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Alzheimer’s Disease is Associated with Distinctive Semantic Feature Loss

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Abstract

A central topic of discussion in the exploration of semantic disturbance in AD concerns the relative contribution of semantic content (e.g., semantic features) and semantic process. Studies have suggested that semantic dysfunction in AD is the result of deficits to either semantic process, semantic content or both. Studies that have supported the loss of semantic content have been criticized for their use of verbal stimuli and cognitively challenging experimental tasks. The current study used a novel version of the yes-no recognition memory task to compare the processing of distinctive and non-distinctive features in participants with AD whilst controlling the cognitive demands of the task. The task involved five conditions which denoted the relationship between the items in the test and study phase. A ‘non-distinctive’ and a ‘distinctive’ condition were included where non-distinctive and distinctive semantic features were manipulated between study and test, respectively. Task accuracy of participants with AD decreased relative to control participants when distinctive features were manipulated between the study and test phase of the experiment. There was no significant difference between groups when non-distinctive features were manipulated. These findings provide evidence to support the loss of semantic content in AD.

Keywords: Alzheimer’s disease; Semantic features; Semantic content; Semantic process
1 Introduction

1.1 Semantic Disturbance in AD

Language difficulties are very common for people with Alzheimer’s disease (AD) (Cummings, Benson, Hill, & Read, 1985). The key clinical language characteristics of people with AD are word finding difficulties, semantic paraphasias and comprehension deficits with the relative sparing of repetition, morphology, syntax, phonology and motor speech skills (Blair, Marczinski, Davis-Faroque, & Kertesz, 2007; Huff, Corkin, & Growdon, 1986). It is widely regarded that the language deficits observed in AD stem from semantic disturbance (Chenery, 1996; Christensen, Kopelman, Stanhope, Lorentz, & Owen, 1998; Garrard & Carroll, 2006; Huff et al., 1986; Martins & Lloyd-Jones, 2006). As a consensus has not been reached in the literature as to the nature of semantic disturbance in AD, this study aims to explore competing accounts.

Alzheimer’s disease is associated with multiple cognitive deficits and it is widely accepted that the semantic disturbance of AD involves deficits in semantic control (Reilly, Peelle, Antonucci, & Grossman, 2011). Semantic control is a collective term for the cognitive processes and skills believed to be necessary for completing semantic tasks and includes attention, memory, noise suppression, and enactment (Jefferies, Patterson, & Ralph, 2008). Of controversy in the literature exploring language in AD is the co-occurrence of disturbance to underlying semantic representations (Hornberger, Bell, Graham, & Rogers, 2009). The debate echoes Warrington and Shallice’s (1979) access versus storage dichotomy where a division is drawn between semantic deficits caused by either disturbances to the access of semantic information or disturbance to the semantic information itself. However, the discussion of semantic disturbance could be more
accurately described as one of access and storage (or process and content) versus access only (Reilly et al., 2011).

Authors who have supported the loss of semantic content have claimed that the neuropathology of AD compromises structures responsible for storing semantic information, and loss of this information contributes to semantic disturbance (Chertkow & Bub, 1990; Martin, 1992). Authors supporting the loss of semantic process only have suggested that semantic information remains largely intact but access to semantic information is impeded by the cognitive decline associated with the disease (Daum, Riesch, Sartori, & Birbaumer, 1996; Hartman, 1991; Nebes, Brady, & Huff, 1989; Nebes, Martin, & Horn, 1984). Each side of the debate is based upon a different theory of semantic representation and, therefore, the resolution of this argument has implications for our understanding of semantic disturbance in AD as well as our understanding of the structure of the semantic system.

In Warrington and Shallice’s (1979) discussion of access versus storage, storage/content disturbances were associated with consistent errors, frequency effects, selective loss of subordinate information, lack of priming and cueing effects. These criteria have been criticized for their lack of empirical or consistent theoretical basis (Rapp & Caramazza, 1993). Many subsequent studies that have supported loss of content in AD have focused upon semantic feature loss (Almor et al., 2009; Garrard, Ralph, Patterson, Pratt, & Hodges, 2005; Laisney et al., 2011). Semantic features can be defined as a description of the properties of a concept and can be classed as distinctive (defining features and therefore common to only one or two concepts) or non-distinctive (non-
defining features and therefore common to many concepts) (McRae, Cree, Seidenberg, & McNorgan, 2005).

A number of computational models have been developed to explain semantic disturbance in AD that rely on semantic feature loss. Prominent models include Gonnerman, Andersen, Devlin, Kempler, and Seidenberg (1997), Plaut (1996) and Develin, Gonnerman, Andersen and Seidenberg (1998). Within these models, concepts are generally viewed as an interconnected network of semantic features. As non-distinctive features are common to many items within a category, they are frequently co-active, highly intercorrelated and therefore share numerous, strong links. Distinctive features, on the other hand, share few interconnecting links. With cortical damage characteristic of AD, interconnections between semantic features are expected to be lost. Being highly intercorrelated, non-distinctive features are not affected by the loss of interconnections early in the disease as many other connections are available to compensate. Distinctive features, however, are vulnerable early in the disease process.

Although these connectionist models were originally used to describe category specific deficits in AD, the vulnerability of distinctive semantic features has also been used to explain other patterns of semantic error in AD (Done & Gale, 1997; Garrard et al., 2005; Laisney et al., 2011; Rogers & Friedman, 2008). Early in the disease, people with AD are frequently reported to make category co-ordinate (e.g., calling a ‘horse’ a ‘cow’) and superordinate (e.g., calling a ‘horse’ an ‘animal’) semantic paraphasias (Bowles, Obler, & Albert, 1987; Hodges & Patterson, 1995). Such errors may be explained by the loss of distinctive semantic features, which make it difficult to distinguish between concepts within a category, yet category level knowledge is retained.
In the latter stages of the disease, people with AD are reported to frequently make unrelated errors or give ‘I don’t know’ responses on naming tasks (Bowles et al., 1987; Hodges & Patterson, 1995). These errors may be explained by the loss of numerous interconnections later in the disease process, which compromises non-distinctive features and leads to the loss of category level knowledge (Done & Gale, 1997; Garrard et al., 2005; Laisney et al., 2011; Rogers & Friedman, 2008). The loss of semantic features in AD, particularly the loss of distinctive features, has been supported by a number of behavioural studies over the past decade (Done & Gale, 1997; Garrard et al., 2005; Laisney et al., 2011; Rogers & Friedman, 2008).

