Are judgments of semantic relatedness systematically impaired in Alzheimer’s disease?

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ABSTRACT

We employed a triadic comparison task in patients with Alzheimer’s disease (AD) and healthy controls to contrast (a) multidimensional scaling (MDS) and accuracy-based assessments of semantic memory, and (b) degraded-store versus degraded-access accounts of semantic impairment in Alzheimer’s disease (AD). Similar to other studies using triadic comparison tasks, participants were asked to indicate which two out of three words (animal names) were most similar in meaning. Novel to this investigation, we contrasted performance on two semantic dimensions of strong and equal saliency to controls, but varying in their specificity (land/water versus bird/non-bird). Degraded-store accounts predict that the more specific bird/non-bird dimension should be more consistently impaired in AD, whereas degraded-access accounts predict that both dimensions, because they are equally salient, should be equivalently impaired in the disorder. The MDS results suggested that both patient and control group responses were not discriminating from random responding, consistent with previous studies. By contrast an accuracy-based analysis on the same data showed that controls showed good knowledge of both salient dimensions, and were evenly split in their individual preference for one dimension over another. In contrast, patients showed higher accuracy and sensitivity to the broader land/water dimension than to the more specific bird/non-bird dimension, consistent with a storage-based account of the semantic impairment in AD. Our results further suggest that MDS methods can fail to reveal important and systematic behaviour in semantic tasks, in both patient and control groups.

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1. Introduction

In addition to profound episodic memory impairment and many other cognitive disabilities, patients with Alzheimer’s disease (AD) often perform poorly on various tests of semantic memory, our store of every-day knowledge about the meanings of words and objects (Garrard, Patterson, Watson, & Hodges, 1998; Grober, Buschke, Kawas, & Fuld, 1985; Lambon Ralph, Patterson, Graham, Dawson, & Hodges, 2003; Rohrer, Wixted, Salmon, & Butters, 1995; Salmon, Butters, & Chan, 1999). The root cause of these impairments is the subject of considerable controversy, with many commentators orienting themselves around one of two positions. The first position, termed the degraded-store view, is that semantic impairment in AD arises when the neural structures that encode semantic knowledge are compromised by disease (Alathari, Trinh Ngo, & Dopkins, 2004; Chan, Salmon, Nordin, Murphy, & Razani, 1998; Chan, Salmon, Butters, & Johnson, 1995; Chertkow & Bub, 1990; Garrard, Lambon Ralph, Patterson, Pratt, & Hodges, 2005; Grober et al., 1983; Knodt, Bayles, & Kaszniaik, 1990; Lambon Ralph, Patterson, & Hodges, 1997). The second position, termed the degraded-access view, is that semantic knowledge is largely intact in AD, but semantic impairments arise nonetheless because the processes used to access semantic knowledge stores are affected by the disease (Bonilla & Johnson, 1995; Fung, Chertkow, & Templeman, 2000; Nebes & Brady, 1988; Ober & Shenaut, 1999). “Degraded-store” and “degraded-access” syndromes have been observed as the consequence of other forms of neuropathology, and these syndromes have been characterized in considerable detail in the literature both by Warrington and Shallice (1979, 1984), who initially coined the distinction, and subsequently by other investigators (e.g. Hodges, Salmon, & Butters, 1992). The struggle to explain semantic impairment in AD has largely been informed by attempts to link patterns of behaviour in AD to patterns of behaviour in these other syndromes, across a range of standard seman-
tic tasks, such as naming, sorting and category fluency (Henley, 1969).

In a series of papers, Chan et al. (1997, 1993, 1995, 2001) proposed a new means of addressing the access/ degraded-store controversy in AD, through the application of multidimensional scaling (MDS) techniques to data generated in a similarity-judgment task. In each trial of the standard task, participants were presented with three written words arranged in a triad, and were asked to judge which two were most similar in meaning. For example, Chan, Butters, and Salmon (1997) had healthy controls and patients with AD generate such similarity judgments for all possible triads from a set of 12 animal names (dog, cat, cow, horse, rabbit, pig, tiger, lion, bear, elephant, giraffe and zebra). From this data the group computed similarity matrices for the 12 names, for each individual participant, by tabulating how frequently each pair of items was chosen as the “most similar” across all the triads in which they appeared. These similarity matrices were amenable to decomposition using various MDS techniques; and 2-dimensional scaling solutions could be plotted to yield a graphical representation of the semantic relationships that were, supposedly, governing the similarity judgments. In this and other studies, Chan and colleagues showed that the judgments made by patients with AD, and the resulting graphical representations of their knowledge, differed strikingly from those of age-matched controls. These analyses appeared to indicate that certain aspects of semantic knowledge were systematically spared or disrupted in the individual patients. For example, Chan et al. showed that AD patients focused mainly on concrete dimensions in such triadic comparison tasks, whereas elderly controls focused more on abstract dimensions (Chan et al., 1997; Chan, Butters, Salmon, & McGuire, 1993). In a further study the same group observed differential semantic knowledge for living vs. non-living concepts in AD patients (Chan, Salmon, & De La Pena, 2001). Under a degraded-access view of semantic impairment, it is not clear why some semantic relationships should be vulnerable to impairment and others not and hence Chan and colleagues argued that their data indicated disruption of the semantic store in AD.

