group that had more severe loss of feature knowledge demonstrated hyperpriming between words from the same category. Three follow-up sessions, conducted at six-month intervals, revealed that as semantic knowledge continued to decline, hyperpriming was no longer evident (Giffard et al., 2002). It was concluded that neural pathology early in the course of the disease caused a loss of distinctive features, thus producing hyperpriming, but that continued pathology caused a loss of shared as well as distinctive features, thus returning priming levels to normal.

The hyperpriming data that Martin cites do not, however, constitute unequivocal support for his account. Martin's interpretation of the data is problematic in several respects. One problem is that the data are assumed to reflect a process of spreading activation. The viability of the spreading activation concept has recently been called into question. On-line priming has been attributed instead to a process of compound cuing (Dosher & Rosedale, 1989; McKoon & Ratcliff, 1992; Ratcliff & McKoon, 1988, 1994, 1995). According to the compound cue account of priming, recognition of an item reflects a familiarity judgment with respect to a compound cue consisting of the item and the context in which it appears. In a lexical decision task, for example, the compound cue would contain the target and the word preceding it - the prime. Several theories of memory (e.g., SAM, Gillund & Shiffrin, 1984; TODAM, Murdock, 1982) predict that the familiarity of a compound cue will be greater if it contains two related items than if it does not. Priming effects are predicted accordingly (McNamara, 1992).

Granting the general viability of the spreading activation concept, Martin's interpretation is problematic in that it depends on rather strong quantitative assumptions regarding the relationship between processing speed and activation level. Specifically, Martin assumes that a stimulus is processed

more quickly the more activation is present in its representation. Support for this assumption has not been provided.

Finally, Martin's interpretation is problematic in that other interpretations are possible for the key hyperpriming data. According to one such interpretation, hyperpriming occurs in AD because AD patients produce longer baseline response times than normal older adults in cognitive tasks, and because the amount of priming in a task increases with baseline response time in the task (Faust, Balota, Spieler, & Ferraro, 1999). Some studies have tried to take these factors into account by reporting priming as the percentage rather than the absolute reduction in response time (Chertkow & Bub, 1990). This procedure may not produce unbiased results, however (Faust, et al., 1999).

In sum, the hyperpriming data that Martin cites do not unambiguously support his contention that pairs of concepts share a larger proportion of their associated features in AD than in normal aging. The present study sought to demonstrate more clear-cut support for this contention.

The aim of the present study, then, was to seek further support for Martin's version of the degraded store hypothesis. Two experiments were administered to moderate AD patients, older controls and younger controls. Moderate AD patients were used because semantic memory deficits are not always apparent in mild AD patients and because severe AD patients are often unable to perform the sorts of cognitive tasks that the experiments involved. The first experiment sought more conclusive evidence that AD patients are deficient in knowledge of semantic features and especially deficient in knowledge of features that distinguish concepts from one another. The second experiment sought more conclusive evidence that pairs of concepts share a larger proportion of their associated features in AD than in normal aging.

Experiment 1

The stimulus materials for this experiment were pairs of concepts, with the two concepts in each pair being exemplars of a different superordinate category. During the first stage of the experiment, a group of moderate AD participants and a group of normal older control (OC) participants listed as many features as they could for each of the concepts in the stimulus set. During the second stage of the experiment, a group of normal younger control (YC) participants indicated, for each of the features that was listed by the first two groups, whether it was, on one hand, distinctive to the concept for which it was listed, or, on the other hand, shared by both the concept for which it was listed and other concepts from the same superordinate category. On the basis of the modal response of the YC group, each of the features was then classified as either distinctive or shared. Finally, the average number of distinctive and shared features was calculated for the AD and the OC participants. Martin's (1992) version of the degraded store hypothesis predicted that the number of distinctive and shared features would be smaller for the AD than for the OC group and that the number of distinctive features would be particularly small for the AD group.

Notice that the features produced by the AD and OC participants were classified as distinctive or shared by younger participants. The objective here was to come up with normative classifications. Although no evidence currently exists to the effect the classifications of older participants are abnormal, younger participants were used to ensure that the classifications would be normative.