Garrard et al. (2005) requested participants with AD to list as many features as possible for a given object. Compared with controls, participants with AD listed fewer features, with particular difficulty listing distinctive features. The authors also found that the number of features given for an item was correlated with the ability to name that item. Laisney et al. (2011) created a semantic priming experiment where prime-target pairs consisted of concept-attribute pairs of either distinctive (e.g. zebra-stripes) or non-distinctive features (e.g. duck-feathers). Semantic priming was impaired in AD for distinctive attribute-concept pairs but not for non-distinctive attribute-concept pairs, whereas controls showed priming for both conditions. The findings of these studies have led the authors to conclude that semantic disturbance in AD involves the loss of semantic feature information, with distinctive semantic features being more vulnerable to loss than non-distinctive features (Garrard et al., 2005; Laisney et al., 2011). This differential loss of distinctive semantic features in AD is central to claims of semantic content loss as it is
used to explain the progressive nature of semantic disturbance in the disease (Done & Gale, 1997; Garrard et al., 2005; Laisney et al., 2011; Rogers & Friedman, 2008).

A number of authors have suggested that semantic disturbance in AD is due to the disturbance of semantic processes only and not a deficit in semantic representations (Daum et al., 1996; Fung, Chertkow, & Templeman, 2000; Nebes et al., 1984; Ober & Shenaut, 1999; Perri et al., 2003). These authors have claimed that because people with AD have impaired cognition, especially attention and executive functioning, the ability to access otherwise spared semantic representations is also impaired. Furthermore, if the cognitive demands of a task are reduced (in a situation where automatic rather than effortful retrieval can occur), then the semantic disturbance observed in AD would be reduced (Daum et al., 1996; Nebes et al., 1984; Perri et al., 2003). Evidence for this account comes from a number of behavioural studies exploring semantic functioning in AD while controlling the cognitive demands of the task.

The first behavioural evidence for the semantic process only view was published by Nebes et al. (1984), who tested semantic memory in participants with AD and healthy controls using tasks with low cognitive demands (semantic priming, approximation to English and approximation to text tasks). The authors reported that participants with AD performed as well as controls on measures of semantic memory. Similarly, Daum et al. (1996) reported that participants with AD showed improved performance on semantic tasks with low cognitive demands such as object decision and preference judgment tasks compared with effortful tasks such as confrontation naming and definitions. These findings led the authors to reason that the semantic deficits of AD were the product of effortful semantic tasks with high cognitive demands preventing access to intact semantic
representations (Daum et al., 1996; Nebes et al., 1984). Since these early studies, other authors have also reported that the semantic deficits of AD can be reduced through using non-effortful cognitive tasks (Fung et al., 2000; Perri et al., 2003). Though studies supporting deficits to semantic process only are in the minority, they highlight the importance of minimizing and/or accounting for the cognitive demands associated with task performance in AD.

1.2 Theories of Semantic Representation in Relation to AD

The outcome of the debate over loss of content in semantic dysfunction in AD has implications for models of semantic representation. Loss of semantic content, unlike disturbance to semantic process only, is consistent with models of semantic representation that rely on grounded representation. Proponents of grounded models assert that semantic memory is based on sensory representations (Barsalou, 2008). These models are distinct from amodal and hub and spoke models in which semantic memory is based on a central store of amodal symbols (Caramazza, 1990; Mahon & Caramazza, 2008; Reilly & Peelle, 2008). Within the context of grounded models, semantic concepts are represented as a distributed network of perceptual symbols/semantic features spread throughout the cerebral cortex, in particular, the somatosensory areas of the brain (Barsalou, Simmons, Barbey, & Wilson, 2003; Coltheart et al., 1998; Dove, 2009; Mayberry, Sage, & Ralph, 2011). Grounded models would predict that because AD involves progressive neural loss in many regions over the cerebral cortex (Perl, 2010), semantic feature loss, or disruptions to interconnections between semantic features, is likely to occur and this progressive loss of semantic features will result in semantic disturbance (Done & Gale, 1997; Done & Hajilou, 2005). Furthermore, grounded models
predict the differential loss of distinctive over non-distinctive semantic features in AD due to greater intercorrelation and stronger synaptic links for non-distinctive features than distinctive semantic features (Done & Gale, 1997; Pulvermuller, 2001; Ursino, Cuppini, & Magosso, 2011). These predictions are consistent with disturbance to semantic process and content, but not process only, and therefore the debate between these competing accounts has implications for semantic theory. Thus, if an experiment with reduced cognitive demands reveals a processing deficit for semantic features in AD relative to control participants, this would provide evidence for semantic content loss and grounded modeling.

1.3 Semantic Tasks and Cognitive Demands

One of the key limitations of previous studies that have found evidence for loss of semantic content in AD is the use of verbal stimuli. More specifically, the difficulties that people with AD have in processing verbal stimuli could either mask or exaggerate changes to underlying semantic representations (Garrard et al., 2005). Difficulties processing verbal stimuli do not necessarily reflect changes to the semantic system as words and underlying conceptual representations share only arbitrary links (Mayberry et al., 2011; Rogers et al., 2004). It is widely held that the processing of lexical stimuli (e.g., reading and naming) can be impaired in the absence of semantic disturbance (Glosser & Friedman, 1991; Kay, Lesser, & Coltheart, 1996). Difficulty processing lexical stimuli could prevent a semantic deficit being detected or be incorrectly interpreted as a semantic deficit. Studies of semantic processing in populations such as AD, could therefore benefit from avoiding lexical stimuli in order to minimize the potential confounds of lexical processing.
Picture stimuli may provide a suitable alternative to lexical stimuli and may help lower cognitive confounds in experimental tasks for an AD population. According to the picture superiority effect, people with AD perform better on cognitive tasks using pictures rather than words (Stopford, Thompson, Neary, Richardson, & Snowden, 2012). Moreover, people with AD perform better on semantic tasks using coloured pictures and photographs than the black and white line drawings that are often used in semantic studies (Zannino, Perri, Caltagirone, & Carlesimo, 2007; Zannino et al., 2010). Taken together, the use of photographs as stimuli, without the requirement of naming, could potentially reduce the cognitive demands on participants with AD compared with lexical stimuli and provide a more valid assessment of semantic memory.