This conclusion was challenged in a paper by Storms, Dirikx, Saerens, Verstraeten, and De Deyn (2003) that highlighted some methodological flaws in Chan et al.’s work. The principal observation was that Chan and colleagues had sometimes neglected to report measures of fit for their scaling solutions, and where such measures had been reported, the fits were exceedingly poor. Indeed, Storms et al. (2003) showed that the fits of Chan’s scaling models to patient data were no better than one would expect if the data had been generated completely at random. Storms and colleagues further replicated one of Chan’s studies in a new group of patients with AD, and again observed that, from the fit of the scaling model, patient judgments were indistinguishable from random. Thus, Storms et al. (2003) concluded that similarity judgments in the triads task provided no evidence for a degraded-store view, and hence question the nature of the semantic impairment in AD. In light of Storms et al.’s analyses, the key question is the following: What accounts for the apparently random choices made by AD patients in the Triads task, as observed in both the Chan et al. (1997, 1993, 2001) and Storms et al. (2003) work. The rationale for our approach was as follows. If patients with AD suffer from a storage-like syndrome, some aspects of their semantic knowledge—those that are degraded within the “store”—should be more vulnerable to impairment than others (Rozeat, Lambon Ralph, Patterson, Garrard, & Hodges, 2000; Hodges, Graham, & Patterson, 1995; Rogers et al., 2004). For instance patients should be less impaired on a relatively broad semantic distinction (e.g. is this a land or a water animal?) than on a more narrow distinction (e.g. is this a bird or an animal?). In contrast, access-based accounts predict that semantic distinctions that are equally salient to healthy controls should be equally affected by degraded retrieval. Consequently, patients should not reliably employ one such distinction more readily than the other, and they should show a similar level of impairment across both dimensions.

Furthermore, if the semantic distinctions are sufficiently salient that healthy controls virtually always use the same dimensions to govern their decisions, this provides a means of assessing the validity of the MDS methods typically employed in these experiments. In addition to decomposing the similarity matrices yielded by participants’ judgments, one can simply measure whether individual patients tend to make the same choices as healthy controls in different trial conditions, in a straight-forward analysis of accuracy. If accuracy analyses and MDS methods yield similar results, this supports the validity of the MDS methods more broadly. On the other hand, if patients and controls are shown to behave systematically in an accuracy analysis, but appear to behave unsystematically in the MDS analysis (for instance, yielding poor fit measures in the scaling solution), this would suggest that the MDS methods themselves are failing to pick up on important information in the raw data.

With these considerations in mind, we designed a novel triadic categorization experiment to ask two different questions: (a) are MDS methods valid techniques for analyzing these types of tasks; and (b) do patients with AD show worse knowledge of more specific semantic distinctions relative to more general semantic distinctions in this task? The study, therefore, provides us with an opportunity to assess both the validity of MDS scaling methods, and the alternative theories of semantic impairment in AD.
2. Methods

2.1. Participants

Eight patients with the clinical diagnosis of probable AD (4 male) and 16 elderly healthy controls (7 male) participated in the study. Two additional AD patients were excluded from the experiment (prior to undertaking the triadic comparison task) as they were passionate bird-watchers and had expert knowledge of most stimulus items. No other patient or control participant was a bird watcher. The 8 AD patients (2 male) had a mean age (SD) of 66.6 (7.5) years and mean education of 12.1 (4.1) years; the 16 controls had a mean age (SD) of 67.8 (6.24) years and mean education of 13.2 (1.9) years. One-way ANOVAs did not reveal any significant differences for age (F1,22 = 1.62, p > .6) or education (F1,20 = .631, p > .4) between both participants groups. All participants gave informed consent to participate in the study, which was approved by the Cambridge Health Authority Local Research Ethics Committee (UK).

All patients presented via the Memory Clinic at Addenbrooke’s Hospital, Cambridge, and were given a diagnosis of probable AD after detailed evaluation by a senior staff neuropsychologist, neuropsychologist and psychiatrist at Addenbrooke’s Hospital, Cambridge, UK. All cases fulfilled the criteria for probable AD as defined by the National Institute of Neurological and Communicative Disorders and Stroke and the Alzheimer’s Disease and Related Disorders Association, and other causes of dementia were excluded prior to investigation. Patients were selected according to their overall cognitive functioning. At the time of testing all patients had mild to moderate AD with a minimum MMSE of 21. Neurologically healthy control subjects were recruited from the MRC Cognition and Brain Sciences Unit Volunteer Panel and were matched for age and educational level to the AD group.

As part of the study, all AD patients were also administered a battery of standard neuropsychological tests, shown in Table 1. All patients showed reduced scores on the Addenbrooke’s Cognitive Examination (ACE) and the Mini-Mental State Examination (MMSE) tests. Consistent with the diagnosis of AD, patients were poor at tests of episodic memory (e.g. Logical Memory from the MMSE) tests. All patients showed clear impairments on a graded picture-naming task and on a test of associative matching between concepts (Camel & Cactus Test—picture version), indicating mild-moderate semantic deficits. The Camel & Cactus Test (CCT) is based on the same principle of the Pyramids and Palm Trees test, i.e. subjects are asked to choose which one of four same-category items has an associative relationship with the target (Bozat et al., 2000). In summary, patients tested showed particular difficulties with episodic and semantic memory on standard neuropsychological tests.

### Table 1

<table>
<thead>
<tr>
<th>Test</th>
<th>AD patients Mean (SD)</th>
<th>Normative data Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Cognitive tests</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACE (100)</td>
<td>66.88 (16.32)</td>
<td>Cut-off: 81</td>
</tr>
<tr>
<td>MMSE (30)</td>
<td>21.50 (5.37)</td>
<td>29.1</td>
</tr>
<tr>
<td>Episodic memory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log. Memory—imn. recall (47)</td>
<td>4.31 (2.00)</td>
<td>34</td>
</tr>
<tr>
<td>Log. Memory—del. recall (47)</td>
<td>0.44 (0.09)</td>
<td>17</td>
</tr>
<tr>
<td>Log. Memory—recognition (20)</td>
<td>6.63 (1.76)</td>
<td>17</td>
</tr>
<tr>
<td>Working memory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digit Span (24)</td>
<td>10.00 (3.99)</td>
<td>11.5 (2.1)</td>
</tr>
<tr>
<td>Semantic memory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Camel &amp; Cactus Test—picture version (64)</td>
<td>51.86 (8.22)</td>
<td>60.7 (2.06)</td>
</tr>
<tr>
<td>Graded Naming Test (30)</td>
<td>17.25 (7.35)</td>
<td>25th Percentile</td>
</tr>
<tr>
<td>Vision-perception</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VOSP incomplete letters (20)</td>
<td>18.50 (2.38)</td>
<td>Cut-off: 16</td>
</tr>
<tr>
<td>VOSP dot counting (10)</td>
<td>9.50 (1.04)</td>
<td>Cut-off: 8</td>
</tr>
</tbody>
</table>

Normative data taken from (Hodges & Patterson, 1995) and unpublished data collected in our research group.

