Effects of Graded Levels of Physical Similarity and Density on Visual Selective Attention in Patients With Alzheimer’s Disease

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A multitarget visual cancellation test was administered to patients with Alzheimer’s disease (AD) and age-matched healthy controls (HC). Attentional loads—physical similarity (number of features shared by target and distractors; 3 levels) and density (number of items per page; 3 levels)—were varied systematically. As physical similarity increased, both groups slowed their search, but whereas the HC group maintained accuracy, the AD group increased commission errors and tended to miss more targets. Increased density yielded slower search and more target omissions in the AD group. Commission errors are additional indicators of higher order attentional deficits, especially in early disease. The findings suggest that patients with AD may rely increasingly on physical features of stimuli during a search, leading to inefficient bottom-up processing strategies.

Impairment of visual selective attention in Alzheimer’s disease (AD) was not initially recognized as a criterion for diagnosis of the disease (American Psychiatric Association, 1987) but has since been acknowledged as a compromised area in the AD cognitive profile (Baddeley, Baddeley, Bucks, & Wilcock, 2001; Della Sala, Laiacona, Spinnler, & Ubezio, 1992; Foster, 2001; Parasuraman, Greenwood, Haxby, & Grady, 1992; Parasuraman & Haxby, 1993; Perry & Hodges, 1999, 2003). Many of the selective attention deficits in AD have been identified in relatively controlled, timed visual search experiments (e.g., Perry & Hodges, 1999), as well as in cancellation tasks (Della Sala et al., 1992; Foldi, Jutagir, Da- vidoff, & Gould, 1992; Gainotti, Marra, & Villa, 2001; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994), which offer ease of administration in clinical settings. Despite the evidence that selective attention deficits are prominent in AD (Parasuraman & Greenwood, 1998), clinical assessment of such attentional functions is relatively underutilized. Sensitive attentional measures could serve as markers of early cognitive and functional decline (Perry, Watson, & Hodges, 2000), or, as the cholinergic system is involved in the mediation of attentional function (Lawrence & Sahakian, 1995), attentional measures could serve as response indicators to cholinergic treatment.

The success of selective attention depends on available attentional resources and varies as a function of load (Lavie, 1995; Lavie & Tsal, 1994). One explanation of the disproportionate deficit in AD patients compared with controls is that the disease diminishes the available capacity of attentional resources, with the consequence that high load tasks become more vulnerable. This has been demonstrated in AD on tasks of divided attention (Baddeley et al., 2001; Baddeley, Bressi, Della Sala, Logie, & Spinnler, 1991; Parasuraman & Greenwood, 1998) and is also shown by the distinction between disjunctive and conjunctive search tasks. These tasks, according to the feature integration theory (Treisman & Gelade, 1980; Treisman & Sato, 1990), differ on load demands. A disjunctive target has a unique identifying feature that “pops out” from surrounding stimuli (e.g., a red item surrounded by blue items). A disjunctive search is considered preattentive, placing minimal demands on resources; target detection is not influenced by increasing the number of distractors (i.e., load). Disjunctive tasks remain intact in AD, at least during the early phase of the disease (Greenwood, Parasuraman, & Alexander, 1997; Higgins,
Grande, McGlinchey-Berroth, & Milberg, 2002). In contrast, targets in a conjunctive search (Treisman & Sato, 1990) share features with distractors (e.g., a red circle surrounded by red squares and blue circles) and may be detected only by serially searching other competing stimuli; this requires subjects to deploy more resources. Patients with AD are disproportionately affected on conjunctive searches compared to controls, and increased load (i.e., array size) results in their detecting significantly fewer targets (Baddeley et al., 2001; Foldi et al., 1992; Foster, 2001; Foster, Behrmann, & Stuss, 1999) or making responses with longer latencies (Foster et al., 1999; Nebes & Brady, 1989).

Perceptual discrimination of visually similar stimuli is another type of load, and although it has been shown to affect search efficiency in healthy participants (Norman & Bobrow, 1975; Stuart-Hamilton, Rabbitt, & Huddy, 1988), its effect in AD remains unclear. Much like a disjunctive search, physically distinct stimuli that stand out from the surround easily capture attentional interest and use minimal attentional resources (Duncan & Humphreys, 1989). But, as a target becomes less distinct from surrounding stimuli, more attentional resources must be recruited to detect it. Therefore, increasing perceptual demands, by increasing the physical similarity between stimuli, should also tax the attentional resources in patients with AD performing a conjunctive search.

There is an additional reason to explore the role of physical similarity in selective search in AD: Individuals with the disease may have to rely more on physical discrimination in order to perceive and understand their visual environment. That is, their available search strategies may differ from those of healthy counterparts. In line with Wolfe’s theory of guided search (Chun & Wolfe, 2000; Wolfe, 1994), perceptual search in healthy adults is facilitated by means of top-down processing strategies. Such top-down guided strategies (Bacon & Egeth, 1997; Wolfe, Friedman-Hill, Steward, & O’Connel, 1992) enable individuals to search more efficiently by drawing on a set of criteria (e.g., internal representations, prior instructions). In contrast, bottom-up strategies depend on less efficient feature-based physical discrimination. Each strategy, top-down or bottom-up, could be used alone, but more likely, healthy subjects flexibly alternate both strategies to meet the demands of the situation (Wolfe, 2003). Patients with AD may be disadvantaged in their ability to draw on top-down mechanisms because of different or impaired access to semantic representations (Glosser, Friedman, Grugan, Lee, & Grossman, 1998; Hodges, Salmon, & Butters, 1992; Monsch et al., 1992), or because of poorer ability to draw on frontally mediated organizing instructions to guide a search. In turn, this may force patients to rely more on bottom-up processing strategies. Thus, physically similar stimuli would be particularly disruptive. The influence of perceptual features in a cancellation task was incidentally observed in patients with AD when they were required to cancel target shapes (circles and diamonds) distributed among other shapes (ovals, triangles, and squares; Foldi et al., 1992). Although the total number of cancelled distractors did not significantly differ from that in a control group, the patients showed a pattern of canceling those distractors that shared some feature (e.g., an arc or an acute corner) with the intended target. This suggested that patients were using a search strategy reliant on feature analysis.