Method

Participants. The participants were sixteen patients with moderate AD, sixteen normal older controls (OC), and eight normal younger controls (YC). The AD participants were residents of an assisted care facility. The AD classification was made on the basis of a neurological evaluation and according to the criteria of the National Institute of Neurological and Communicative Disorders and

Stroke (NINCDS) and the Alzheimer's Disease and Related Disorders Association (ADRDA) (McKhann, Drachman, Folstein, Katzman, Price, & Stadlan, 1984). The OC participants were volunteers recruited through advertisements placed in newspapers and newsletters throughout the Washington, DC area. They were paid for participating in the study. The YC participants were students at the George Washington University. They received extra credit in psychology classes in exchange for their efforts.

The Mini Mental-State Examination (MMSE) was used to assess the level of cognitive impairment in each potential AD and OC participant (Folstein, Folstein, & McHugh, 1975). AD patients were not included in the experiment unless their MMSE scores fell into the range from 11 to 20. OC participants were not included in the experiment unless their MMSE scores were above 26.

The AD group consisted of 6 males and 10 females, with a mean age of 80.3 (SD= 3.7, range = 70-85), a mean educational level of 18.3 years (SD = 4.6, range = 16-23), and a mean MMSE score of 17.0 (SD = 2.3, range = 15-20). The OC group consisted of 7 males and 9 females, with a mean age of 77.9 (SD = 9.7, range = 71-83), a mean educational level of 18.0 years (SD= 2.1, range = 16-21), and a mean MMSE score of 29.1 (SD = .8, range = 27-30). The YC group consisted of 4 females and 4 males, with a mean age of 19.4 (SD = .7, range = 17-21), and a mean educational level of 14.6 years (SD = .8, range = 13-16). There were no significant differences between the AD and the OC participants in age or educational level. The difference in educational level between, the AD and OC participants, on one hand, and the YC participants, on the other hand, was not deemed a problem inasmuch as the AD and OC participants were not directly compared with the YC participants. All participants spoke fluent English. No participant was accepted into the study who had a history of major

cardiovascular disease, alcoholism, or drug abuse. Written informed consent was obtained from all participants or from their caregivers, where the latter was appropriate.

Materials. The materials for the experiment were constructed as follows: Thirteen categories were selected from a set of categories listed by Ashcraft (1976). Two high frequency concepts were selected from each of these categories. For each concept, a statement of the following form was typed on a sheet of paper: "*Concept* (has, can, is)". The concepts that were used in the experiment are presented in Table 1.

Insert Table 1 here

Procedure. At the beginning of the session, all participants signed a consent form, briefly describing the study, and answered questions regarding age and education level. There were 26 trials in the experiment. For the AD participants, the procedure on each trial was follows: The participant was presented with a sheet of paper upon which was typed a single incomplete statement, such as was described in the materials section. The experimenter read the statement and asked the participant to "say as many words and phrases as possible that would complete the statement". For the OC participants, the procedure on each trial was follows: The participant was presented with a sheet of paper upon which was typed a single incomplete statement such as was described in the materials section. The participant was instructed to "write down as many words and phrases as possible that would complete the statement typed on the sheet". There were no time constraints on the listing process for either AD or OC participants. The 26 statements were presented in a different random order to each participant.

For the YC participants, the procedure after the initial questioning was as follows: The participant was given a sheet of paper that listed all of the features generated by the first two groups,

broken down by the thirteen categories and by the two concepts within each category. The participant indicated, for each feature, whether it was "distinctive to the concept for which it was listed or shared with other concepts in the category to which the concept belonged". The participant indicated his/her response by placing a *D* or an *S* next to each feature.

Results

The AD participants produced occasional intrusions. They sometimes repeated words that were given as responses to the previous statement or repeated the concept from the current statement, and they engaged somewhat more frequently in rambling conversation. In rare cases, AD participants produced responses that were incorrect, e.g. saying that an apple is purple.

In aggregating the data produced by the AD and OC participants, a small amount of standardization was imposed. That is, when two participants produced responses with the same meaning, as indicated by the presence of synonyms in corresponding positions in the two cases, the two responses were treated as statements of the same feature.

The index of inter-rater reliability for the judgments of the YC participants, aggregated across all of the features listed by the AD or OC group, was .88. On the basis of the modal judgment across the YC group, each feature was classified as distinctive or shared. In general, the classifications achieved on the basis of judgments of the YC participants corresponded with the objective reality of the listings given by the AD and OC participants. Among the AD participants, 100 percent of the features that were classified as distinctive were produced for only one of the two concepts in the relevant concept-pair. Among the OC participants, 99 percent of the features that were classified as distinctive were produced for only one of the two concepts in the relevant pair. Among the AD participants, 67 percent of the features that were classified as shared were produced for both of the concepts in the relevant pair.