3. Experimental materials

3.1. Rationale

Our goal was to employ stimuli varying in two orthogonal semantic dimensions of comparable saliency, but with one distinction considerably more broad (i.e. spanning a broader range of concepts) than the other. To this end, we considered birds and 4-legged animals living on land or on water. We consider the bird/non-bird distinction relatively narrow, because both birds and 4-legged animals are classes grouping items that are semantically quite similar to one another. Birds tend to have many properties in common, and so are represented as quite similar within the semantic system. Consequently set of all birds spans a relatively narrow range of the semantic representation space. The same is intuitively true of 4-legged land animals. In contrast, the class of land-dwelling animals includes a wide variety of quite different animals, which are represented as quite distinct from one another in the semantic system. Hence the properties “land-dwelling” and “water-dwelling” each span a more diverse set of concepts. They are, in this sense, more similar to superordinate category distinctions. A long tradition of research has shown that more narrow distinctions (like bird/non-bird) are more vulnerable to semantic impairment in storage-like syndromes than are more general distinctions (like land/water-dweller; see Garrard, Lambon-Ralph, Hodges, & Patterson, 2001).

To test our intuition that the classes of land-dwellers and water-dwellers span a wider range of concepts than do the classes of birds and four-legged animals, we investigated the similarities existing among such items as represented in a large semantic feature-norming corpus published by McRae, Cree, Seidenberg, and McNorgan (2005). This corpus includes semantic feature norms for 541 items across 2526 attributes. Each concept is associated with a binary vector indicating which of the 2526 attributes are reliably associated with the concept in property-generation norms. The similarity structure of the items in this corpus has been shown to predict semantic priming effects, property-verification latencies, and a variety of other phenomena (e.g. Hare, Jones, Thomson, Kelly, & McRae, 2009).

From the animals in the corpus, we selected 8 water-dwelling birds, 8 water-dwelling animals, 8 forest-dwelling birds, and 8 forest-dwelling animals. From the attribute vectors associated with each item, we computed the Hamming distance (Hamming, 1950) between all pairs of items. Hamming distance is a measure of dissimilarity between binary vectors of equal length. It ranges from 0 to 1 and indicates the proportion of elements that differ in their value between the two vectors. We then subjected the resulting matrix to a 2-dimensional principal components analysis. The results are plotted in Fig. 1. Both left and right panels show the same 2-dimensional PCA solution. The first principal component strongly separated the birds from the animals; the second component separated the land-dwelling from the water-dwelling creatures. The shading in Fig. 1 shows the range of items spanned by the 2 semantic distinctions in our study. The left panel shows the range of similarity space spanned by the birds (light grey) and by the animals (dark grey). Because both groups consist of items that are quite similar to one another, these distinctions span relatively narrow parts of the space. The right panel shows the
3.2. Stimuli

We selected 6 bird and 6 animal names crossing the two salient dimensions (land/water, bird/non-bird) for use in the experiment. The items were selected from a battery normed for name-agreement in a different study, with all items having name agreement of 75% or greater. The twelve items were: LAND BIRDS: woodpecker, magpie, pheasant; WATER BIRDS: penguin, duck, swan; LAND ANIMALS: badger, squirrel, hedgehog; WATER ANIMALS: turtle, frog, crocodile.

Basic psycholinguistic information for these stimuli was collected via the CELEX database (MPI, Nijmegen) and showed the following average lemma and wordform frequencies for land birds (51 and 17), water birds (157 and 77), land animals (93 and 46), and water animals (112 and 43), respectively. ANOVAs for lemma and wordform frequencies with the factor animal type (land birds, water birds, land animals, water animals) revealed an effect of animal type for wordform \( (F_{3,11} = 4.902, p < .05) \) but not for lemma frequency \( (p > .1) \). Post hoc analyses showed that the wordform frequencies of land and water birds differed significantly \( (t(4) = 7.522, p < .01) \). Regression analyses confirmed, however, that these linguistic factors did not predict which items were (or were not) selected by either controls or patients during testing (lemma: \( r = -.13, p > .6 \) for controls, \( r = -.24, p > .4 \) for patients; wordform: \( r = -.13, p > .6 \) for controls, \( r = -.24, p > .4 \) for patients).

The twelve names were grouped into all possible combinations of three to form 220 triads. The three words in each triad were printed on a separate page, forming an equilateral triad. The 220 separate pages were then placed in a folder in a fixed pseudo-random order, which was held constant across all participants.

3.3. Procedure

All patients were tested in their own homes over one or at most two testing sessions. The order of presentation of the test battery was as follows: the ACE (which incorporates the MMSE), the triadic comparison task, Logical Memory, Camel & Cactus Test, Graded Naming Test, Digit Span, Incomplete Letters & Dot Counting of the VOSP. Healthy elderly controls were all tested in a quiet testing room at the MRC Cognition and Brain Sciences Unit and received only the triadic comparison task since they were screened beforehand for any cognitive deficits. The patient’s neuropsychological scores were compared to age-appropriate norms (see Table 1). All participants received a short practice in advance of the triadic comparison task, which comprised six triads of animal and vehicle names not included in the later test. The experimenter made sure during the practice that the participants understood the task and if necessary repeated the practice session until participants performed accordingly. On each of the 220 trials in the experimental triad test participants were instructed to indicate which two of the three words were most similar in meaning. The instruction was repeated for the AD patients for each triad to avoid any task confusion. The experimenter recorded each participant’s answer for each trial on a separate record sheet.