Research has shown that challenging perceptual discrimination tasks do tax attentional resources in healthy young participants (Hammar, Hugdahl, Lund, Asbjornsen, & Roness, 1998) and in healthy older participants (Gilmore, Tobias, & Royer, 1985; Maylor & Lavie, 1998; Scialfa, Esau, & Joffe, 1998; Scialfa & Harpur, 1994); patients with focal frontal lesions (Stuss, Binns, Murphy, & Alexander, 2002) are especially vulnerable, implicating increased susceptibility of frontal mechanisms. In AD, several search studies have investigated the effects of similar perceptual features. Stuart-Hamilton and colleagues (1988) reported that participants with AD missed more targets than controls in a search when stimuli shared similar outlines (e.g., a fish and an oval). Zazzo (cited in Amieva, Lafont, Dartigues, & Fabrigoule, 1999) and Gainotti and colleagues (2001) used cancellation tasks requiring identification of multiple targets. The stimuli in both of these studies were arrays of boxes with added internal or external lines. Both studies demonstrated that patients with AD not only cancelled fewer targets (i.e., hits) with longer response latencies than controls, but they also made higher numbers of false positive commission errors, which were hypothesized to reflect compromised inhibitory mechanisms. This inability of patients with AD to resist nontarget items was highlighted by Baddeley and colleagues (2001). Experiment 2 of their series tested the influence of physical similarity in a search by requiring healthy participants and AD patients to search for a target letter Z distributed among similar letters with straight lines, or among dissimilar letters with predominantly curved lines. The patient group, particularly the more severely demented patients, missed more targets and responded with longer response times when the target Z was surrounded by similar, as opposed to dissimilar, letters. Although false alarm errors were rare, Baddeley and colleagues suggested that the inability to resist interference in AD was more demonstrable when distractors with similar features surrounded a target.

The stimuli used in many of these experiments have varied in terms of meaningfulness and familiarity, which could promote a top-down approach to managing target search. One study showed that when stimuli are more familiar (particularly the distractors), accuracy of target detection improves (Wang, Cavanagh, & Green, 1994). Familiar items could thus serve to reduce the attentional resources needed to perform a search, compared to a search based predominantly on features or bottom-up integration. Familiar stimuli such as letters (Baddeley et al., 2001), drawings of objects such as the fish and the oval (Stuart-Hamilton et al., 1988), or common geometric shapes (Foldi et al., 1992) may have facilitated the search patients with AD because these stimuli have preexisting internal representations. To understand the effect of physical similarity independent of internal representation, it would be important, therefore, to minimize the meaningfulness of stimuli. It should be noted that although nonfamiliar stimuli were used by other investigators (e.g., box designs; Amieva et al., 1999; Gainotti et al., 2001), these studies did not vary the degree of similarity between targets and distractors.

The current study was designed to investigate the effect of physical similarity on selective search using unfamiliar, nonmeaningful stimuli across graded levels of similarity between targets and distractors. Three hypotheses were posited. The first was that although demand on attentional resources would vary directly with physical similarity in both controls and patients with AD, patients would be disproportionately affected, with slower search times and increased omission and commission errors. We hypothesized that patients with AD would be compromised even when stimuli were perceptually quite different. We operationalized physical similarity
by applying the feature integration model (Treisman & Gelade, 1980). Similarity was manipulated by varying the number of features a distractor stimulus had in common with the target; the degree of similarity was ranked and rated in a pilot study (see http://dx.doi.org/10.1037/0894-4105.19.1.5 supp). The second hypothesis was that the AD participants, whose attentional resources are diminished, would be more affected than controls by the combined increase of the physical similarity among stimuli and of the density of the array. These two independent variables, physical similarity and density, were each increased in an ordinal stepwise fashion with three levels of load (1 = low level, 2 = mid level, and 3 = high level). If both types of load tax capacity, then the interaction of increased density and physical similarity of items in a visual array should place more demands on the available attentional resources. In the third hypothesis, we addressed severity of disease, expecting that greater severity would compromise selective search skills in response to increased load. Moreover, we were especially interested in identifying measures of attentional deficits that might occur early in the course of the disease and could be used to differentiate high-functioning patients from controls; we predicted that commission errors would be such a sensitive indicator.

Method

Participants

Thirty-six participants took part in the study, 18 with probable AD (14 female) and 18 healthy controls (HC, 14 female), see Table 1. The AD group was recruited from patients of the Neuropsychology Service at Winthrop–University Hospital, Mineola, NY. All patients met National Institute of Neurological and Communication Disorders and Stroke–Alzheimer’s Disease and Related Disorders Association (McKhann et al., 1984) criteria for AD, established by interviews with the patient and a third party, medical and neurological examinations, full neuropsychology evaluations, laboratory screening, and structural imaging (computed tomography or magnetic resonance imaging), For inclusion, patients with AD met criteria of a Mini-Mental Status Examination (MMSE) score < 26/30 (Folstein, Folstein, & McHugh, 1975; Monsh et al., 1995) and/or Dementia Rating Scale (DRS) score < 130/144 (DRS, Mattis, 1988). At the time

Table 1

Demographic Characteristics and Performance on Neuropsychological Variables of Patients With Alzheimer’s Disease (AD) and Healthy Controls (HC)