Among the OC participants, 40 percent of the features that were classified as shared were produced for both of the concepts in the relevant pair. (The percentage of shared features produced for both concepts by the OC participants may seem low. It must be noted, however, that an average of 33.8 features were produced per category across the OC group whereas each OC participant produced an average of only 7.9 features per category. In general, then, a given participant produced only a fraction of the possible features for a given concept. As a consequence of the sparse coverage from the individual participants, there were evidently a substantial number (60%) of cases in which a given feature was not produced for both concepts across participants. The same pattern was evidently mitigated in the AD group by the tendency of these participants to report shared as opposed to distinctive features).

The mean numbers of distinctive and shared features for the two groups are listed in Table 2. The AD participants produced fewer of both types of features than the OC participants, $F\ (1,30) = 181.1$, $MSe = 37{,}345$ (This and all other analyses were conducted with alpha set at .05). Both the OC and the AD participants produced fewer distinctive than shared features, $F\ (1,30) = 954.7$, $MSe = 156{,}025$. The ratio of distinctive to shared features was significantly smaller in the AD than the OC group, $t(30) = 17.4$. By implication, the AD participants produced particularly few distinctive features.

Insert Table 2 here

One possible explanation of the fact that the AD participants produced few distinctive features is that distinctive features are stated in terms of lower frequency words than shared features and that AD patients have difficulty producing low frequency words. To rule this explanation out, frequency data were collected for the words that the AD and OC participants used to state the distinctive and shared features. An analysis of variance showed that the distinctive and shared words did not differ in frequency, $F(1,837) = 2.34$, $MSe = 124{,}254$, that the words used by the AD and OC participants did

not differ in frequency, $F(1,837) = 1.18$, $MSe = 124{,}254$, and that the effects of feature type (distinctive/shared) and participant group did not interact, $F(1,837) < 1$. Thus, the results cannot be explained in terms of the frequencies of the words that were used to state the distinctive and shared features.

Discussion

These results support the first contention in Martin's (1992) version of the degraded store hypothesis: AD patients are deficient in knowledge of semantic features and especially deficient in knowledge of the features that distinguish concepts from one another. The second experiment explored the ramifications of this deficiency for conceptual knowledge in AD.

Experiment 2

According to Martin's (1992) version of the degraded store hypothesis, the AD deficit in distinctive features has important consequences for the mental representation of concepts. In semantic memory, the proportion of the features associated with a given pair of concepts that are shared by the two concepts (as opposed to being distinctive to either) is larger in AD than in normal aging (Martin, 1992). As evidence in support of this contention, Martin has cited the fact that AD patients often show hyperpriming with verbal stimuli – larger amounts of on-line priming than normal older adults for a given pair of stimuli. As has been argued earlier, Martin's interpretation of the hyperpriming data is open to question. Experiment 2 sought to support Martin's contention with a different sort of on-line priming data.

Most past studies of on-line priming with verbal stimuli have compared processing for target stimuli that were preceded by related stimuli and by neutral stimuli. In a few studies, however, several levels of relatedness have been used, and the amount of priming has been examined as a function of

level of relatedness (Balota, Watson, Ducheck, & Ferraro, 1999; (see also Bayles, Tomoeda, & Cruz, 1999). The present experiment extended the methodology of these latter studies, using pairs of stimuli at a range of levels of relatedness. The object was to observe priming for AD patients at levels of relatedness at which priming was not observed for normal older adults.

It was reasoned that this result would constitute support for Martin's (1992) version of the degraded store hypothesis, by the following rationale: On-line priming only occurs with verbal stimuli when the underlying concepts share a certain requisite proportion of features. If priming occurs for AD patients at levels of relatedness at which priming does not occur for normal older adults, this implies that pairs of concepts share a larger proportion of their associated features in AD than in normal aging.