Another advantage to utilizing picture stimuli is that it allows for semantic feature processing to be explored through the direct manipulation of semantic features. For example, according to published semantic feature norms (McRae et al., 2005), a semantic feature of ‘deer’ is that they <have antlers>; this feature could be altered or removed when using picture stimuli and the processing of the stimulus compared between participants with AD and controls. Therefore, by selectively altering distinctive and non-distinctive semantic features of picture stimuli, the differential processing of these feature types in AD could be tested. Imaging studies have shown that people with AD have lesions throughout motor and sensory areas of the cerebral cortex with the visual cortex being affected in the early stages of the disease (Frisoni, Prestia, Rasser, Bonetti, & Thompson, 2009). Therefore, if semantic feature loss has occurred, it would be likely to involve distinctive visual semantic features and affect the processing of picture stimuli.
The cognitive confounds of previous studies that have found evidence of semantic content loss could be further reduced by using picture stimuli in a simple cognitive task such as the yes-no recognition memory task (Daum et al., 1996; Nebes et al., 1984). The yes-no recognition memory task involves a participant being shown a number of items during a learning phase, and then being re-shown these ‘old’ items with the addition of previously unseen ‘new’ items in a test phase (Macmillan & Creelman, 2005). The participant must learn the old items in the study phase and correctly determine which items are old and those that are new in the test phase. Performance is generally reported in terms of the ‘hit rate’ (proportion of correct response to old items) and ‘false alarm rate’ (proportion of incorrect responses to new items) (Macmillan & Creelman, 2005; Snodgrass & Corwin, 1988). The yes-no recognition memory task has been previously used to explore semantic processing in AD by using semantically related and unrelated new items. Budson, Daffner, Desikan, and Schacter (2000) found that false alarm rates increased for control participants but not participants with AD when stimuli in the test phase were semantically related to items in the study phase compared to items that were unrelated. The novel use of this paradigm involving the manipulation of semantic features of stimuli could provide new insight into semantic feature processing in AD and the presence of disturbance to semantic content.

The present study aimed to investigate disturbance to semantic content in AD using a simple cognitive task to minimize the potential confounds of semantic process. Many contemporary models have used the semantic feature as a basic unit of semantic content and a number of behavioural studies have cited the loss of semantic features as a contributing factor to semantic disturbance in AD. To this end, distinctive and non-
distinctive semantic features of picture stimuli were manipulated between study and test phases of a yes-no recognition experiment. Five conditions were included: The identical condition (old items and therefore identical between study and test), the non-distinctive condition (new items altered by non-distinctive features between study and test), the distinctive condition (new items altered by distinctive semantic features between study and test), the semantic condition (new items that are category co-ordinates of items in the study phase) and the unrelated condition (new items that are not related to items in the test phase).

Based on the notion that semantic feature loss may contribute to semantic disturbance in AD, and that non-distinctive features are more resistant to loss in the disease, a differential performance across groups was predicted. Specifically, it was predicted that if a non-distinctive feature was altered between study and test phases, participants with AD and control participants would have similar false alarm rates. When distinctive features were altered between study and test phases, then participants with AD were predicted to have a significantly higher false alarm rate than control participants.

2 Methods

2.1 Participants

The participant cohort consisted of 11 participants with AD (7 males) and 23 healthy control participants (8 males). Consistent with previous studies (Garrard et al., 2005; Hornberger et al., 2009; McKhann et al., 1984; Reilly et al., 2011; Tippett, Meier, Blackwood, & Diaz-Asper, 2007; Weiner, Neubecker, Bret, & Hynan, 2008), diagnosis of AD was based on the clinical opinion of the treating clinician with reference to the Diagnostic and Statistical Manual of Mental Disorders – Fourth Edition (American
Psychological Association, 1994) and the National Institute of Neurological and Communication Disorders and Stroke (NINCDS) and Alzheimer’s Disease and Related Disorders Association (ADRDA) (McKhann et al., 1984) criteria. The study received ethical clearance through the Research Ethics committees of the University of Queensland, the Royal Brisbane and Women’s Hospital, Darling Downs - West Moreton Health Service District and the Princess Alexandra Hospital. Written informed consent was obtained from all participants.

Participants with AD had a mean age of 75.36 (SD = 10.67) and 15 (SD = 3.36) years of education. Control participants had a mean age of 68.39 (SD = 9.11) and 13 (SD = 3.74) years of education. Independent t-tests revealed no significant differences between the two groups for education \([t(32) = 1.492, p = 0.146]\), whilst the difference in mean age between groups approached significance \([t(32) = 1.976, p = 0.057]\). Pearson Chi-Squared test found no significant differences in gender representation \((\chi^2(1) = 2.513, p = 0.113)\). All participants had English as their first and only language, were right handed and had no uncorrected vision or hearing impairments. The average period of time between diagnosis of AD and participation in the study was 1.18 (SD = 0.982) years and all but two participants with AD were taking cholinesterase inhibitors as prescribed by their geriatrician.

A battery of standardized neuropsychological assessments was administered to all participants in order to measure cognitive skills relevant to the study, including visual memory, visual-spatial skills, semantic skills, premorbid intelligence and attention. The assessments included the Boston Naming Test (Goodglass, Kaplan, & Weintraub, 1983), the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS)
(Randolph, 1998), the Pyramids and Palm Trees (Howard & Patterson, 1992), the National Adult Reading Test – Revised (Nelson & Willison, 1991), Mini Mental State Examination (MMSE) (Folstein, Folstein, & McHugh, 1975) and the Birmingham Object Recognition Battery (Riddoch & Humphreys, 1993). The RBANS was not completed on one participant with AD due to time constraints.

Results for each participant with AD together with mean performance of the AD and control group on these neuropsychological tests are presented in Table 1. Although the mean MMSE score for the AD group is within the average range at 26.27 (SD = 3.77) (Tombaugh, McDowell, Kristjansson, & Hubley, 1996), this result can be expected as the MMSE has been observed to lack sensitivity to cognitive impairment in mild AD and highly educated participants (>12 years education) (Galasko et al., 1990; Tombaugh et al., 1996). The RBANS, on the other hand has been shown to be sensitive to cognitive impairment in mild AD (Duff et al., 2008) and this is reflected in the mean total RBANS score of 66.80 (SD = 17.42) for the AD group, which is well below the average range.

[Insert Table 1 about here]

### 2.2 Design

This experiment used a mixed model design with a between groups factor (AD, Control) and a within subjects factor of ‘Study-Test Relationship’, which concerned the 5 possible relationships between stimuli in the study and test phases: Identical, non-distinctive, distinctive, semantic and unrelated. A description of each experimental condition is provided in Table 2.