<table>
<thead>
<tr>
<th>Demographics</th>
<th>AD (n = 18)</th>
<th>Range</th>
<th>HC (n = 18)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>74.56 (7.72)</td>
<td>55–83</td>
<td>74.16 (6.00)</td>
<td>64–86</td>
</tr>
<tr>
<td>Education (years)</td>
<td>13.11 (2.89)</td>
<td>8–19</td>
<td>14.38 (2.79)</td>
<td>8–20</td>
</tr>
<tr>
<td>Estimated time of diagnosis (months)</td>
<td>12.22 (11.64)</td>
<td>0–36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tests</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MMSE</td>
<td>22.11 (3.70)</td>
<td>12–27</td>
<td>28.89 (0.83)</td>
<td>27–30</td>
</tr>
<tr>
<td>DRS Total Score</td>
<td>119.22 (14.14)</td>
<td>79–137</td>
<td>140.44 (3.00)</td>
<td>133–144</td>
</tr>
<tr>
<td>DRS Attention</td>
<td>35.72 (1.36)</td>
<td>33–37</td>
<td>36.78 (0.55)</td>
<td>35–37</td>
</tr>
<tr>
<td>DRS Initiation and Perseveration</td>
<td>26.83 (6.94)</td>
<td>12–37</td>
<td>36.11 (1.50)</td>
<td>32–37</td>
</tr>
<tr>
<td>DRS Construction</td>
<td>5.06 (1.21)</td>
<td>2–6</td>
<td>5.83 (0.51)</td>
<td>4–6</td>
</tr>
<tr>
<td>DRS Conceptualization</td>
<td>35.39 (4.13)</td>
<td>23–29</td>
<td>37.39 (1.50)</td>
<td>33–39</td>
</tr>
<tr>
<td>DRS Memory</td>
<td>16.33 (3.77)</td>
<td>9–25</td>
<td>24.33 (1.08)</td>
<td>21–25</td>
</tr>
<tr>
<td>FAS</td>
<td>9.59 (5.07)</td>
<td>3–23</td>
<td>13.53 (4.01)</td>
<td>6–23</td>
</tr>
<tr>
<td>COWAT–Category Fluency</td>
<td>8.05 (3.65)</td>
<td>2–13</td>
<td>13.89 (2.60)</td>
<td>8–20</td>
</tr>
<tr>
<td>CVLT Trial 5</td>
<td>–2.22 (0.81)</td>
<td>–3 to –1</td>
<td>0.56 (0.85)</td>
<td>–1 to +2</td>
</tr>
<tr>
<td>CVLT SDR</td>
<td>–2.89 (0.68)</td>
<td>–4 to –1</td>
<td>0.28 (0.67)</td>
<td>–1 to +1</td>
</tr>
<tr>
<td>CVLT SDCR</td>
<td>–2.67 (0.91)</td>
<td>–4 to –1</td>
<td>–0.06 (0.94)</td>
<td>–1 to +1</td>
</tr>
<tr>
<td>CVLT LDRF</td>
<td>–2.78 (0.88)</td>
<td>–5 to –1</td>
<td>0.06 (0.87)</td>
<td>–1 to +1</td>
</tr>
<tr>
<td>CVLT semantic cluster</td>
<td>–1.00 (0.77)</td>
<td>–3 to 0</td>
<td>0.17 (0.92)</td>
<td>–1 to +2</td>
</tr>
<tr>
<td>CVLT serial cluster</td>
<td>0.56 (1.10)</td>
<td>–1 to +3</td>
<td>0.11 (0.90)</td>
<td>–1 to +2</td>
</tr>
<tr>
<td>CVLT correct recognition</td>
<td>–0.39 (1.35)</td>
<td>–4 to +1</td>
<td>0.22 (1.21)</td>
<td>–4 to +1</td>
</tr>
<tr>
<td>CVLT false positives</td>
<td>3.17 (2.01)</td>
<td>–1 to +5</td>
<td>0.06 (0.80)</td>
<td>–1 to +1</td>
</tr>
<tr>
<td>Trails–A (time in seconds)</td>
<td>64.27 (29.88)</td>
<td>27–118</td>
<td>41.11 (12.06)</td>
<td>23.61–63.08</td>
</tr>
<tr>
<td>Trails–B (time in seconds)</td>
<td>172.78 (95.86)</td>
<td>59–410</td>
<td>92.82 (44.06)</td>
<td>34.61–217.63</td>
</tr>
<tr>
<td>WAIS–III Digit Symbol (total items cancelled)</td>
<td>35.41 (15.15)</td>
<td>15–68</td>
<td>54.22 (12.53)</td>
<td>29.00–78.00</td>
</tr>
<tr>
<td>Boston Naming Test</td>
<td>39.50 (13.31)</td>
<td>9–56</td>
<td>50.50 (9.10)</td>
<td>36–59</td>
</tr>
<tr>
<td>WMS–R Digit Span forward</td>
<td>7.47 (1.84)</td>
<td>3–11</td>
<td>8.50 (1.79)</td>
<td>5–11</td>
</tr>
<tr>
<td>WMS–R Digit Span backward</td>
<td>5.06 (1.85)</td>
<td>2–9</td>
<td>7.00 (1.94)</td>
<td>4–10</td>
</tr>
<tr>
<td>WMS–R Visual Span forward</td>
<td>6.17 (1.65)</td>
<td>4–11</td>
<td>7.39 (1.33)</td>
<td>5–10</td>
</tr>
<tr>
<td>WMS–R Visual Span backward</td>
<td>4.33 (1.53)</td>
<td>2–7</td>
<td>6.78 (1.11)</td>
<td>5–9</td>
</tr>
</tbody>
</table>

Note. MMSE = Mini-Mental Status Examination; DRS = Dementia Rating Scale; CVLT = California Verbal Learning Test (First Edition; values listed as standard scores); SDFR = Short Delayed Free Recall; SDCR = Short Delayed Cued Recall; LDFR = Long Delayed Free Recall; LDCR = Long Delayed Cued Recall; FAS = Letter Word Generation (mean number of words in 60 s); COWAT = Controlled Oral Word Association Test (categories: fruit, vegetables, animals; mean number of words in 60 s); Trails = Trail Making Test; WAIS–III = Wechsler Adult Intelligence Scale (Third Edition); WMS–R = Wechsler Memory Scale—Revised Edition, Digit Span and Visual Span (maximum score).
of study, 9 patients with AD were on treatment with acetylcholinesterase inhibitors (8 on donepezil, 1 on galantamine), with a mean estimated disease duration of 12.22 months (see Table 1). One participant in the AD group, since deceased, had autopsy-confirmed AD. The HC participants, recruited from local senior centers or relatives of the patients with AD, met inclusion criteria of MMSE scores ≥ 26. Exclusion criteria for all participants included past history of neurologic or psychiatric disease, including alcohol abuse, head trauma, and concurrent use of pharmacologic treatment that could affect cognition (e.g., for cardiac, oncologic, or urinary incontinence). The screening scores differentiated the two groups: MMSE, t(34) = 7.67, p < .001; DRS, t(34) = 6.33, p < .001. Group means of age and education did not significantly differ (age, p = .87; education, p = .18).

The study was approved by Winthrop–University Hospital’s Institutional Review Board, and all participants gave informed consent prior to testing. The next of kin, caretaker, or legal guardian of AD participants also gave written consent.

Stimuli

Stimuli were created in a pilot study (see http://dx.doi.org/10.1037/0894-4105.19.1.5.supp). Experimental procedures were used to select a target stimulus with three equivalent sets of three distractors that were judged in terms of the degree of physical similarity to the target.

Disjunctive Search Tasks

Five cancellation tasks were presented on separate 8.5 × 11.0-in. (21.6 × 27.9-cm) sheets of paper to ensure that participants were able to perform a selective disjunctive search. The first task used colored stimuli (target = orange, distractors = green). The remaining tasks were presented as black line drawings with the target markedly different from a single type of distractor. The stimuli used in these tasks were not used in the experimental study but were drawn from unused items from the pilot test. These multiple cancellation tasks also served to get participants into task set.