4. Individual Difference Scaling (INDSCAL) analysis

4.1. Method

In the first analysis, we employed a MDS technique that replicates the methods described in Chan et al. (1997, 1993, 1995, 2001) and Storms et al. (2003). For each individual participant, pairwise proximities were calculated for all pairs of the twelve words in the test by counting the number of times every stimulus pair was chosen as the most similar pair in a triad. For each combination of two stimuli, at the individual patient level, this calculation provided a proximity value between 0 (never chosen as a pair) and 10 (always chosen as a pair whenever the two items appear together). Participants presumably choose two items as “most similar” when they discern some semantic relationship between them; hence the proximity matrices provide some indication of the semantic similarity relations that exist amongst all pairs of words, in the judgment of a single individual. Matrices for multiple individuals may be com-

Fig. 1. Principal components analysis of the distances among 8 land birds, 8 water birds, 8 land animals, and 8 water animals, according to the semantic feature norms of McRae et al. (2005). Both panels show the same plot of the first 2 principal components, with the first component separating birds from non-birds, and the second component separating land- from water-dwellers. The left panel shows the subspace spanned by bird (light grey) and animals (dark grey); the right panel shows the subspace spanned by land dwellers (light grey) and water-dwellers (dark grey). The land/water classes both span a broader region of the space than do the bird/animal classes, and so should be less vulnerable to semantic storage impairment.

combined by summing the individual matrices, and where individuals in a group tend to make the same systematic judgments, these will be reflected in the group similarity matrix.

Group matrices and individual matrices can be decomposed using a variety of MDS techniques. The common aim of such techniques is to find a set of short (usually 2- or 3-element) vectors for each item in the original matrix such that the proximities between all pairs of vectors come as near as possible to replicating the proximities between all pairs of items in the initial similarity matrix. The vectors representing individual items may then be plotted as points in 2-D or 3-D maps, with the distances between points providing a visual indication of the similarities captured in the original proximity matrix. Hence MDS techniques should provide an intuitive means of “seeing” the similarity relations that may otherwise be difficult to discern in a matrix of raw proximities. In the current case, they allow the theorist to “see” the similarity relationships that underlie the participants’ judgments of semantic relatedness in the triad’s task.

The MDS method we chose for analysis was an Individual Difference Scaling (INDSCAL) algorithm (Carroll & Chang, 1970), which was applied to the proximity matrices of all participants. The INDSCAL algorithm produces both an overall group solution (indicating the dimensions of similarity apparent across all individuals) as well as a weighting index for each separate individual. The weighting index can be construed as a measure of how salient each dimension from the group solution is to a particular individual compared to all other participants. Dimensions with higher weightings are more salient to the individual, in the sense that the individual is more likely to employ that dimension in making his/her judgments. The INDSCAL algorithm also calculates a skewness index ($R^2$), which indicates how consistently the group solutions’ dimensions are used by a given individual. The value ranges from 0 to 1, with 0 indicating that all dimensions from the group solution are used equally throughout the task, and 1 indicating that the participant prefers to use only one dimension throughout the test. Finally, the INDSCAL algorithm provides a ‘goodness-of-fit’ value, which describes how well the data are represented by the scaling solution according to Kruskal’s Stress formula 1. On this measure, 20% indicates a poor fit, 10% a fair fit, 5% a good fit and 2.5% perfect. The MDS solution was constrained to 2 dimensions, reflecting the two dimensions that, a-priori, we expected would be salient to controls (land/water vs. bird/non-bird). A 2-dimensional solution also satisfied the accuracy criterion defined by Kruskal and Wish (1978) that the number of dimensions included in the solution should be four times less than the number of stimuli minus one.

5. Results

Fig. 2 shows the MDS group solution for all cases including AD cases and control participants. The group solution shows tight clustering, with the 12 items separated on 2 dimensions, which clearly correspond to the land/water and bird/non-bird categories. Thus the plot suggests that the 2 dimensions that were, a priori, thought to be salient were in fact used to govern similarity judgments. However, the Kruskal Stress value of the plot was .29, which according to the criteria set by Kruskal (1964) indicates a very poor fit for a 2-dimensional solution. Kruskal (1964) stated that a stress value of .22 is worse than poor as a goodness-of-fit factor. Separate 2-dimensional MDS solutions were plotted for the AD patients and the control group in order to investigate whether a difference in Kruskal Stress value between the groups could explain the poor value obtained for the combined analysis. For the AD patient group, a Kruskal Stress mean value of .35 was calculated, while the controls mean Stress value of .22 indicated a better, but still very poor, fit in the 2-D space. An independent sample t-test confirmed that there was a significant difference in the Stress values obtained between the groups ($t(22) = 3.823, p < .001$).

Fig. 3 plots the dimension weights for each individual participant, indicating how much emphasis that subject placed on each of the two dimensions. Distance from the origin indicates the consistency of an individual’s choices with respect to each of the two dimensions. AD patients (filled squares) showed smaller weights overall for both dimensions, with their values clustering near the bottom left of the graph. The controls (empty squares) show much higher and wider spread weight values than the patients for both dimensions. Controls appear to be more consistent overall in their application of the two dimensions, but individual controls vary widely in their preference for using one dimension over another. Some controls appear to attend only to the bird/non-bird distinction (those in upper-left corner); some only to the land/water distinction (lower-right); and some seem to use both distinctions alternately (in the middle).

This observation is confirmed by the $R^2$ values (consistency indices), which show a significantly higher average value (.79) for the controls than for the AD patients (.22), $t(22) = 6.183, p < .001$, suggesting more consistency in the control’s similarity judgments.

6. Discussion: INDSCAL analysis

The group solution for the INDSCAL analysis yields tight clusters, with the 12 concepts organized by two salient dimensions corresponding to land/water and bird/non-bird. Amongst the controls, different individuals appear to weight these two dimensions differently in making their similarity decisions, with some favouring land/water, others favouring bird/non-bird, and still others lending equal weight to both dimensions. Overall there is no group-level preference for one dimension over the other, suggesting that, on average, the two dimensions are equally salient. The patients appear to be less systematic in their use of both dimensions, yielding smaller weight indices on both variables, with no reliable preference for using one dimension over another. The poor fit of the INDSCAL solution to both control and patient data, however, suggests that the scaling model does not accurately capture the decisions made by the different participants. Thus the results largely replicate the observations of Storms et al. (2003): (i) the scaling model does not fit the patient data by standard criteria, (ii) there appears to be little consistency in the weight attributed to different
dimensions even in healthy controls and (iii) even if one accepts the MDS results despite these problems, there is no evidence from this analysis to suggest that the conceptual space underlying the similarity judgments is systematically disrupted in AD.