[Insert Table 2 about here]
2.3 Stimuli

One hundred and thirty five photographs were selected from the digital Hemera Photo-Objects collection (Hemera Technologies, 2001). Fifteen pictures were selected for the identical, non-distinctive and distinctive feature conditions, 30 pictures were selected for the semantic condition and 60 pictures were selected for the unrelated condition. Photographs for the test phase for the non-distinctive and distinctive conditions were formed by digitally altering the original photographs used in the study phase in GIMPshop according to the semantic feature norms of McRae et al. (2005). Items in the distinctive condition were altered by features classified as distinctive by McRae et al. (2005) whereas items in the non-distinctive condition were altered by features that were not classified as distinctive features by McRae et al., (2005). The semantic condition used 15 category coordinate pairs according to Wordnet 2.1 (Maki, McKinley, & Thomson, 2004). The number of stimuli used in each condition was chosen so that there would be an equal number of related and unrelated stimuli between study and test. The number of stimuli for each condition classed as either ‘artefacts’ or ‘biological kinds’ can be found in Table 2.

Using the same instructions as Snodgrass and Vanderwart (1980), the stimuli (including the digitally altered items) were normed for image agreement, visual complexity and familiarity (see Table 3) by a cohort of 49 (21 males) healthy, native English speakers with a mean age and education of 25.87 (SD = 2.99) and 16.98 (SD = 3.23) years, respectively. Normative data for written word frequency was obtained from the Sydney Morning Herald Word Database (Dennis, 1995) and normative data for name agreement was taken from LaGrone and Spieler (2006). A series of t-tests found that
there were no significant differences between study and test items for name agreement \[t(177) = 0.322, p = 0.748\], image agreement \[t(172) = 0.208, p = 0.835\], familiarity \[t(172) = -0.497, p = 0.620\], visual complexity \[t(172) = 0.518, p = 0.605\] and frequency \[t(145) = -1.027, p = 0.306\]. A series of one-way ANOVA tests found that image agreement differed significantly between the conditions of the test phase \[F(4,10) = 2.609, p = 0.039\], which was expected due to the modification of stimuli for the distinctive and non-distinctive conditions. However, there were no significant differences between the conditions of the test phase for name agreement \[F(4, 114) = 1.468, p = 0.268\], visual complexity \[F(4, 110) = 0.711, p = 0.586\], familiarity \[F(4, 110) = 1.484, p = 0.212\] or frequency \[F(4, 92) = 0.986, p = 0.491\].

In addition to the items for the critical conditions, a further 60 filler stimuli, which were identical between study and test phase, were included to increase the proportion of trials with identical (old) items. The filler stimuli were not normed and were not analysed. The task was subsequently divided into four ‘study’ and four ‘test’ phases. There were 30 items in each study phase and 45 items in each test phase. For each study phase there were 15 filler trials and 3-4 items from each of the identical, non-distinctive, distinctive and semantic conditions. Each test phase included the same number of trials for each condition as the study phase, with the addition of the unrelated condition, which included 15 trials per test phase.

[Insert Table 3 about here]

2.4 Procedure

This experiment employed a yes-no recognition memory task. Each study and test phase of the recognition memory task was separated by a gap of 10 minutes in which
participants completed standardised neuropsychological testing. Previous research has found that a study-test gap of 10 minutes gave similar accuracy between AD and control participants for picture recognition (Christensen et al., 1998). To prevent fatigue, the participants were invited to have a rest break after each test phase. The stimuli were presented on a Toshiba Satellite M100 computer using EPrime (1.0) software which automatically recorded participant accuracy through a Psychology Software Tools 200A response box. Buttons 1 and 2 of the response box were marked with the words ‘yes’ and ‘no’ respectively. The pictures were presented centrally with a uniform silver background no larger than 450 x 500 pixels in size. The stimuli in each of the study and test phases were organised into a randomised block design with two blocks to each study and each test phase and each block containing equal numbers of stimuli. The order of stimuli was randomized within each block for each participant but programmed such that no more than two items from the same condition could appear sequentially. The order of the blocks did not change between participants or between study and test phases.

Prior to each study phase, the participants were instructed that they were about to view a series of photographs and that they would be tested to see how many they could remember. During each study phase, participants were shown 30 unmodified photographs which included either 3 or 4 items from each of the identical, non-distinctive (unaltered), distinctive (unaltered) and semantic conditions and 15 filler items. Stimuli were exposed for 8 seconds as previous research has reported that this exposure has improved the performance of participants with AD relative to controls (Christensen et al., 1998). Prior to each test phase, the participants were instructed to press ‘yes’ if an item was identical to an item from the study phase and ‘no’ if a given item was not identical to an item from
the study phase. During each test phase, the participants were shown 45 photographs including 15 items from the unrelated condition, either 3 or 4 items from each of the identical, non-distinctive (altered), distinctive (altered) and semantic conditions and 15 filler items. Participants had 5 seconds to make their decision. The entire experiment took approximately 80 minutes to complete.

2.5 Statistical Analysis

The results were analysed in terms of accuracy and signal detection. All analyses were calculated with respect to hit rate and false alarm rate, which was calculated for each condition by dividing either the number of hits or false alarms by the number of items in that condition.

The analysis of accuracy involved the comparison of hit rates between groups and the comparison of false alarm rates between and within groups. Hit rates were compared between groups using a t-test. False alarm rates were analysed using a repeated measures ANOVA with participant group as the between subjects factor and condition as the within subjects factor. Post-hoc analysis using a series of t-tests was used to compare false alarm rates between and within groups.

Signal detection was calculated in terms of response bias (c) and sensitivity (d’) using the formulae suggested by MacMillan and Creelman (1991) and the data transformations of Snodgrass and Corwin (1988). Analysis of bias and sensitivity helped to determine if the accuracy of the participants was due to a response strategy of the participants (response bias) or difficulty discriminating between old and new stimuli (sensitivity) (Macmillan & Creelman, 2005). Without comparison to signal detection data, accuracy data can be misleading. For example, if the participants were found to
have a very high hit rate the use of accuracy data alone would lead to the conclusion that
accuracy was high. In such a case, analysis of sensitivity and response bias might indicate
that the high accuracy was due to a tendency to classify all items as old items (Macmillan
& Creelman, 2005). Between and within groups analyses of sensitivity were conducted
using a repeated measures ANOVA to determine if sensitivity changed within and
between each group due to the semantic manipulations of each condition. For response
bias, on the other hand, only between groups comparisons were made.

3 Results

Investigation of the standardised residuals of the accuracy and signal detection
data revealed positively skewed data and as a result, the square root of all data was taken
as recommended by Box and Cox (1964). Subsequent analysis of standardised residuals
revealed normally distributed data and therefore all subsequent analyses were calculated
using the square root of the original data. The means and standard deviations reported for
accuracy and signal detection are in their original form.