Pretests

Two pretests assessed visual discrimination in nonsearch paradigms. The stimuli used in the pretests were developed for the pilot study (see http://dx.doi.org/10.1037/0894-4105.19.1.5.supp) but were not used in the experimental study. In Pretest 1, participants determined whether two stimuli were the same or different for 15 pairs of drawings. In Pretest 2, an odd-man-out task, participants determined which one of three stimuli was anomalous on 11 different sets.

Experimental Cancellation Tests

Eighteen cancellation tests using the target and distractor stimuli determined by the pilot study (see http://dx.doi.org/10.1037/0894-4105.19.1.5.supp) were created. Each cancellation test was presented on a separate 8.5 × 11.0-in. (21.6 × 27.9-cm) sheet of paper, containing the distractors and multiple instances of the same target. Each cancellation test was designed by manipulating physical similarity and density. Physical similarity (three levels) ranged from least similar (Level 1) to most similar (Level 3). (See Figure 1 on the Web at http://dx.doi.org/10.1037/0894-4105.19.1.5.supp.) Density (three levels) depended on the total number of stimuli in the array. The three levels of density were composed of targets (4, 8, or 12) and distractors (12, 24, or 36, respectively) resulting in total array sizes of 16, 32, and 48 stimuli per page. The target-to-distractor ratio remained constant at 1:3 across all levels of density. Equal numbers of targets and distractors were placed in the four visual quadrants. A description of the stimulus placement technique and an example of a cancellation test are shown in the supplemental information (see Figure 2 on the Web at http://dx.doi.org/10.1037/0894-4105.19.1.5.supp). A third variable, complexity (two levels), was included to ensure that the task was conjunctive; distractors from two or three distractor triads were included in the surround to avoid pop-out effects. For the purposes of this article, complexity is not discussed. An initial presentation order of the 18 tests was randomized; presentation sequence was counterbalanced by rotating the order for each participant to start at a different point.

Posttests

Two posttests, administered after the cancellation tasks, were equivalent to the same/different and odd-man-out pretests and used actual stimuli from the cancellation tests.

Neuropsychological Tests

In addition to the cancellation tests, all participants were administered a series of neuropsychological tests that was part of a larger clinical battery (see Table 1). These included the DRS (Mattis, 1988), MMSE (Folstein et al., 1975), California Verbal Learning Test (CVLT; Delis, Kramer, Kaplan, & Ober, 1987), Line Cancellation (Albert, 1973), Boston Naming Test (BNT; Kaplan, Goodglass, & Weintraub, 1983), FAS generative fluency measures (Spreen & Strauss, 1998; Stuss & Benson, 1986), Controlled Oral Word Association Test (COWAT; Benton & Hamsher, 1976), Wechsler Memory Scale—Revised (WMS–R) Digit Span and Visual Span subtests (Wechsler, 1987), Wechsler Adult Intelligence Scale—Third Edition (WAIS–III) Digit Symbol subtest (Wechsler, 1997), and Trails–A and Trails–B (Reitan & Wolfson, 1985).

Procedure

The study was conducted in a well-lit, quiet room. The presentation order remained consistent, with the pretests followed by the disjunctive tasks, experimental cancellation tests, and posttests. The AD patients were administered these tasks in a single session with breaks allowed when deemed necessary; neuropsychological tests were completed in a previous session. The HC participants completed the experimental cancellation and neuropsychological tests during a single session. During administration of the 18 cancellation tests, a picture of the target remained in the participant’s view to reduce reliance on memory. Before administration of each cancellation test, the examiner pointed to the target design and asked the participant to draw a line through that same design each time it occurred on the page, and to proceed as accurately and quickly as possible. Accuracy and completion time were recorded.

Experimental Design and Analyses

Analyses of the cancellation tests were conducted with repeated measures analyses of variance (ANOVA) with group (2 levels) as the between-subjects variable, and physical similarity (3 levels) × density (3 levels) × complexity (2 levels) as the within-subject variables. The ANOVAs were conducted on three dependent measures: omission errors, commission errors, and completion time. Omission and commission error scores were converted to proportions in order to compensate for the different numbers of stimuli present in the three array sizes (i.e., [number of missed targets ÷ total number of targets present] or [number of cancelled distractors ÷ total number of distractors present]). As reaction time data from clinical populations can be more variable (Chapman, Chapman, Curran, & Miller, 1994), and because variance is likely to increase with the longer completion times characteristic of patients with AD, our goal was to be confident that our interpretation of the ANOVA results on completion time truly reflected the underlying speed of processing in the AD and control groups. Completion time was calculated both on raw completion times (untransformed) and their logs (log base 10; transformed). Analyses
of skew and kurtosis were then performed for untransformed and transformed data to demonstrate the effect of the transformation. In the following sections, both transformed and untransformed completion time data are reported, and any discrepancies are discussed. All post hoc analyses for the ANOVAs were conducted by means of Tukey’s honestly significant difference test; p values of < .05 are reported as significant.

The effect of disease severity was investigated by dividing the AD patients into two subgroups, determined by a median split (MMSE = 22.00). As seen in Table 2, this resulted in a low-MMSE subgroup (n = 11, including 4 participants whose MMSE score was exactly 22) and a high-MMSE subgroup (n = 7). The subgroups differed on age, t(16) = 2.21, p = .04, with the high-MMSE group (M = 70.00 years, SD = 8.90) younger than the low-MMSE group (M = 77.45 years, SD = 5.44). The groups did not differ on education, t(16) = 0.52, p = .60, sex, \( \chi^2(1, N = 18) = 0.27, p = .62 \), or acetylcholinesterase inhibitor status, \( \chi^2(1, N = 18) = 0.23, p = .63 \).

In order to measure the relationship between the neuropsychological tests and the omission and commission errors from the cancellation tests, we conducted multiple correlations with Bonferroni adjustments (Siegel, 1956) used for the critical rho (\( \rho \)) values in order to maintain the overall Type I error probability of .05.

### Results

**Cancellation Tests**

The results indicated that although each group’s cancellation performance was affected by increases in both physical similarity and density, each group responded differently to the increases. Across all cancellation tests, the AD group made more omission errors, \( F(1, 34) = 5.09, p = .03 \), and more commission errors, \( F(1, 34) = 9.40, p = .004 \). As noted earlier, analyses were performed on transformed and untransformed completion times; the transformed data are presented first, followed by the untransformed data. Analysis on completion time showed that the AD group was significantly slower than the HC group, \( F(1, 34) = 12.89, p = .001 \). Analysis of the untransformed completion times, \( F(1, 34) = 5.32, p = .027 \), yielded equivalent findings.