It was reasoned that interpretation of the projected result would not be liable to the same criticisms as Martin's interpretation of the hyperpriming that has been observed in AD patients. Unlike Martin's interpretation, the proposed interpretation does not assume that on-line priming operates by any specific mechanism. Furthermore, the proposed interpretation is not subject to the objection that the observed results would have been expected simply on the basis of the fact that AD patients produce longer baseline response times than older adults in cognitive tasks. The key point is that Martin's strategy involved between-group statistical tests whereas the present strategy involves within-group tests. More specifically, Martin's strategy involved comparing the amount of priming for AD and control participants. The present strategy, in contrast, involves comparing the levels of relatedness at which priming occurs for AD and control participants. To do this, performance will be compared at different levels of relatedness, within the AD and control groups. Thus, between- group differences in baseline response time will not be as important.

Because previous priming experiments with verbal stimuli have differed along a number of dimensions, it was necessary to make a number of choices in setting up the present experiment. Previous experiments have differed, first, in the type of relationship that has existed between the prime and the target stimuli. On one hand, prime and target stimuli have sometimes been linked with associative relationships (e.g. 'doctor', 'illness'). On the other hand, prime and target stimuli have sometimes been linked with semantic relationships (e.g. 'fox', 'bear'). In studies of AD patients, more reliable priming has been observed with associative than with semantic relationships (Chenery, 1996; Glosser & Friedman, 1991; Glosser, Friedman, Grugan, Lee, & Grossman, 1998). It was decided, therefore, to use associative relationships in the present experiment. It was assumed that the patterns of feature overlap posited under Martin's account would hold for associative as well as semantic relationships. This assumption was consistent with recent attempts at modeling conceptual processing in terms of semantic features (McRae, et al, 1997).

Previous priming experiments have also differed in the nature of the task that is constructed with the prime and target stimuli. Several dimensions have been crucial here. First, priming experiments have differed in the cognitive operation that participants are required to perform with respect to the target stimuli. In general, participants have been required either to pronounce or to make lexical decisions with respect to the target stimuli. Second, priming experiments have differed in whether or not the participant can distinguish between the prime and the target stimuli. In the continuous method of presentation, the participant is presented with a series of stimuli in which prime-target pairs are embedded. The participant is required to respond to both primes and targets. Thus, the participant cannot distinguish between the prime and the target stimuli. In the pair-wise method of presentation, the participant is presented with a series of prime-target pairs. The participant is required to respond to the targets and

may or may not be required to respond to the primes. In either case, the participant can distinguish between primes and targets on the basis of their pair-positions. Third, priming experiments have differed in the length of the prime-target interval. The interval has been relatively short (250-300 ms) in some experiments and relatively long (1000-2000 ms) in others. Fourth, priming experiments have differed in the proportion of trials on which target stimuli are preceded by related stimuli. The proportion of such trials has been relatively low in some experiments and relatively high in other experiments.

The choices that are made with respect to these task dimensions determine the nature of the priming that is demonstrated for normal participants. Automatic priming is more likely to occur when participants pronounce the target stimuli, with the continuous method of presentation, when the prime-target interval is short, and when target stimuli are preceded by related stimuli infrequently enough that participants are insensitive to the contingency. Strategic priming is more likely to occur when participants make lexical decisions with respect to the target stimuli, with the pair-wise method of presentation, when the prime-target interval is long, and when target stimuli are preceded by related stimuli frequently enough that participants are sensitive to the contingency.

What sort of task should be used in the present experiment? One point of view holds that the task should be such as to encourage automatic priming in normal participants. The thinking here is that automatic priming reflects less involvement of cognitive processes than strategic priming and is therefore more suited to exploration of questions of semantic representation in AD. Several considerations argue against that choice, however.

First, this point of view is based on the assumption that automatic priming reflects a process of spreading activation. Spreading activation is assumed to passively reflect extant mental representations without involving complex cognitive processes. As has already been noted, however, recent work has

challenged the viability of spreading activation as a theoretical concept (Dosher & Rosedale, 1989; McKoon & Ratcliff, 1992; Ratcliff & McKoon, 1988, 1994, 1995).

More importantly, in order to have a chance of producing the proposed result, it is necessary to show priming for both AD patients and normal older adults at high levels of relatedness. If this cannot be done, then it is fruitless to attempt to show priming for AD patients but not older adults at lower levels of relatedness. Priming has been shown most consistently in AD patients under conditions that encourage strategic priming in normal participants. In several recent cases (Bell & Chenery, 2001; Knight, 1996) priming has not been shown in AD patients under conditions that encourage automatic priming in normal participants.