3.1 Accuracy

Means and standard deviations for the hit rates and false alarm rates for control
participants and participants with AD can be found in Table 4. A t-test was conducted to
compare hit rates between the AD and Control groups. Participants with AD had a
significantly lower hit rate than control participants \[t(11) = -2.39, p = 0.036\].

Analysis of the false alarm data with repeated measures ANOVA revealed a
significant effect of both group \[F(1, 32) = 32.343, p < 0.001\] and condition \[F(3, 96) =
100.217, p < 0.001\]. A two-way interaction between group and condition \[F(3, 96) =
11.876, p < 0.001\] was also found, justifying post-hoc analysis of false alarm rate
between and within groups. Due to the large number of post-hoc comparisons, a
Bonferroni adjustment was applied as described by Keppel (1991), which changed $\alpha$ from
$\alpha = 0.05$ to $\alpha = 0.0094$ for all comparisons.

Between groups analyses revealed that participants with AD had significantly
higher false alarm rates than control participants for the distinctively different, semantic
and unrelated conditions (see Table 4). No significant difference was found between
control participants and participants with AD for the non-distinctive condition.

Within the control group, there was a significant difference between most
conditions (see Table 5); the false alarm rate of the non-distinctive condition was
significantly higher than that of the distinctively different, semantic and unrelated
conditions. The false alarm rate of the distinctive condition was significantly higher than
the false alarm rate of the semantic and unrelated conditions. There was no significant
difference between the false alarm rate of the semantic condition and the unrelated
condition.

For participants with AD (see Table 5), the false alarm rate of the non-distinctive
condition was significantly higher than the false alarm rate of the semantic and unrelated
conditions. The false alarm rate of the distinctive condition was also significantly higher
than the unrelated condition. A higher false alarm rate was found for the distinctive
condition than the semantic condition, which was approaching significance. There was no
significant difference between the false alarm rate of the distinctive and non-distinctive
conditions or the semantic and unrelated conditions.

[Insert Table 4 about here]

[Insert Table 5 about here]
3.2 Signal Detection

Means and standard deviations for the control group and AD group for sensitivity and response bias are presented in Table 6.

3.2.1 Sensitivity

Repeated measures ANOVA revealed a main effect of condition \([F(3, 96) = 101.817, p < 0.001]\) and group \([F(1, 32) = 25.232, p < 0.001]\) with a significant two-way interaction between group and condition \([F(3, 96) = 7.796, p < 0.001]\).

Post-hoc analyses were conducted through a series of t-tests. Due to the large number of post-hoc comparisons, a Bonferroni adjustment was applied as described by Keppel (1991) which changed \(\alpha\) from \(\alpha = 0.05\) to \(\alpha = 0.0094\).

Between groups analysis revealed that controls had significantly higher sensitivity scores than participants with AD for the non-distinctive, distinctive, semantic and unrelated conditions (see Table 6).

Within the control group, sensitivity varied significantly between all conditions (see Table 7). Sensitivity for the non-distinctive condition was significantly lower than that of the distinctively different, semantic and unrelated conditions. Sensitivity for the distinctive condition was significantly lower than sensitivity for the semantic and unrelated conditions and the sensitivity for the semantic condition was significantly lower than the sensitivity for the unrelated condition.

Within the AD group, sensitivity for the non-distinctive condition was significantly lower than the sensitivity for the unrelated condition (see Table 7). Sensitivity for the non-distinctive condition was lower than the semantic condition, and was approaching significance. The sensitivity for the distinctive condition was
significantly lower than sensitivity for the unrelated condition. There was no significant difference between sensitivity for the distinctive and non-distinctive conditions, distinctive and semantic conditions or the semantic and unrelated conditions.

3.2.2 Response bias

Between groups comparisons were made for response bias using a series of paired samples t-tests. Due to the small number of planned comparisons the Bonferroni adjustment was not required. There was a significant difference between the response bias of controls and participants with AD for the unrelated condition with participants with AD using a more liberal response bias than controls (see Table 6). There was no significant difference between the response bias of controls and participants with AD for the non-distinctive, distinctive or semantic conditions.

[Insert Table 6 about here]

[Insert Table 7 about here]

4 Discussion

The present study used a novel version of the yes-no recognition memory task to investigate semantic content loss in AD. Overall, the AD group performed more poorly than the control group. As was predicted, participants with AD showed differential loss of distinctive features as evidenced by an equivalent false alarm rate for the non-distinctive feature condition, but significantly higher false alarm rate for the distinctive feature condition, relative to the control group. These results could not be accounted for by response bias which was not significantly different between groups for these conditions.

Between groups analysis of hit rate and false alarm rate demonstrated that, overall, participants with AD had lower accuracy than control participants. However, the
performance of control participants and participants with AD was comparable in some respects. Looking first at the identical condition and unrelated condition, the two mandatory conditions of the yes-no recognition task (Macmillan & Creelman, 2005), accuracy above 60% (hit rate above 0.60 and false alarm rate below 0.40) is considered to be above basal performance (Christensen et al., 1998) and therefore demonstrates the ability to complete the task. Participants with AD had a lower hit rate and higher false alarm rate for unrelated new items than control participants but, for both groups, these rates were above basal performance. This result is consistent with reports in the literature that although performance on the yes-no recognition memory task is impaired for people with AD, the task is within their cognitive abilities (Daum et al., 1996). Therefore, differences in performance observed between the two groups can not be explained by a general inability of the AD group to perform the task.

Between groups analyses of false alarm rates revealed that participants with AD had higher false alarm rates than control participants for the distinctive condition but not for the non-distinctive condition. With response bias being equal between groups for both these conditions, the differences between groups for the processing of distinctive and non-distinctive features are not the result of a differing response strategy (Macmillan & Creelman, 2005). These results suggest, as predicted, that participants with AD had difficulty, relative to controls, processing distinctive semantic features but not with processing non-distinctive semantic features. These findings are consistent with semantic content disturbance due to the progressive loss of semantic features with distinctive semantic features being the most vulnerable to loss (Almor et al., 2009; Done & Gale, 1997; Garrard et al., 2005). These results are also consistent with previous investigations
which have used word based tasks such as feature listing and verification, naming and priming (Almor et al., 2009; Done & Gale, 1997; Garrard et al., 2005; Laisney et al., 2011; Rogers & Friedman, 2008). The present experiment added to this growing body of evidence through the direct manipulation of semantic feature information without reliance on verbal performance.