What accounts for the poor fit of the scaling models to even the control data? Storms et al. (2003) raise two possibilities. First, it may be that separate individuals discern different similarity relations among the 12 items, so that the group solution does not accurately reflect the dimensions of similarity apparent to separate individuals. Our stimuli were selected to vary on two salient dimensions, which were subsequently recovered by the group MDS solution—but it is still possible that this “average” solution does not match the similarities exhibited by individual participants. Second, it may be that individuals are behaving somewhat more systematically than the fit indices would suggest, but that the INDSCAL algorithm is not picking up on these tendencies.

In any case, any conclusion regarding the status of semantic knowledge in the AD group is suspect, given that the controls themselves do not appear to behave consistently in both analyses. In our second analysis, we investigated the similarity judgments of AD patients and controls by tabulating overall accuracy performance for different trial types in the experiment to see whether such an analysis would yield more revealing results.

7. Accuracy analysis

7.1. Method

To contrast with the INDSCAL analysis, the same data were investigated using a standard accuracy analysis. Specifically, we distinguished between 5 different trial types across the 220 trials:

- Unidimensional land/water (N = 35): Trials that varied only in the land/water dimension; for example, DUCK, SWAN, PHEASANT. For these trials, only the land/water distinction is relevant to the judgment, and so we scored as “correct” trials where the participant chose the two that were similar on this dimension (e.g. DUCK/SWAN).
- Unidimensional bird/non-bird (N = 37): For trials that vary only in the bird/non-bird dimension; for example, FROG, SWAN, PHEASANT. For these trials, only the bird/non-bird distinction is relevant to the judgment, and so we scored as “correct” trials where the participant chose the two that were similar on this dimension (e.g. DUCK/SWAN). High accuracy indicates that the participant is sensitive to the land/water distinction and is consistently using this distinction to guide judgments where it is the only salient information available.
- Convergent trials (N = 36): Trials that vary on both dimensions, with both dimensions indicating the same response; for example, FROG, PHEASANT, MAGPIE. Here PHEASANT and MAGPIE are most similar, both because they are birds and because they are land animals. Participants who choose these as most similar score correctly, but it is unclear on what basis they have made their choice. High accuracy thus indicates knowledge of some semantic similarity, but does not indicate particular knowledge of either salient dimension. Erratic or random choices (such as FROG/MAGPIE or FROG/PHEASANT) indicate that neither salient dimension is being used to guide the choice.
- Divergent trials (N = 108): Triads that vary on both dimensions, with each dimension suggesting a different possible response; for example, FROG, DUCK, PHEASANT. Here FROG and DUCK may be grouped together because both are water animals; or DUCK and PHEASANT might be grouped together because they are both birds. For such trials there is no obvious “correct” answer, and if both dimensions are salient to the respondent, he or she may pick and choose which dimension to use for the response. Across such trials for each individual we tabulated the proportion of times the individual chose on the basis of the land/water dimension, the bird/non-bird dimension, or neither of these. Participants who have access to both salient dimensions, but no reliable preference for either, would make the land/water choice for half the items, the bird/non-bird choice for the other half, and would rarely or never fail to use these dimensions. Participants with a preference for one dimension over another should consistently use that dimension; whereas participants who are insensitive to both dimensions should respond randomly (i.e., with 1/3 of their responses in each category).
- Unsystematic trials (N = 4): There were four trials that did not vary on either salient dimension (e.g. FROG, TURTLE, CROCODILE). These trials were excluded from the analysis, since choices on these trials cannot inform us as to whether participants have access to the land/water or bird/non-bird distinctions.

In summary, the accuracy analysis entailed three main comparisons:

1. Unidimensional trials, to determine whether controls and patients are able to use each dimension to guide their judgments. If controls are sensitive to the land/water and bird/non-bird distinctions and using these to guide their judgments, they should perform near ceiling for both dimensions. If controls are using some other information to guide their judgments, they should be off ceiling. According to the degraded-access view, patients should be less accurate for trials testing the more narrow semantic distinction (bird/non-bird). From the degraded-access view, patients should be equally impaired for both dimensions, assuming the two dimensions are equally salient.

2. Convergent trials, to determine whether controls and patients are ever completely insensitive to these two dimensions. Controls should be at ceiling for these trials; and both degraded-store and degraded-access views predict somewhat milder impairments for this trial type in the patient group, since access to either dimension will result in correct performance.

3. Divergent trials, to determine whether controls and patients differ in their overall preferences for choosing one salient dimension over another. If the two dimensions are equally salient, then controls should, on average, make a land/water choice 50% of the time, a bird/non-bird choice 50% of the time, and rarely or never make a random choice. Individual controls may reliably prefer one dimension compared to another; but if the dimensions are, on average, equally salient, there should be no group-level preference for one dimension over the other. The degraded-store view predicts that patients should more frequently use the land/water distinction for these trials, their knowledge of the more narrow distinction is more likely to be eroded. The degraded-access view predicts that patients should be equally impaired for both dimensions, assuming that the two dimensions are equally salient premorbidly; or that they should more frequently use the more salient dimension if this assumption fails.

8. Results

Fig. 4 shows mean percent correct for the two unidimensional trial types – trials that varied only on the land/water dimension, or on the bird/non-bird dimension – for healthy controls and the patient group. Controls show very high mean accuracy (and thus a
very low random choice rate) for both dimensions (land/water: 94% correct; bird/non-bird: 91% correct) with no significant difference between them ($t(15) = 0.705, p > 0.4$). The single subject data for controls, shown in Table 2, further indicates that very few controls performed below ceiling. These observations suggest that healthy controls have access to both of the salient dimensions and reliably use these in the trials of interest rather than some other unforeseen semantic cues. The high and equivalent accuracy in both conditions further suggests that the two dimensions are comparably salient to controls.