For these reasons, the experimental task was designed to encourage strategic priming in normal participants (although it was, of course, acknowledged that automatic priming might also occur).

In sum, the experiment tested on-line priming for pairs of words at a range of levels of relatedness. Primary focus was on the performance of a group of AD participants and a group of normal older (OC) control participants. The goal was to observe priming for AD participants at levels of relatedness at which priming was not observed for the OC participants. To establish a frame of reference, a group of younger control (YC) participants was also tested.

Method

Participants. The participants were sixteen patients with AD, sixteen normal older controls (OC), and sixteen normal younger controls (YC). The AD participants were the same as were used in Experiment 1, tested in a different session than the one for Experiment 1. The OC participants were volunteers recruited through advertisements placed in the newsletters throughout the Washington, DC area. They were paid for their participation in the study. The YC participants were students at the

George Washington University. They received extra-credit in psychology classes in exchange for their efforts.

The OC group consisted of 6 males and 10 females, with a mean age of 78.7 (SD = 4.7, range = 74-81), a mean educational level of 17.0 years (SD= 4.3, range = 16-22), and a mean MMSE score of 29.3 (SD = .7, range = 27-30). The YC group consisted of 8 females and 8 males, with a mean age of 21.3 (SD = 3.4, range = 18-23), and a mean educational level of 14.4 years (SD = 2.3, range = 12-14). There were no significant differences between the AD and the OC participants in age or educational level. All participants spoke fluent English. No participant was accepted into the study who had a history of major cardiovascular disease, alcoholism, or drug abuse. Written informed consent was obtained from all participants or from their caregivers, where the latter was appropriate.

Materials. There were 186 trials in the experiment, with the first 10 trials being set aside for practice and the remaining 176 trials being dedicated to the experiment proper. On 66 of the experimental trials, the prime and target were both words; on 66 of the trials, the prime was a word and the target was a non-word; on 22 of the trials, the prime was a non-word and the target was a word; and on 22 of the trials, the prime and target were both non-words. Thus, word and non-word targets occurred with equal probability regardless of whether the prime was a word or a non-word.

There were eight material sets. The target words for the word/word and non-word/word trials remained constant across sets. The sets differed in the primes that were paired with the target words on the word/word and non-word/word trials. Across sets, each target word was paired with word primes at all six degrees of relatedness and twice with a non-word prime. The materials for the word/non-word and non-word/non-word trials remained constant across sets. Participants were randomly assigned to materials sets.

Word/word and non-word/word items. The same 88 items were used on word/word and non-word/word trials. Each of these items consisted of a target word, six word primes (which appeared on word/word trials) and a single non-word prime (which appeared on non-word/word trials). The word primes varied in degree of relatedness to the target word. A prime at the first level of relatedness was highly related to the target word. A prime at the second level of relatedness was less highly related and so on. A prime at the sixth level of relatedness was completely unrelated to the target word. For example, for the target word "doctor", the word primes were "nurse", "illness", "degree", "helpful", "husband", and "monument".

The items for word/word and non-word/word trials were constructed with the aid of the Keppel and Underwood (1970) word association norms. Each entry in these norms records the associate words that participants in a large sample generated to a stem word. For each associate word, the norms list the frequency with which it was generated across participants in the sample. The eighty-eight target words for the word/word and the non-word/word trials appeared as associate words in the Keppel and Underwood norms. The word primes at the first four levels of relatedness appeared as stem words in the Keppel and Underwood norms. More specifically, for a given target word, the word primes at the first four levels of relatedness were stem words to which the target word was given as an associate word. The word primes at the four relatedness levels differed in the frequency with which they evoked the target word. Thus, the frequency with which the primes evoked the target was taken as an index of the degree of relatedness between the primes and the target. Table 3 gives information regarding the frequency with which the word primes at the first four relatedness levels evoked the relevant target words.

Insert Table 3 here

The word primes at the lowest two relatedness levels were devised by the experimenters. The primes at the fifth level of relatedness were judged by the experimenters to have a remote connection with the target word. The primes at the sixth level of relatedness were judged to have no appreciable connection with the target word.