Worthy of note is that since distinctive features are central to object identification, items in the distinctive condition could be classed as non-real objects (Cree, McNorgan, & McRae, 2006; Done & Gale, 1997). The task of deciding if items in the distinctive condition during the test phase were identical to items in the study phase may have been aided by deciding if the items were ‘non-objects’. Hence, the cognitive demands for the distinctive condition may have been lower than the other conditions in the experiment. Despite this, the AD group still demonstrated the weakest performance on this condition, strengthening our interpretation that participants with AD have difficulty processing distinctive semantic features relative to control participants.

Unlike the accuracy analysis, where false alarm rate was not significantly different between groups for the non-distinctive condition, participants with AD had significantly lower sensitivity than the control group for the non-distinctive condition. This finding does not necessarily undermine the accuracy analysis as sensitivity is dependent on both the hit rate and false alarm rate such that as the hit rate decreases, so too does sensitivity (Macmillan & Creelman, 2005). The hit rate was significantly lower for the AD group than the control group, whilst the false alarm rate was not significantly different between the two groups for the non-distinctive condition. Therefore, the difference in sensitivity between the two groups for the non-distinctive condition is the
result of the difference in the hit rate. For the remainder of the between groups comparisons, sensitivity was significantly lower for the AD group. Previous studies have also reported that sensitivity is generally lower for AD than controls in yes-no recognition memory tasks (Budson, Wolk, Chong, & Waring, 2006; Snodgrass & Corwin, 1988).

Within the control group, the false alarm rate for the non-distinctive condition was significantly higher than the false alarm rate for the distinctive condition. Similarly, sensitivity was lower for the non-distinctive condition than the distinctive condition. This pattern of performance reflects the differential roles of non-distinctive and distinctive semantic feature information in semantic representation. Previous research has reported that distinctive features play a more significant role in differentiating between concepts than non-distinctive features (Cree et al., 2006; Tyler, Moss, Durrant-peatfield, & Levy, 2000). The present investigation supported this finding as evidenced by control participants being more likely to confuse new items as old when non-distinctive features were changed than when distinctive features were changed.

Within the AD group, unlike the control group, there was no significant difference between the false alarm rate of the non-distinctive condition and the distinctive condition, nor was there a significant difference in sensitivity for these conditions. This pattern of results is consistent with disturbance to semantic content in AD. As participants with AD were equally likely to confuse new items from the non-distinctive and distinctive conditions with old items, these participants, unlike control participants, must not have been sensitive to the distinctive feature changes. This observation could be explained by the loss of semantic feature information, in particular, distinctive semantic features. If cognitive deficits could explain the pattern of performance within the AD group, false
alarm rates would be significantly lower for the distinctive than the non-distinctive condition because, as discussed earlier, the cognitive demands of the distinctive condition may have been lower. However, this explanation is incompatible with the between groups analysis which has shown that participants with AD performed as well as control participants on the non-distinctive condition but more poorly on the distinctive condition; a finding that would suggest that the cognitive demands of the non-distinctive condition were lower than the distinctive condition. Therefore, the loss of semantic content provides a more consistent explanation for the within groups results than the loss of semantic process only.

In the present study, the Control group and AD group did not have significantly different false alarm rates for the semantic and unrelated conditions. This finding is consistent with previous studies for the AD group but not the Control group (Balota, Cortese, & Duchek, 1999; Budson et al., 2000; Roediger & McDermott, 1995; Westerberg & Marsolek, 2003). For control participants, previous studies have found increased false alarm rates for test items semantically related to items in the study phase relative to unrelated items. It is reasoned that false alarm rates should be higher for semantically related stimuli (either category coordinates or associates) than unrelated stimuli due to spreading activation effects (Roediger & McDermott, 1995; Westerberg & Marsolek, 2003). However, it should be noted that previous yes-no recognition experiments have reported that there was no gap between study and test phases (Balota et al., 1999; Budson et al., 2000; Roediger & McDermott, 1995; Westerberg & Marsolek, 2003), whereas a 10 minute gap was used in the present study. Since semantic priming can be reduced by time and intervening trials (Dannenbring & Briand, 1982), it is
possible that the gap between study and test phases reduced semantic priming effects for the control group and prevented a higher false alarm rate for the semantic condition than the unrelated condition. The 10 minute gap between study and test may also explain the lack of difference in false alarm rate between the semantic and unrelated conditions for the AD group, although previous yes-no recognition memory studies have reported that for participants with AD, false alarm rate does not increase for semantically related items compared to unrelated items (Balota et al., 1999; Budson et al., 2000).

### 4.2 Semantic Content Loss and Grounded Models

In finding evidence to support the loss of semantic content in AD, the results of this study are consistent with grounded modeling of the semantic system. According to grounded models, the semantic system is represented as a distributed network of semantic information (perceptual symbols/semantic features) throughout the sensory and motor areas of the brain (Barsalou, 1999; Pulvermuller, 1999). Disturbance to sensory areas of the brain will result in perceptual symbol/semantic feature loss or disruption to interconnections between these meaning units (Barsalou, 1999; Pulvermuller, 1999). By Barsalou’s (1999) perceptual symbol systems model, the integration of semantic features into concepts (simulation) involves a number of cognitive processes such as attention and memory. By this reasoning, semantic disturbance observed in AD involves both cognitive/semantic process impairment and the progressive loss of semantic information caused by lesions throughout the sensory and motor areas of the brain (Done & Gale, 1997; Done & Hajilou, 2005). As a result, grounded models would predict, as observed in this experiment, that participants with AD would have difficulty processing semantic features relative to control participants. As shown in computer simulations and as
expected from Hebbian learning, grounded models propose that non-distinctive features are less vulnerable to loss than distinctive features due to their greater intercorrelation and stronger synaptic links between non-distinctive features (Done & Gale, 1997; Pulvermuller, 2001; Ursino et al., 2011). Therefore, grounded models, such as Barsalou’s (1999) perceptual symbol systems provide a comprehensive explanation for the performance of the AD group in processing distinctive and non-distinctive features.