In contrast, AD patients show reduced accuracy in both categories on average (land/water: 67% correct; bird/non-bird: 50% correct). Analysis of variance treating unidimensional trial type (land/water or bird/non-bird) as a within-subject factor and group as a between-subjects factor revealed a reliable main effect of group ($F(1,22) = 52.493, p < 0.001$) and trial type ($F(1,22) = 12.857, p < 0.01$) as well as a group-by-type interaction ($F(1,22) = 7.14, p < 0.05$). Post hoc analyses confirmed that the patients were significantly more impaired on the unidimensional bird/non-bird trials than the unidimensional land/water trials ($t(7) = 5.761, p < 0.01$). Further, seven of eight individual patients performed numerically worse on bird/non-bird than land/water trials. If both dimensions are equally available to every participant, about half the patients should show better performance in one trial type, and about half in the other. Under this null hypothesis, the likelihood that 7 or more of the 8 patients would do better on land/water trials is $p < 0.04$ from a one-tailed test on the binomial distribution.

Fig. 5 shows the proportion correct for convergent trials: trials that varied on both salient dimensions, but with both dimensions indicating the same correct choice. As in the above unidimensional trial types, controls performed at ceiling for the convergent trials, whereas AD patients showed a reduced accuracy for this trial type (see Table 3 for individual performance). This observation is confirmed by a one-way ANOVA for the correct choices with a between subject factor of group (AD patients or Controls), revealing a significant main effect ($F(1,22) = 13.206, p < 0.01$). Planned post hoc comparisons for the AD patient group further indicated that the patients performed better in the convergent than in the unidimensional bird/non-bird trials ($t(7) = 4.0, p < 0.01$), whereas the level of performance was not significantly different from the unidimensional land/water trials ($t(7) = 1.798, p > 0.1$).

Fig. 6 shows performance for the divergent trials, in which stimuli varied on both salient dimensions, but with each dimension indicating a different possible answer. Here participants can choose the pair favoured by the land/water dimension, the pair favoured by the bird/non-bird distinction, or the remaining pair (i.e. random choice). The mean proportion of trials selected for each of these possibilities for controls and AD patients is plotted. Table 4 shows the data for each individual separately (Fig. 6).

Control choices were evenly split between the responses favoured by the two salient dimensions; the third nonsensical alter-

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Table 2

<table>
<thead>
<tr>
<th>Patients</th>
<th>Unidimensional—land/water</th>
<th>Unidimensional—bird/non-bird</th>
<th>Controls</th>
<th>Unidimensional—land/water</th>
<th>Unidimensional—bird/non-bird</th>
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</thead>
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<tr>
<td>ZS</td>
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<td>0.78</td>
<td>Ctrl 1.00</td>
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<tr>
<td>RB</td>
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<td>1.00</td>
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</tr>
<tr>
<td>IH</td>
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<td>0.49</td>
<td>Ctrl 0.94</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>JJ</td>
<td>0.80</td>
<td>0.57</td>
<td>Ctrl 0.69</td>
<td>0.97</td>
<td></td>
</tr>
<tr>
<td>PB</td>
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<td>0.41</td>
<td>Ctrl 1.00</td>
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</tr>
<tr>
<td>AT</td>
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</tr>
<tr>
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<tr>
<td>RG</td>
<td>0.40</td>
<td>0.27</td>
<td>Ctrl 0.91</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>0.67</td>
<td>Mean 0.94</td>
<td>0.91</td>
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<tr>
<td></td>
<td>SD</td>
<td>0.18</td>
<td>SD 0.09</td>
<td>0.10</td>
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</tr>
</tbody>
</table>

Chance level = .33%.
Table 3
Percentage correct (%) and standard deviation (SD) of the convergent trials for AD patients (ordered according to patients Camel and Cactus semantic association test (CCT) performance; top: highest CCT score; bottom: lowest CCT score) and controls.

<table>
<thead>
<tr>
<th>Patients</th>
<th>Convergent</th>
<th>Controls</th>
<th>Convergent</th>
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</thead>
<tbody>
<tr>
<td>ZS</td>
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<td>Cntrl 1.00</td>
<td>0.97</td>
</tr>
<tr>
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<td>Cntrl 1.00</td>
<td>0.97</td>
</tr>
<tr>
<td>IH</td>
<td>0.69</td>
<td>Cntrl 0.97</td>
<td>0.97</td>
</tr>
<tr>
<td>JJ</td>
<td>1.00</td>
<td>Cntrl 0.92</td>
<td>0.97</td>
</tr>
<tr>
<td>PB</td>
<td>0.78</td>
<td>Cntrl 1.00</td>
<td>0.97</td>
</tr>
<tr>
<td>AT</td>
<td>0.36</td>
<td>Cntrl 0.94</td>
<td>0.97</td>
</tr>
<tr>
<td>MD</td>
<td>0.92</td>
<td>Cntrl 0.97</td>
<td>0.97</td>
</tr>
<tr>
<td>RG</td>
<td>0.31</td>
<td>Cntrl 1.00</td>
<td>0.97</td>
</tr>
</tbody>
</table>

Mean 0.74  Mean 0.99 SD 0.27   SD 0.02

Chance level = .33%.

Fig. 5. Bar graph in percentage correct (error bars indicate standard error) for Control (white bar) and AD patients (black bar) performance in the convergent trials. Dashed line indicates chance level.

Table 4
Percentage correct (%) and standard deviation (SD) of the divergent trials for AD patients (ordered according to patients Camel and Cactus semantic association test (CCT) performance; top: highest CCT score; bottom: lowest CCT score) and controls.