Rating data were collected to verify that the word primes at the three lowest relatedness levels played their intended roles in the stimulus set. A sample of 42 undergraduates rated the degree of relatedness between the target words and the word primes at the three lowest relatedness levels. Each target word was paired with a prime from the fourth, fifth, and sixth levels of relatedness. The word pairs were randomized and printed on a sheet of paper. Participants were asked to assign a number to each pair indicating the degree of relatedness between the words of the pair. Participants were asked to base their ratings on a scale running from 1 to 5, with a rating of 1 corresponding to a low degree of relatedness and a rating of 5 corresponding to a high degree of relatedness. As reference points, participants were given examples of word pairs with a low degree of relatedness (cola-kangaroo) and pairs with a high degree of relatedness (bread-butter and nurse-doctor). A regression analysis revealed a decreasing linear function in the relatedness ratings that were given for the word primes at the three lowest relatedness levels $t(262) = -18.82$, $SE = .043$.

Thus, the Keppel and Underwood norms gave the degree of relatedness for the primes at the first through the fourth relatedness levels and the rating task verified 1) that the primes at the fifth relatedness level were less related than the primes at the fourth relatedness level and 2) that the primes at the sixth relatedness level were less related than the primes at the fifth relatedness level.

An analysis of variance was conducted to determine whether the word primes at the different levels of relatedness differed in lexical frequency. Four items were excluded from this analysis because

frequency information was not available for some of the word primes. The analysis showed that the words primes at the different levels of relatedness did not differ in lexical frequency, $F(5,498) = 1.64$, $MSe = 1{,}093{,}453$.

Analyses of variance were also conducted to determine whether the word primes at the different levels of relatedness differed in numbers of syllables and letters. The analyses showed that the word primes at the different levels of relatedness did differ in number of syllables, $F(5,522) = 19.55$, $MSe = 9.87$, and number of letters, $F(5,522) = 31.01$, $MSe = 78.54$. Once the data for the experiment were collected, however, a regression analysis was conducted to demonstrate that these factors were not responsible for the results that were observed. The 288 cases in the analysis were the mean response times for the 48 participants at each of the six levels of relatedness. The independent variables were Number of syllables, Number of letters, and Relatedness. The value of the Number of syllables and Number of letters variables for a response time at a given level of relatedness were the mean numbers of syllables and letters for the word primes at that level of relatedness. In addition, dummy variables were included to reflect the effects of participant variability. The analysis failed to show a predictive effect of either Number of syllables, $t(237) = -.63$, $SE = 145$, or Number of letters, $t(237) = .98$, $SE = 47$.

The non-word primes for the non-word/word trials were devised by the experimenters. Each non-word prime was approximately the same length as the average word prime and was easily pronounceable (e.g. wafic). The complete set of items used for word/word and non-word/word trials is given in the appendix.

<u>Word/non-word and non-word/non-word items</u>. Distinct sets of 66 and 22 items were used on word/non-word trials and non-word/non-word trials. The non-words used on these trials had the same properties as the non-words used on non-word/word trials.

Procedure. At the beginning of the session, the participant signed a consent form, briefly describing the study, and answered questions regarding age and education level. The participant was then seated at a computer, so that the participant's face was approximately 30 cm from the monitor screen. At the beginning of each trial, the participant saw a prompt that said, "Ready for next trial?" The characters for this as well as all other messages in the experiment were 5 cm high. When the participant pressed the space bar of the computer, the trial began. The participant saw a prime letter-string and then, 750 ms later, a target letter-string. The participant was instructed to say "yes" or "no" to indicate whether the target string was a word. The sound of the participant's voice stopped a millisecond timer that started with the presentation of the target string. When the participant responded, the target string disappeared and the ready message was presented again. When the participant pressed the space bar, the next trial began. The experimenter noted erroneous responses when they occurred.

Results

The results for the crucial word/word trials are summarized in Table 4. Response times were longer for the AD participants than for the OC and YC participants, $F(2,45) = 71.48$, $MSe = 609{,}756$. For all three groups of participants, response times increased as the level of relatedness between prime and target decreased, $F(5, 225) = 16.20$, $MSe = 7{,}275$, linear trend, $F(1, 45) = 48.07$, $MSe = 10{,}993$. The three groups differed in the way response time varied with relatedness level, $F(10, 225) = 6.63$, $MSe = 7{,}275$. In particular, the three groups showed different linear trends as a function of relatedness level, $F(2,45) = 17.90$, $MSe = 10{,}993$. Error rates were very low and did not differ among the three groups.