An alternative group of models of the semantic system which would also predict semantic feature loss in AD are the hub and spoke models. One such model is the sparse representation model of Reilly and Peelle (2008), which suggests that the semantic system contains a central semantic store holding stripped-down abstract amodal representations of concepts which are able to index perceptual details/semantic feature information of a concept. The central amodal store is located in the temporal cortex whereas perceptual details/semantic feature information is stored in cortical regions involved in sensorimotor processing (Reilly & Peelle, 2008). Since sensorimotor regions of the brain are damaged in AD, feature loss is expected (Reilly et al., 2011). The ability to index perceptual details/semantic feature information involves semantic control which, in the case of AD, is generally compromised, and therefore, these deficits also contribute to semantic disturbance (Reilly et al., 2011). In the present experiment, the sparse representation model would also predict that participants with AD should have difficulty processing semantic features relative to control participants. Although the results of the present study are consistent with grounded models such as perceptual symbol systems, the results cannot rule out the possibility of co-occurring amodal representation as described by proponents of hub and spoke models.
4.3 Conclusions and Future Directions

The present study provided evidence of semantic content loss in AD. A novel paradigm based upon the yes-no recognition memory task was developed where semantic features of picture stimuli were altered between study and test. The cognitive demands of the task were kept as low as possible so that overall performance was comparable between control participants and participants with AD. The key finding was that there was no significant difference between control participants and participants with AD when non-distinctive features were altered between study and test, but a significant difference was found between groups when distinctive features were altered. The findings suggest that AD involves the loss of semantic content and process, not just semantic process alone. The methodology developed for this experiment would be applicable to the study of other clinical populations that experience semantic disturbance to investigate the occurrence and impact of semantic feature loss.
Acknowledgements

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Disclosure Statement

The authors of this investigation have no conflicts of interest to disclose.

Role of Sponsor

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References


Table 1: Results of Neuropsychological Assessments for Individual AD Participants and Means for the AD and Control Groups

<table>
<thead>
<tr>
<th>Assessment</th>
<th>AD Participants</th>
<th>AD Group Mean</th>
<th>Control Group Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M (standard deviation)</td>
<td>M (standard deviation)</td>
<td></td>
</tr>
<tr>
<td>BNT (maximum score: 60)</td>
<td>44 48 57 43 58</td>
<td>7 3 44 47 29</td>
<td>50 2 6 8 6</td>
</tr>
<tr>
<td>PPT (Maximum Score: 52)</td>
<td>49 47 47 49 50</td>
<td>1 5 42 49 48</td>
<td>5 5 6 0 0</td>
</tr>
<tr>
<td>RBANS (Average Range: 85-115)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Immediate Memory</td>
<td>65 73 90 90 76</td>
<td>1 53 78 57 65</td>
<td>0 87 8 73</td>
</tr>
<tr>
<td>Visuospatial/Constructional</td>
<td>66 92 5 9 2</td>
<td>2 50 78 58 66</td>
<td>0 50 96 84</td>
</tr>
<tr>
<td>Language</td>
<td>71 86 3 92 96</td>
<td>7 78 82 44 92</td>
<td>0 46 26 15</td>
</tr>
<tr>
<td>Attention</td>
<td>6 12 11 0</td>
<td>86.9 23. 106. 11.</td>
<td></td>
</tr>
<tr>
<td>Delayed Memory</td>
<td>91 88 2 97 5</td>
<td>3 53 72 72 56</td>
<td>0 45 17 61</td>
</tr>
<tr>
<td>BORB Minimal Feature Match (Average Range: 18.5-25)</td>
<td>24 24 24 25 25</td>
<td>2 2 21 22 18 25</td>
<td>23.2 2.5 24.8 0.4</td>
</tr>
<tr>
<td>Foreshortened Match (Average Range: 16.5-25)</td>
<td>24 25 23 25 25</td>
<td>2 2 22 23 18 21</td>
<td>22.9 2.0 24.5 0.6</td>
</tr>
<tr>
<td>Object Decision (A:Hard) (Average Range: 22-30)</td>
<td>25 15 18 24 28</td>
<td>2 2 24 22 22 20</td>
<td>22.9 4.0 27.0 2.0</td>
</tr>
<tr>
<td>MMSE</td>
<td>28 25 29 28 28</td>
<td>8 8 20 29 18 28</td>
<td>7 7 3 1</td>
</tr>
<tr>
<td>NART (Average Range: 85-115)</td>
<td>10 99 11 11 1</td>
<td>9 10 11 99 118</td>
<td>107. 8.2 114. 5.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
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</tr>
<tr>
<td>6</td>
<td>6</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Verbal IQ</td>
<td>10</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>6</td>
<td>99</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Performance IQ</td>
<td>10</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

*Note.* Participant 6 did not complete the RBANS on account of time constraints.
<table>
<thead>
<tr>
<th>Condition</th>
<th>Description</th>
<th>Semantic Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identical</td>
<td>‘Old items’ such that the picture is identical between study and test phase. Accuracy measured as hit rate. (15 Trials)</td>
<td>Biological Kinds 10</td>
</tr>
<tr>
<td>Non-Distinctive</td>
<td>Items that appeared in the study phase and had a non-distinctive featured altered before appearing in the test phase (e.g. a washing basket changing colour between study and test phase). Feature changes included manipulation of size, colour and orientation and were not distinctive features according to McRae et al. (2005). Accuracy measured as false alarm rate. (15 Trials)</td>
<td>Biological Kinds 2</td>
</tr>
<tr>
<td>Distinctive</td>
<td>Items that appeared in the study phase and had a distinctive featured altered (as classified by McRae et al. (2005)) before appearing in the test phase. Examples include an elephant having its trunk removed, a coconut changing colour from brown to green and bolt losing its thread between study and test phases. Accuracy measured as false alarm rate. (15 Trials)</td>
<td>Biological Kinds 4</td>
</tr>
<tr>
<td>Semantic</td>
<td>Items that appeared in the study and test phase that were category co-ordinates (e.g. a cat in the study phase and a dog in the test phase). Accuracy measured as false alarm rate. (15 Trials)</td>
<td>Biological Kinds 7</td>
</tr>
<tr>
<td>Unrelated</td>
<td>‘New Items’ where no relationship exists between items in the study and test phase. Accuracy measured as false alarm rate. (60 Trials)</td>
<td>Biological Kinds 21</td>
</tr>
</tbody>
</table>
Table 3
Normative Data of Stimuli