**Physical Similarity**

Increasing the similarity between distractors and the target affected both groups, decreasing accuracy and increasing the time to complete the tasks (see Table 3 for means and standard deviations on all dependent variables). This was shown by a main effect of physical similarity on all dependent variables: omission errors, \( F(2, 578) = 7.00, p < .001 \); commission errors, \( F(2, 578) = 19.05, p < .001 \); and completion time, \( F(2, 578) = 45.435, p < .001 \). Group × Physical Similarity interactions (see Figures 1a–1c) showed that increasing physical similarity affected the AD group disproportionately on commission errors, \( F(2, 578) = 3.29, p = .04 \), with trends on both omission errors, \( F(2, 578) = 2.72, p = .07 \), and completion time, \( F(2, 578) = 2.80, p = .06 \). Post hoc analyses indicated that controls did not significantly increase omission errors as the physical similarity increased. In contrast, the AD group did increase commission errors as similarity increased, with significant differences both between Levels 1 and 2, and Levels 1 and 3. This suggested that by Level 2 the AD group encountered significant difficulty in resisting distractors. The AD group made significantly more errors than the control group at Levels 2 and 3, but not at Level 1. Post hoc analyses on the omission error data showed that the HC group did not significantly increase omission errors as physical similarity increased. The increase in omission errors in the AD group was significant for differences between Levels 1 and 3, but not between Levels 1 and 2, or 2 and 3. The AD group omitted more targets than the HC group at the two higher levels of similarity.

The ANOVA calculated on the untransformed completion time data yielded results similar to those of the transformed analysis: main effect of physical similarity, \( F(1, 34) = 7.14, p < .001 \), except that the Group × Similarity interaction, \( F(2, 578) = 0.90, p = .40 \), was nonsignificant. Reviewing the transformed and untransformed analyses, we conclude that the trend found on the transformed

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1 We estimated the skew and kurtosis of the completion time data to ascertain the effect of the log transformation, with an emphasis on skewness, as skew could bias means and affect the conclusions of the ANOVA. We compared the transformed and untransformed skew values, checking for the significance of their departure from normal using an asymptotic variance formula (Snedecor, 1956). The log transformation eliminates the skew of the HC group, untransformed \( r(323) = 10.79, p < .001; \) transformed \( r(323) = 0.31, p = .75, ns \). For the AD group, the \( r \) value is clearly reduced: untransformed \( r(323) = 25.41, p < .001; \) transformed \( r(323) = 4.79, p < .001 \), although the transformation does not entirely normalize the distribution. The results were similar for kurtosis: HC, untransformed \( r(323) = 9.29, p < .001; \) transformed \( r(323) = 1.96, p = .05; \) AD, transformed \( r(323) = 48.99, p < .001; \) untransformed \( r(323) = 2.71, p = .01 \). Moreover, the logarithmic transformation reduced the \( F \) ratio for the within-group variances: Levene’s test of equality of variance, transformed \( F = 73.1, p < .001 \); transformed \( F = 16.9, p < .001 \). Again, although the transformation does not completely create equality of variances, the reduction was significant (Levene, 1960).

2 Analysis of right versus left visual fields was nonsignificant on all dependent variables and is not discussed further.
Physical Similarity interaction is likely nonsignificant. This would indicate that although the AD group was slower overall, their slower speed did not increase disproportionately at each subsequent level: They slowed their response times to increased similarity much like the controls.

Both groups responded to density increases with slower completion times, $F(2, 578) = 723.02, p < .001$; more omission errors, $F(2, 578) = 30.64, p < .001$; and a trend for more commission errors, $F(2, 578) = 2.9, p = .06$ (see Table 4 for means and standard deviations on all dependent variables). The significant Group × Density interaction on omission errors, $F(2, 578) = 4.29, p = .01$, indicated that the AD group missed disproportionately more targets than the HC group as density increased (see Figures 2a–2c). Although the AD group showed significant and progressive increase in omission errors at each level, the control group only showed significant increases between Levels 1 and 2. Also, the Group × Density interaction for completion times, $F(2, 578) = 3.42, p = .03$, was significant, and post hoc analyses revealed that although the AD group was slower than the HC group, there was disproportionate slowing as density increased (see Figure 2c). The ANOVA calculated on untransformed completion times yielded the same findings as the transformed data: for group main effect, $F(2, 578) = 5.31, p = .03$, and the Group × Density interaction, $F(2, 578) = 7.99, p < .001$. The Group × Density interaction on commission errors was not significant, $F(2, 578) = 0.72, p = .48$.

An exploratory analysis was carried out to estimate participants’ average speed of making a cancellation. First, a total cancellation

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>AD ($n = 18$)</th>
<th>HC ($n = 18$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Similarity Level 1</td>
<td></td>
</tr>
<tr>
<td>Omission errors$^a$</td>
<td>0.09 (0.16)</td>
<td>0.05 (0.09)</td>
</tr>
<tr>
<td>Commission errors$^b$</td>
<td>0.02 (0.07)</td>
<td>0.002 (0.02)</td>
</tr>
<tr>
<td>Completion time$^c$</td>
<td>1.49 (0.32)/43.16 (48.34)</td>
<td>1.22 (0.23)/19.08 (10.53)</td>
</tr>
<tr>
<td></td>
<td>Similarity Level 2</td>
<td></td>
</tr>
<tr>
<td>Omission errors</td>
<td>0.14 (0.18)</td>
<td>0.06 (0.10)</td>
</tr>
<tr>
<td>Commission errors</td>
<td>0.06 (0.10)</td>
<td>0.02 (0.07)</td>
</tr>
<tr>
<td>Completion time</td>
<td>1.52 (0.37)/51.62 (66.76)</td>
<td>1.26 (0.26)/21.22 (14.52)</td>
</tr>
<tr>
<td></td>
<td>Similarity Level 3</td>
<td></td>
</tr>
<tr>
<td>Omission errors</td>
<td>0.16 (0.21)</td>
<td>0.07 (0.12)</td>
</tr>
<tr>
<td>Commission errors</td>
<td>0.09 (0.15)</td>
<td>0.03 (0.07)</td>
</tr>
<tr>
<td>Completion time</td>
<td>1.57 (0.32)/51.42 (54.91)</td>
<td>1.36 (0.31)/25.75 (14.11)</td>
</tr>
</tbody>
</table>