Insert Table 4 here

The response time data for word/word trials were analyzed with Dunnett's many-one test. This test is designed for comparing multiple treatment means with a control mean. For the purpose of the present study, the control mean corresponded to the sixth level of relatedness. Means for the first five levels of relatedness were compared with this mean. The results of this analysis are shown in Table 5. For the YC and OC participants, the means for only the first two levels of relatedness were significantly different from the sixth-level mean. For the AD participants, the means for all five levels of relatedness were significantly different from the sixth-level mean.

Insert Table 5 here

As has been noted, previous studies of on-line priming in AD have sometimes reported priming as the percentage rather than the absolute reduction in response time. For purposes of continuity, Table 6 shows the results that are obtained when the present data are analyzed in this way. Notice that the percentage analysis produces the same basic pattern as the original analysis.

Insert Table 6 here

Discussion

Priming occurred for AD participants at levels of relatedness at which priming did not occur for normal older participants. These results support the second contention in Martin's (1992) version of the degraded store hypothesis. They imply that the concepts corresponding to the primes and targets at these levels of relatedness shared a larger proportion of their associated features for the AD than for the normal older participants.

Several other respects of these results deserve comment. First, priming was observed even for words that were ostensibly unrelated. Similar results have been observed previously. Silveri, Monteleone, Burani, and Tabossi (1996) found that AD participants processed target words more

quickly when they were preceded by either related or unrelated words than when they were preceded by neutral stimuli. Silveri, et al. invoked a deficit of distinctive features such as Martin has proposed to explain these results. Together with these previous results, the present results suggest that the loss of distinctive features in AD may be quite substantial, at least in so far as it is reflected in on-line priming.

It should be noted that the present results and the results of Silveri et al. (1996) differ from results of another study that observed on-line priming in AD at multiple levels of relatedness. Balota, et al. (1999) found that homographs primed words associated with their dominant readings to an equivalent degree in AD and normal participants, but that homographs primed words associated with their subordinate readings to a greater degree in normal participants than in AD participants. The key difference here is no doubt that the dominant and subordinate words of Balota, et al. were in competition with one another as potential meanings of the homographs whereas the high and low related words of the present study and Silveri et al. were in no such competition.

The pattern of priming for the YC and OC participants did not covary completely with the pattern of relatedness, at least as it was reflected in the Keppel and Underwood norms. Priming was observed for these participants at the first two levels of relatedness, but the amount of priming at the two relatedness levels did not differ. At the same time, the mean Keppel and Underwood frequency for the first level of relatedness was much higher than the mean frequency for the second level of relatedness. These results suggest that the relationship between relatedness and on-line priming is non-linear in intact participants. More specifically, the results support a threshold view of on-line priming, under which priming occurs to the same degree whenever the degree of relatedness is above some value.

It is, of course, difficult to characterize the priming mechanism that operated for the AD participants. We can attempt to characterize the priming mechanism that operated for OC and YC

participants because we have, in the Keppel and Underwood (1970) norms, an independent index of the degree of relatedness between the prime-target pairs in the different conditions. We have no such index for the AD participants because our results suggest that the concepts in the stimulus set were represented differently for the AD participants than for the participants who contributed to these norms.

General Discussion

The results of the present study contribute to an evolving understanding of the semantic memory impairment in AD. A deficit in semantic abilities is a prominent feature of the dementia produced by AD (Bayles, 1982). AD patients have substantial difficulties with a range of semantic tasks (Gewirth, et al., 1984; Grober, et al., 1985; Kempler, et al., 1987; Kirshner, et al., 1984; Martin & Fedio, 1983). The semantic deficit in AD appears to be a characteristic symptom of the disease; it is not a prominent component of other dementing diseases (Randolph, Braun, Goldberg, & Chase, 1993); nor is it part of the cognitive decline associated with normal aging (Light, 1992). However, the exact nature of the impairment is still controversial. According to the degraded access hypothesis, semantic knowledge remains intact in AD but cannot be accessed in an effective manner (Nebes, et al., 1984). According to the degraded store hypothesis, semantic knowledge is permanently lost in AD (Martin, 1992). According to Martin's particular version of the degraded store hypothesis, AD patients are deficient in knowledge concerning the features that determine the mental representations of concepts. The loss of knowledge is more severe for features that are distinctive to individual concepts than for features that are shared by multiple concepts. As a consequence, the pairs of concepts share a larger proportion of their associated features in AD than in normal aging.