<table>
<thead>
<tr>
<th>Phase</th>
<th>Condition</th>
<th>Parameter</th>
<th>Study</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Name Agreement</td>
<td>0.83 (0.17)</td>
<td>0.83 (0.17)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Image Agreement</td>
<td>3.94 (0.63)</td>
<td>3.94 (0.63)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Visual Complexity</td>
<td>2.72 (0.81)</td>
<td>2.72 (0.81)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Familiarity</td>
<td>3.09 (0.81)</td>
<td>3.09 (0.81)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frequency</td>
<td>0.58 (0.57)</td>
<td>0.58 (0.57)</td>
</tr>
<tr>
<td>Study</td>
<td>Identical</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Non-Distinctive</td>
<td></td>
<td>0.80 (0.21)</td>
<td>0.80 (0.21)</td>
</tr>
<tr>
<td></td>
<td>Distinctive</td>
<td></td>
<td>0.87 (0.17)</td>
<td>0.87 (0.17)</td>
</tr>
<tr>
<td></td>
<td>Semantic</td>
<td></td>
<td>0.78 (0.27)</td>
<td>0.78 (0.27)</td>
</tr>
<tr>
<td>Test</td>
<td>Identical</td>
<td></td>
<td>0.83 (0.17)</td>
<td>0.83 (0.17)</td>
</tr>
<tr>
<td></td>
<td>Non-Distinctive</td>
<td></td>
<td>0.80 (0.21)</td>
<td>0.80 (0.21)</td>
</tr>
<tr>
<td></td>
<td>Distinctive</td>
<td></td>
<td>0.87 (0.17)</td>
<td>0.87 (0.17)</td>
</tr>
<tr>
<td></td>
<td>Semantic</td>
<td></td>
<td>0.69 (0.22)</td>
<td>0.69 (0.22)</td>
</tr>
<tr>
<td></td>
<td>Unrelated</td>
<td></td>
<td>0.82 (0.24)</td>
<td>0.82 (0.24)</td>
</tr>
</tbody>
</table>

*Note.* Frequency values are to be divided by 100 000; Standard deviations in brackets.
### Table 4

*Hit and False Alarm Rates for the Control and AD Group for Each Experimental Condition*

<table>
<thead>
<tr>
<th>Group</th>
<th>Old Items (Hit Rate)</th>
<th>New Items (False Alarm Rate)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Identical</td>
<td>Non-Distinctive</td>
<td>Distinctive</td>
</tr>
<tr>
<td>Control</td>
<td>0.96 (0.07)</td>
<td>0.56 (0.19)</td>
<td>0.37 (0.19)</td>
</tr>
<tr>
<td>AD</td>
<td>0.83 (0.17)</td>
<td>0.68 (0.22)</td>
<td>0.60 (0.18)</td>
</tr>
<tr>
<td>p value</td>
<td>0.036</td>
<td>0.189</td>
<td>0.003</td>
</tr>
</tbody>
</table>

*Note.* Standard deviations in brackets. Reported p values are based on between group pair-wise comparisons.
Table 5

*Planned Pair-wise Comparisons for Within Groups False Alarm Rates*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Control Group</th>
<th></th>
<th></th>
<th>AD Group</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t statistic</td>
<td>p value</td>
<td>t statistic</td>
<td>p value</td>
<td></td>
</tr>
<tr>
<td>Non-Distinctive x Distinctive</td>
<td>6.64</td>
<td>&lt; 0.001</td>
<td>1.27</td>
<td>0.233</td>
<td></td>
</tr>
<tr>
<td>Non-Distinctive x Semantic</td>
<td>14.28</td>
<td>&lt; 0.001</td>
<td>3.59</td>
<td>0.005</td>
<td></td>
</tr>
<tr>
<td>Non-Distinctive x Unrelated</td>
<td>24.40</td>
<td>&lt; 0.001</td>
<td>4.51</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>Distinctive x Semantic</td>
<td>10.15</td>
<td>&lt; 0.001</td>
<td>3.14</td>
<td>0.010</td>
<td></td>
</tr>
<tr>
<td>Distinctive x Unrelated</td>
<td>17.87</td>
<td>&lt; 0.001</td>
<td>3.37</td>
<td>0.007</td>
<td></td>
</tr>
<tr>
<td>Semantic x Unrelated</td>
<td>2.23</td>
<td>0.037</td>
<td>0.15</td>
<td>0.162</td>
<td></td>
</tr>
</tbody>
</table>

*Note.* Reported p values are based on within group pair-wise comparisons.
Table 6
Signal Detection Results for the Control and AD Groups

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group</th>
<th>Hit Rate vs. Non-Distinctive</th>
<th>Hit Rate vs. Distinctive</th>
<th>Hit Rate vs. Semantic</th>
<th>Hit Rate vs. Unrelated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>Control</td>
<td>1.37 (0.64)</td>
<td>1.90 (0.66)</td>
<td>2.92 (0.68)</td>
<td>3.50 (0.60)</td>
</tr>
<tr>
<td></td>
<td>AD</td>
<td>0.51 (0.87)</td>
<td>0.76 (0.98)</td>
<td>1.38 (1.11)</td>
<td>1.65 (1.19)</td>
</tr>
<tr>
<td>p value</td>
<td></td>
<td>0.003</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Response Bias</td>
<td>Control</td>
<td>-0.89 (0.31)</td>
<td>-0.63 (0.31)</td>
<td>-0.12 (0.27)</td>
<td>0.17 (0.27)</td>
</tr>
<tr>
<td></td>
<td>AD</td>
<td>-0.77 (0.50)</td>
<td>-0.65 (0.35)</td>
<td>-0.34 (0.28)</td>
<td>-0.20 (0.40)</td>
</tr>
<tr>
<td>p value</td>
<td></td>
<td>0.382</td>
<td>0.963</td>
<td>0.070</td>
<td>0.007</td>
</tr>
</tbody>
</table>

Note. Standard deviations in brackets. Reported p values are based on between group pair-wise comparisons.
Table 7
Planned Pair-wise Comparisons for Within Groups Sensitivity

<table>
<thead>
<tr>
<th>Condition</th>
<th>Control Group</th>
<th>AD Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t Statistic</td>
<td>p value</td>
</tr>
<tr>
<td>Non-Distinctive x Distinctive</td>
<td>-6.38</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Non-Distinctive x Semantic</td>
<td>-15.16</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Non-Distinctive x Unrelated</td>
<td>-22.40</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Distinctive x Semantic</td>
<td>-10.89</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Distinctive x Unrelated</td>
<td>-19.45</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Semantic x Unrelated</td>
<td>-5.69</td>
<td>0.001</td>
</tr>
</tbody>
</table>

*Note. Reported p values are based on within group pair-wise comparisons.*

**Highlights**

- The loss of semantic content as a contributing factor to semantic disturbance in Alzheimer’s disease (AD) is debated in the literature.
- The present investigation reports a novel paradigm for testing semantic feature loss in AD and healthy aging.
- Results indicated no difference between control and AD group processing non-distinctive semantic features.
- A significant difference was found between control and AD for the processing of distinctive semantic features.