<table>
<thead>
<tr>
<th>Patients</th>
<th>Divergent land/water</th>
<th>Divergent bird/non-bird</th>
<th>Divergent random</th>
<th>Controls</th>
<th>Divergent land/water</th>
<th>Divergent bird/non-bird</th>
<th>Divergent random</th>
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<tbody>
<tr>
<td>ZS</td>
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<td>Cntrl</td>
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<td>RB</td>
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<td>0.03</td>
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<td>0.00</td>
</tr>
<tr>
<td>IH</td>
<td>0.66</td>
<td>0.29</td>
<td>0.06</td>
<td>Cntrl</td>
<td>0.06</td>
<td>0.93</td>
<td>0.01</td>
</tr>
<tr>
<td>JJ</td>
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<td>0.16</td>
<td>0.06</td>
<td>Cntrl</td>
<td>0.14</td>
<td>0.86</td>
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<tr>
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<td>Cntrl</td>
<td>0.19</td>
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</tr>
<tr>
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<td>0.35</td>
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<td>Cntrl</td>
<td>0.40</td>
<td>0.57</td>
<td>0.03</td>
</tr>
<tr>
<td>MD</td>
<td>0.65</td>
<td>0.24</td>
<td>0.11</td>
<td>Cntrl</td>
<td>0.45</td>
<td>0.54</td>
<td>0.01</td>
</tr>
<tr>
<td>RG</td>
<td>0.41</td>
<td>0.33</td>
<td>0.26</td>
<td>Cntrl</td>
<td>0.37</td>
<td>0.47</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Mean 0.57  0.31  0.12 Mean 0.49  0.49  0.02 SD 0.16  0.13  0.08 SD 0.34  0.34  0.04

Like controls, patients chose the alternative favoured by the land/water distinction 57% of the time on average; however they were less likely to choose the alternative favoured by the bird/non-bird distinction (31% of choices) and significantly more likely to make a random/erratic choice (12% of all choices). Analysis of variance was used to compare the proportion of responses of each type (land/water, bird/non-bird or random) in control and patient groups. The results showed a significant main effect of trial type \((F_{2,44} = 14.196, p < .000)\) but no group main effect \((F_{1,22} = .489, p > .4)\), nor a group by trial-type interaction \((F_{2,44} = 1.434, p > .2)\). This null result is not surprising given the extent of variability in the healthy control group, which reduces the power to detect any difference in the patient group.

To determine whether patients were more likely to choose on the basis of the landmark/water distinction than the bird/non-bird distinction, a repeated-measures ANOVA was conducted comparing proportion of land/water and bird/non-bird choices in the patient group (omitting the proportion of random choices). The analysis revealed a significant main effect of choice type \((F_{1,7} = 6.96, p < 0.04)\), with land/water chosen significantly more frequent than bird/non-bird choices. The same contrast in the control group showed no effect \((F_{1,15} = 0.003, p = 0.96)\).
Finally, we considered the number of individuals in each group who were more likely to select on the basis of the land/water than the bird/non-bird distinction (see Table 4). In the control group, exactly half of the individuals used the land/water dimension more frequently than the bird/non-bird dimension on divergent trials, an outcome expected under the null hypothesis that the two dimensions are equally likely to guide an individual’s choice ($p = 0.60$ from the binomial distribution). For the patient group, 7/8 patients chose more frequently on the basis of the land/water distinction; the likelihood of 7 or more of 8 patients showing this pattern under the null hypothesis of random responding is $p < 0.04$ from the binomial distribution. Thus the patients, but not the controls, appear to use the land/water dimension more frequently than the bird/non-bird dimension in guiding their choices on divergent trials.

While most patients showed some degree of preservation of the land/water semantic distinction, there was substantial variability in the overall degree of impairment across patients. A correlation analysis, contrasting performance on an independent measure of semantic memory (the Camel and Cactus Test, CCT) with a composite score based on the triadic accuracy data revealed a significant correlation ($r = .815$, $p < .025$). More specifically, the severity of impairment on the CCT (in Tables 2–4 individuals are according to their scores on this test, with more severely impaired cases listed toward the bottom of the table) was an excellent predictor of overall performance on the triadic task.

9. Discussion: accuracy analysis

Consideration of the control data strongly suggests that the two dimensions are, on average, equally salient to controls. First, controls showed high and equivalent accuracy on unidimensional trials, where items varied on only one of the 2 dimensions. Second, on divergent trials where the different dimensions suggest different choices, controls were near perfectly split on their use of the land/water versus the bird/non-bird distinction. Though individuals often showed a consistent preference for one dimension over the other, the frequency of such preferences was balanced for the two dimensions across individuals. Thus there is no evidence that the bird/non-bird distinction is less salient for healthy individuals than is the land/water distinction for these materials.

In contrast, AD patients were less likely to make use of the bird/non-bird than the land/water distinction. In unidimensional trials, patients performed worse for the bird/non-bird trials relative to land/water trials; and for divergent trials, patients were more likely to choose on the basis of the land/water distinction. Because the controls found the two dimensions to be equally salient, disproportionate use of the land/water distinction in the patients cannot be attributed to premorbid differences in saliency. The findings are thus not easily explained with reference to a degraded-access syndrome, which should produce an equivalent degree of impairment to two equally salient semantic distinctions. In contrast, the degraded-store view predicts greater impairment to more narrow semantic classes, such as the bird/non-bird classes, than to broader classes, such as land- and water-dwellers. The current data are thus more consistent with the degraded-store view.

The analysis of convergent trials revealed a main effect of group with the AD patients performing worse overall than controls. Convergent trials do not allow us to determine which semantic dimensions are being used to guide judgments; however it is worth noting that patient performance on these trials was equivalent to that obtained on the land/water unidimensional trials, and significantly better than that seen for bird/non-bird unidimensional trials. In other words, patients were no more likely to select the correct pair when both land/water and bird/non-bird dimensions indicated the same response than they were when only the land/water distinction was available to guide their choice—again suggesting that bird/non-bird dimension contributes little to their decisions for these trials.