The results of the present study support Martin's version of the degraded store hypothesis. The results of the first experiment support Martin's contention that AD patients suffer from a loss of

knowledge about semantic features and a particular loss of knowledge about distinctive features. For the concepts used in this experiment, AD participants were deficient at listing both distinctive and shared features but especially deficient at listing distinctive features.

The results of the second experiment support Martin's contention that pairs of concepts share a larger proportion of their associated features in AD than in normal aging. In this experiment, AD participants showed priming at levels of relatedness at which normal older participants did not. By implication, the concepts corresponding to the primes and targets that were used at these levels of relatedness shared a larger proportion of features for the AD than for the normal older participants. The support that is thereby obtained for Martin's contention is not open to the criticisms that have been leveled when priming data have been used toward this end in the past.

Martin's contention is also supported by other recent results. For example, AD patients, when asked to produce drawings of concepts from a target category, include in their pictures features that are borrowed from related concepts (Grossman, Mickanin, Onishi, & Robinson, 1996).

The results of the present study may be difficult to square with the degraded access hypothesis. This hypothesis can probably accommodate the results of the first experiment under the assumption that distinctive features are more difficult to access than shared features. The hypothesis should have more trouble accommodating the results of the second experiment. It is not clear why access difficulties should cause AD patients to show priming at levels of relatedness at which normal older persons do not.

One limitation of the present study should be noted. A direct relationship was not shown between the loss of distinctive features in AD and increased levels of on-line priming. To do this, it would have been necessary to use the same concepts in Experiments 1 and 2 and to show that the unrelated pairs of concepts that supported priming for a given participant in Experiment 2 were also

missing distinctive features for that participant in Experiment 1. Future research will attempt to show this relationship.

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Table 1

Experiment 1: Stimulus Materials

Categories	Concepts
Trees	Oak Maple
Fruits	Apple Pear
Domestic Animals	Horse Dog
Birds	Sparrow Robin
Utensils	Spoon Fork
Beverages	Milk Coke
Vehicles of Transportation	Airplane Car
Insects	Ant Bee
Furniture	Chair Sofa
Tools	Hammer Nails
Weapons	Gun Knife
Fish	Trout Bass
Housing	House Apartment

Table 2

Experiment 1: Mean Number of Distinctive and Shared Features per Participant

	OC	AD
Distinctive	56	3
Shared	150	106

Table 3

Experiment 2: Keppel and Underwood Frequencies for Prime Words

	Level of relatedness			
	1	2	3	4
Mean frequency	140	5	2	1
Range	11-354	3-8	2	1

Note. Each entry gives the average frequency with which the prime words at a given level of relatedness evoked the relevant target words.

Table 4

Experiment 2: Mean Response Time (in Milliseconds) as a Function of Level of Relatedness

Group	Level of relatedness					
	1	2	3	4	5	6
YC	636	636	642	674	671	686
OC	627	631	668	662	640	683
AD	1651	1776	1827	1824	1855	1994
Mean	971	1014	1046	1053	1055	1121

Table 5

Experiment 2: Dunnett's Analysis of Results as Function of Relatedness

Group		Level of relatedness					
		1	2	3	4	5	6
YC	Means	636	636	642	674	671	686
	t values	2.51*	2.53*	2.23	.57	.76	
OC	Means	627	631	668	662	640	683
	t values	2.91*	2.70*	.78	1.09	2.23	
AD	Means	1651	1776	1827	1824	1855	1994
	t values	6.99*	4.44*	3.40*	3.47*	2.83*	

Note. Dunnett's one-tailed t at the .05 level is 2.44.

Table 6

Experiment 2: Percentage Priming - Dunnett's Analysis of Results as Function of Relatedness

Group		Level of relatedness					
		1	2	3	4	5	6
YC	Means	.07	.07	.06	.02	.02	0
	t values	2.52*	2.94*	2.08	.78	.68	
OC	Means	.08	.08	.02	.03	.06	0
	t values	2.40	2.06	.59	.44	1.96	
AD	Means	.17	.11	.08	.08	.07	0
	t values	7.17*	4.11*	4.15*	4.45*	3.11*	

Note. Dunnett's one-tailed t at the .05 level is 2.44.