$^a$ Omission error scores are presented as the mean proportion of errors at each level of physical similarity, defined as (number of omitted targets ÷ total targets present in the array). $^b$ Commission error scores are defined as (number of commission errors ÷ total distractors present in the array). $^c$ Completion time performance is reported as transformed (log10[seconds])/untransformed (seconds) values.
The interaction between physical similarity and density was significant for omission errors, $F(4, 578) = 3.54$, $p = .007$ and completion times, $F(4, 578) = 12.04$, $p < .001$, but not for omission errors, $F(4, 578) = 1.09$, $p = .35$. The three-way interactions of Group × Density × Physical Similarity for all three dependent variables were not significant: omission errors, $F(4, 578) = 0.53$, $p = .70$; commission errors, $F(4, 578) = 0.25$, $p = .91$; completion times, $F(4, 578) = 0.86$, $p = .49$. As the $F$ values of the three-way interactions were all less than 1.0, the lack of significant effects was probably not simply due to insufficient power. Thus, the demands of processing changes in both physical similarity and density: Means (and Standard Deviations) of Omission Errors, Commission Errors, and Completion Times for Patients With Alzheimer’s Disease (AD) and Healthy Controls (HC)

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>AD (n = 18)</th>
<th>HC (n = 18)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Density Level 1</td>
<td>Density Level 2</td>
</tr>
<tr>
<td>Omission errors$^a$</td>
<td>0.07 (0.14)</td>
<td>0.03 (0.09)</td>
</tr>
<tr>
<td>Commission errors$^b$</td>
<td>0.07 (0.16)</td>
<td>0.02 (0.07)</td>
</tr>
<tr>
<td>Completion time$^c$</td>
<td>1.30 (0.32)/28.97 (36.65)</td>
<td>1.04 (0.18)/12.09 (6.11)</td>
</tr>
</tbody>
</table>

$^a$ Omission error scores are presented as the mean proportion of errors at each density level, defined as (number of omitted targets ÷ total targets present in the array). $^b$ Commission error scores are presented as the mean proportion of errors at each level of density, defined as (number of commission errors ÷ total distractors present in the array). $^c$ Completion time performance is reported on transformed (log$_{10}$ (seconds)) and untransformed (seconds) values.

Figure 2. Performance by Alzheimer’s disease (AD) and healthy control (HC) groups at three levels of density. a: Omission errors are the mean number of omitted targets as a proportion of the total targets present in the arrays. b: Commission errors are the mean number of cancelled distractors as a proportion of the total distractors present in the array. c: Completion time is presented as mean of log$_{10}$ (completion time in seconds). Error bars indicate standard error.
the quantity of information in the array did not affect the AD group more than the HC group. Analyses of untransformed completion times yielded similar results on the two-way Physical Similarity × Density interaction, $F(2, 578) = 4.14, p = .002$, and the Group × Physical Similarity × Density interaction, $F(4, 578) = 1.53, p = .19$.

**Analysis of Disease Severity**

We expected the low-MMSE subgroup of the AD participants to be more vulnerable to load than the high-MMSE subgroup. Initial examination of transformed completion time showed that the low-MMSE subgroup was slower to complete the task, $F(1, 16) = 5.43, p = .03$. Although removal of the log transformation resulted in nonsignificance, $F(1, 16) = 2.41, p = .14$, the discrepancy between transformed and untransformed analyses points to the beneficial use of the transformation, controlling for the variability typical of low-functioning patients ($M = 62.2, SD = 68.7$; median = 40.3, range 9–390 s) compared to high-functioning patients ($M = 27.6, SD = 16.4$, median = 23.0, range 5–90 s).

We were also interested in determining whether the presence of an error (particularly a commission error) was indicative of selective search difficulty, not only to differentiate performance as a function of disease severity, but also to differentiate performance between high-functioning patients and controls in high load conditions. In an effort to control for issues introduced by the smaller samples of the two subgroups, we created dichotomous measures of each test, depending on whether the test was completed with or without an omission or a commission error. Frequency analyses showed that, overall, the low-MMSE group had higher numbers of tests with commission errors, $\chi^2(1, N = 324) = 12.90, p < .001$, and tests with omission errors, $\chi^2(1, N = 324) = 12.39, p < .001$. To further investigate this difference as a function of load, we compared performance of the two subgroups at each level of physical similarity (see Tables 1 and 2 on the Web at http://dx.doi.org/10.1037/0894-4105.19.1.5 supp). At Levels 1 and 2, low- and high-MMSE subgroups completed equivalent numbers of tests with omission errors, but the low-MMSE subgroup made commission errors on more tests than the high-MMSE subgroup: Level 1, Fisher’s exact test, $p = .001$; Level 2, $\chi^2(1, N = 108) = 7.56, p = .006$. The reverse pattern was seen at Physical Similarity Level 3, where the low-MMSE subgroup omitted one or more targets on significantly more tests than the high-MMSE group, $\chi^2(1, N = 108) = 9.92, p = .002$, but where both subgroups had comparable number of tests with commission errors, $\chi^2(1, N = 108) = 0.77, p = .38$. In an effort to determine whether making an error was indicative of disease, we compared the number of tests with and without errors between high-functioning AD patients and controls. At Level 3, although the high-MMSE AD subgroup did not differ from the controls on the number of tests with or without omission errors, $\chi^2(1, N = 150) = 0.004, p = .95$, the high-MMSE AD subgroup erred on significantly more tests with one or more commission errors, $\chi^2(1, N = 150) = 4.59, p = .03$. Thus, at high loads the distinction was most clear: Completing tests without any omission errors was done significantly better by high-functioning patients than by low-functioning patients, but completing cancellation tests without any commission errors was done significantly better by controls than by either high- or low-functioning patients. The use of commission errors could differentiate controls from patients.

As a function of density, tests with one or more omission error were significant for both AD subgroups: low-MMSE, $\chi^2(2, N = 112) = 12.55, p = .002$; high-MMSE, $\chi^2(2, N = 46) = 13.22, p = .001$, whereas overall commission errors were not significantly different: low-MMSE, $\chi^2(2, N = 86) = 3.09, p = .21$; high-MMSE, $\chi^2(2, N = 30) = .60, p = .74$. For density, accurate target detection (i.e., no omission errors) was a better measure than commission errors for both subgroups, although high-functioning patients were better able to withstand increased density than low-functioning patients.