While the patients were quite consistent overall in the relative preservation of the land/water distinction, they varied in the overall magnitude of impairment. For example, ZS showed only marginal impairment compared to controls for both unidimensional conditions and but a preference, though non-significant, for the bird/non-bird dimension in the divergent trials. By contrast, two other patients, AT and RG, performed extremely poorly overall, scoring close to chance on unidimensional and convergent trials, including trials in which they could utilize the land/water dimension. It would be easy to interpret the profile seen in the latter two cases as support for a degraded-access disorder, as the patients seemingly make random choices across all trial types. The positive correlation obtained between the Camel and Cactus Test (CCT) and a composite measure of the accuracy data, however, clearly indicates that this variability in the triadic comparison task is positively associated with an independent measure of conceptual loss: patients with mild semantic impairment (as in ZS) performed relatively well for both dimensions, while cases with severe impairment (AT and RG) chose more erratically for both dimensions. These extreme cases thus appear to reflect the tails of a distribution of performance whose variability is influenced by the extent of semantic degradation, rather than a qualitatively different population of “degraded-access” patients. It is also worth noting in this regard that, even for these best- and worst-performing cases, the relative preservation of land/water over bird/non-bird information is apparent for unidimensional trials in all 3 cases, and for divergent trials in 2/3 cases.

10. General discussion

For both patient and control groups, the results of the accuracy analysis differed from those of the MDS analysis. First, the scaling models yielded poor fit values for both groups, with the implication that neither controls nor patients responded systematically in the task, notwithstanding the clustering apparent in plots of the group solution. In contrast, the accuracy analyses showed that controls consistently employed both semantic dimensions: Where stimuli varied on just one of these dimensions, controls used it to direct their choice on 91–99% of trials; and where they varied on both dimensions, controls essentially never made choices that violated both salient dimensions (less than 1% of trials).

Second, the INDSCAL weightings for individual controls seemed to suggest that some participants attended only to one dimension (land/water or bird/non-bird), while others used both dimensions. The accuracy analysis allows us to see that this is not strictly true: all healthy controls were sensitive to both dimensions. When stimuli in a triad varied on only a single dimension, healthy participants virtually always used this dimension to guide their choice. The preference for one dimension over another only surfaced when the two dimensions conflicted, in which case some subjects consistently used one dimension, some used the other, and some alternated. The weightings from the INDSCAL analysis thus failed to capture important information: if an individual received a strong weighting on dimension A and a weak weighting on dimension B it is impossible to tell whether the weaker dimension was completely ignored, or whether the individual simply preferred the stronger dimension when the two were in conflict. This poses obvious difficulties for interpreting the patient weightings: do the overall weaker weightings on both dimensions in the patient group arise because patients are less sensitive to the two salient dimensions, or are they less consistent in the decisions they make when the two salient dimensions conflict?

This consideration leads to a third major difference in results between the MDS and accuracy analyses: whereas the INDSCAL
analysis suggested that both dimensions were equally degraded in AD, the accuracy analysis clearly showed that patients were more impaired on the bird/non-bird than the land/water distinction. Specifically, patients were less accurate on trials that varied only in the bird/non-bird dimension, and were less likely than controls to use the bird/non-bird dimension as the basis for their judgments across all trial types. The control data show the two dimensions to be equally salient to healthy controls, so this difference in the patient data is not easily attributed to premorbid differences in the relative availability of the two dimensions. One conclusion, then, is that the disease process has eroded knowledge of the bird/non-bird distinction more than knowledge of the land/water distinction in this group. This systematic erosion of a more narrow or specific semantic dimension (i.e., bird/non-bird) is consistent with the view that semantic impairments in AD arise from erosion of the semantic store (Hodges et al., 1995; Hodges, Salmon, & Butters, 1991; Rogers, 2003; Warrington, 1975), rather than from degraded access to an intact semantic store, which predicts deficits regardless of the semantic dimensions employed in our experiment.

It is worth noting that the experimental materials employed in this study manipulate only 2 semantic dimensions, with each cell represented by only 3 items. The small number of items is a necessary consequence of the Triad-matching methodology: the 220 trials that result from combining 12 items is about the maximum that can be used in a single test session with this patient population. Still, it is not clear to what extent the current findings will generalize to other kinds of semantic distinctions and stimuli, or to the broader population of typical AD patients, and our conclusions must be tempered accordingly. Future work should assess additional clearly defined semantic categories varying in their breadth to assess the replicability of the current findings; and it is further important to test our conclusions in a larger sample of AD patients. A longitudinal follow-up of AD patients could investigate the pattern of semantic category degradation over time in these patients, with results that may further help to adjudicate different theories; and a large case-series analysis may permit identification of subgroups of AD patients who show different patterns of responding on this kind of task. One take-home message of the current work, however, is that all such efforts should not rely solely on multi-dimensional scaling analyses, or at least not upon the INDSCAL algorithm. It is possible that more contemporary scaling methods will produce more satisfactory results, but this question is left for future research.

11. Conclusion

In summary, two important conclusions can be drawn from our findings. First, the MDS results obscure important regularities in both the control and the patient data, and hence demonstrate that such methods are not always useful for drawing conclusions about the integrity of conceptual knowledge in healthy or degraded cognition. Although the INDSCAL algorithm can be helpful for visualizing data, we agree with Storms et al. (2003) that it is problematic to draw any further conclusions about the status of semantic memory from such plots. Nevertheless, the current results show that proximity data can provide important insights into semantic impairment when they are subjected to complimentary analyses. We propose that MDS analyses should be accompanied by standard accuracy analyses of the kind presented here, as an external validity check to rectify some of the methodological issues noted by Storms et al. (2003).

Second, although the limitations of MDS techniques revealed here might lead one to question earlier claims about semantic impairments in Alzheimer’s disease, our data actually confirm some of the conclusions drawn from these earlier investigations. Specifically, the results of the accuracy analysis are consistent with the claim that the semantic impairment in AD is largely a storage problem: similarity judgments based on one conceptual dimension (such as bird/non-bird) are more affected in AD than those that require the use of another dimension (land/water). This pattern of differential impairment for different but equally salient semantic distinctions is not consistent with the degraded-access theory of semantic breakdown in AD. Our results suggest that, although the MDS methods previously used to investigate similarity judgments in AD suffer from the shortcomings identified by Storms et al. (2003), the basic message from these earlier studies can be confirmed through accuracy analyses: semantic knowledge is systematically disrupted in the AD patients of our study, with some aspects of knowledge more vulnerable to impairment than others.

Acknowledgments

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References