**Correlations With Neuropsychological Tests**

To explore how the two error types correlated with domains of neuropsychological functioning, we calculated Spearman correlations between neuropsychological tests and omission or commission error scores for the whole AD group. The DRS measure of severity in AD was negatively correlated with omission errors (DRS Total score, $p_1 = -0.172, p < .05$). Attentional measures were also correlated negatively with omission errors, suggesting that as measures of vigilance and maintenance of attention and working memory deteriorate, target detection is compromised (i.e., DRS Attention subtest: $p_1 = -0.363, p < .05$; WMS–R Digit Span forward: $p_1 = -0.213, p < .05$; WMS–R Digit Span backward: $p_1 = -0.397, p < .05$; WMS–R Visual Span backwards: $p_1 = -0.232, p < .05$; WAIS–III Digit symbol: $p_1 = -0.245, p < .05$; Trails-B: $p_1 = 0.279, p < .05$). Furthermore, omission errors were correlated with memory measures that relied more on attentional and initial encoding processing than on retrieval processing. Thus, omission errors correlated negatively with CVLT learning scores (recall across Trials 1–5: $p_1 = -0.276, p < .05$; CVLT Trial 5: $p_1 = -0.264, p < .05$) but not significantly on Short or Long Delayed Recall scores (CVLT Short Delay Free Recall: $p_1 = 0.105, p > .05$; or Long Delay Free Recall: $p_1 = -0.40, p > .05$).

Modest negative correlation scores were also seen between commission errors and severity (DRS total score: $p_1 = -0.241, p < .05$) and the DRS subscales of Initiation/Perseveration ($p_1 = -0.217, p < .05$) and Memory ($p_1 = -0.170, p < .05$), which are the two subscales typically impaired in the profile of AD (Vitaliano, Breen, Albert, Russo, & Prinz, 1984). Although commission errors showed a negative relationship with the DRS Attention subtest ($p_1 = -0.190, p < .05$) none of the other attentional markers (i.e., Digit Span Forward, Digit Span Backward, Digit Symbol, Trails) or memory indicators (e.g., CVLT immediate or delayed scores) reached significance, as they had with the omission errors. It was interesting, however, to find significant negative correlations between commission errors and semantic tasks: Commission errors were negatively correlated with BNT ($p_1 = -0.323, p < .05$), COWAT ($p_1 = -0.220, p < .05$), the CVLT Semantic Clustering index score ($p_1 = -0.263, p < .05$) and, as mentioned above, the DRS Initiation and Perseveration subtest ($p_1 = -0.217, p < .05$), a subtest on which much of the score depends on the items from a word generation task. In other words, lower perfor-

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3 Bonferroni adjustment was used to reduce individual criterion $p$ levels according to the number of correlation coefficients being compared.
mance on neuropsychological tasks that required access to the semantic network was associated with more commission errors. No significance was found between phonemic fluency and commission errors (FAS: $r_1 = -0.002$, $p > .05$).

Comparison of Disjunctive Searches, Pretests, and Posttests

The five disjunctive (i.e., pop-out) cancellation tests, administered to ensure that participants were able to detect distinctive targets in an array, were performed equally well by both groups (95.6% accuracy and only with omission errors). However, the AD group took roughly twice as long as the HC group to complete these disjunctive searches, $t(34) = 3.98$, $p < .001$ ([mean completion times transformed (log10)/untransformed] AD group: 1.05, $SD = 0.25/15.75$, $SD = 10.33$ s; HC group: 0.79, $SD = 0.14/7.38$, $SD = 2.88$ s). These results did not vary when untransformed completion time data were used.

The pre- and posttests were administered to determine a participant’s ability to visually discriminate stimuli under nonsearch conditions. Table 5 reports the frequencies of participants with and without error. The AD and HC groups were not significantly different on Pretest 1 or Pretest 2, with most AD participants missing no items or one item; one patient missed four items on Pretest 2. While the two groups did not differ significantly on Posttest 2, there was a significant group difference on Posttest 1, where all HC participants performed perfectly, but where 5 of the 18 participants with AD erred, with 4 making one error (93% accuracy), and 1 (see Footnote 4) making two errors (83% accuracy). Importantly, the 5 AD participants with errors on Posttest 1 were not significantly different from the remaining group members on any demographic or neuropsychological variables. The HC group significantly improved their same/different performance from Posttest 1 to Posttest 1 (Fisher exact probability test, $p = .02$), whereas the AD group did not (Fisher exact probability test, $p = .72$), suggesting that HC participants benefited from repeated exposure to the stimuli over the experiment using the 18 tests.

Discussion

The aim of this study was to determine how the load of physically similar stimuli in a visual array affected conjunctive search in AD. Our first hypothesis posited that increasing the physical similarity between stimuli would impair search in patients with AD relative to controls, and that the AD group would be compromised even when the stimuli were perceptually more different. The data confirmed this hypothesis, with the two groups showing different patterns of response to the varied levels of similarity. The control group slowed their search times as the similarity between target and distractors increased, but they maintained target detection accuracy at all levels of physical similarity (no significant increase in omission errors) without canceling significant numbers of distractors (no increase in commission errors). This suggested that controls slowed their search to avoid errors, demonstrating a speed-accuracy tradeoff. The AD group slowed their search with each level, much like controls, but they did not demonstrate the speed-accuracy tradeoff, as they still made more commission errors and tended to miss more targets. Performance at Level 1 of physical similarity (i.e., easiest discrimination) was comparable in both groups. But the increased similarity at Levels 2 and 3 proved to be more difficult for the AD group, with significantly more errors compared both to controls and to their own performance at Level 1. These findings provide evidence, therefore, that in a conjunctive search, the degree of physical similarity of stimuli affects the ability to selectively attend in AD patients relative to controls; commission errors were important additional measures to document this finding.

The second hypothesis posited that the interaction of increased density and physical similarity loads would disproportionately tax attentional resources in AD patients compared to controls. First, we replicated previous findings that the effect of increasing density, or set size, differentiated the two groups (Cossa, Della Sala, & Spinler, 1989; Foldi et al., 1992; Parasuraman & Haxby, 1993; Perry et al., 2000), and found that patients search more slowly and

Table 5

<table>
<thead>
<tr>
<th>Test</th>
<th>AD (n = 18)</th>
<th>HC (n = 18)</th>
<th>Fisher’s exact (df = 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest 1: Same/different</td>
<td>11</td>
<td>13</td>
<td>0.25</td>
</tr>
<tr>
<td>Pretest 2: Odd-man-out</td>
<td>12</td>
<td>13</td>
<td>0.25</td>
</tr>
<tr>
<td>Posttest 1: Same/different</td>
<td>13</td>
<td>13</td>
<td>0.25</td>
</tr>
<tr>
<td>Posttest 2: Odd-man-out</td>
<td>12</td>
<td>13</td>
<td>0.25</td>
</tr>
</tbody>
</table>

*a See Footnote 4.*

4 This patient’s poorer performance on pre- and posttests raised concern about the individual’s contribution to the dataset. All analyses in the experiment were recalculated with and without the individual’s scores, and results of the significance of the analyses did not differ substantially; the experimental data are presented with this participant included.

5 As a significant HC–AD group difference on the same/different post-test was found, the 5 participants of the AD group who had shown some difficulty performing the task were compared to the 13 participants who had performed without any error. All independent sample t test comparisons were nonsignificant ($p > .05$) for all demographic measures (e.g., age, education, time since diagnosis, presence or absence of cholinergic treatment) and all neuropsychological measures (i.e., MMSE, DRS Total and all DRS subscales, CVLT measures of total performance over five trials, short- and long-delay free and cued recall, measures of intrusion and recognition, Boston Naming Test, word fluency measures of FAS and COWAT, Trails–A and B, Digit Span and Visual Span tests, and Digit Symbol Test).
with less target accuracy than the controls. Second, the two-way Density × Physical Similarity interaction placed greater demands on attentional resources for both groups, as evidenced by longer search times and increased commission errors. Omission errors did not reach significance on this interaction. However, the three-way interaction of Group × Physical Similarity × Density was not significant on any of the dependent variables. We interpret these findings to suggest that increases in physical similarity and stimulus density increase the amount of processing resources required to perform the cancellation task, but, unexpectedly, the effect was similar for both groups. Decreased power alone could not account for the finding. Given that the disease likely reduces total attentional resources, we would have expected that the AD group would be more vulnerable. Future research is needed to address the issues of how combined versus independent types of load affect finite available resources.

The third hypothesis was that disease severity would affect performance during conjunctive visual search. The findings comparing low- and high-functioning patients with AD confirmed our hypothesis, and not surprisingly, patients with more severe disease performed worse than those with milder disease on all measures: The low-functioning subgroup had higher rates of omission and commission errors, and longer completion times. These findings corroborate findings of previous studies on attention that have included severity (Baddeley et al., 2001; Perry et al., 2000). In addition, we were particularly interested in determining whether the presence of an error (an omission or a commission error) would be a sensitive indicator of attentional deficits, different levels of disease severity, and early presence of disease. The frequency data from our smaller AD subsets have to be interpreted carefully, but the analyses using presence or absence of an error in a test showed a revealing pattern of performance, with the profiles of the subgroups and the controls varying as a function of load demands. At lower loads (Physical Similarity Levels 1 and 2), high-functioning patients were significantly better at resisting distractors than low-functioning patients, although the subgroups were similar in their ability to complete tests without any missed targets. In the high load condition (Physical Similarity Level 3), the percentage of tests completed with correct identification of all targets (i.e., no omission errors) could differentiate the AD subgroups, with low-functioning patients performing worse than high-functioning patients, but the high-functioning patients performing similar to controls (low-MMSE < high-MMSE = HC). Although the percentage of tests with one or more commission errors did not differentiate the two AD subgroups, presence of a commission error did differentiate controls from the high-functioning subgroup, with patients performing worse than controls (low-MMSE = high-MMSE < HC). Our findings supported our prediction that presence of commission errors, like other types of intrusion errors (Fuld, Katzman, Davies, & Terry, 1982), is a very sensitive indicator of early stages of the disease.

Groups of patients with varying severity of AD have also been investigated by Perry and colleagues (Perry et al., 2000), who used the selective task of Map Search from the Test of Everyday Attention (Robertson et al., 1994). Their groups (mean MMSE = 20.4 and 26.1) were similar in severity to those of our subgroups, and, as in our study, the accuracy of target detection declined in the more severe AD group. Although the authors explained their findings in terms of inhibitory deficits in AD, the Map Search unfortunately does not measure commission errors, which might be the better indicator of impaired inhibitory mechanisms. It also remains to be determined whether commission errors could be used as sensitive indicators of attentional change in even higher functioning patients with AD, or in patients during the phase of mild cognitive impairment.

The performance on the posttests of both our groups showed that most participants were able to make accurate visual discriminations in nonsearch conditions. The controls appear to have additionally benefited from exposure of the stimuli in the 18 cancellation tests, such that hardly any HC participants made any discrimination errors on the posttests. However, some members of the AD group did make errors, such that group differences on Posttest I were significant. Research provides evidence of visual discrimination deficits in AD (Geldmacher, 2003), and although our patients demonstrated good discrimination skills at study entry, the errors on the posttests suggest that visual discrimination deficits cannot be ruled out as contributing to or exacerbating selective search difficulties.

In summary, our findings show that physical similarity increases attentional load and compromises the speed–accuracy tradeoff of a selective search performance in AD. The analyses underscore the importance of including measures of both target detection accuracy and commission errors on selective attention tasks. Even the presence of a single commission error was an important indicator of impairment associated with disease. Moreover, to detect the selective search deficits, especially in high-functioning patients, the search task must be sufficiently difficult, or, in terms of an attention model, present with sufficiently high load.

**Role of Commission Errors**

Commission errors were not abundant, but they were significant and reflect several important underlying dysfunctions of AD. One dysfunction is the inability to disengage (Posner & Petersen, 1990) from a stimulus (Foster, 2001; Greenwood et al., 1997), a function that has been clearly demonstrated on other attention tasks in AD such as covert orienting (Dankert, Maruff, Crowe, & Currie, 1998). In selective search tasks, the similar inability to disengage from a distractor (as opposed to a covert cue) may be operative, ultimately leading to the incorrect endorsement of that distractor. According to Posner and colleagues (Posner, Walker, Friedrich, & Rafal, 1987), the neurological substrate of disengagement is the posterior attentional system, particularly the inferior parietal region (Donner et al., 2000), and, as these regions are significantly impaired in AD (Buck, Black, Behrmann, Caldwell, & Bronskill, 1997; Greenwood & Parasuraman, 1994), they might represent the source of the commission errors. A second possible explanation of commission errors is the inability to resist interference (Baddeley et al., 2001) as a result of impaired inhibitory mechanisms in AD (Amieva et al., 2002; Butters, Granholm, Salmon, Grant, & Wolfe, 1987; Fuld et al., 1982). Inhibitory deficits, reflecting deficits of frontal system disease such as impairment of anterior cingulate region (Killiany et al., 2000), implicate compromise of the anterior attentional system. Patients with focal frontal lesions (Stuss et al., 1999, 2002) also show impairment in conjunctive discrimination tasks, whereas patients with right dorsolateral or superior medial frontal involvement produce patterns of deficit similar to those of
our AD patients, that is, slower performance and more false positive errors as targets and distractors share more features. A third explanation of commission errors may be impaired integration of the anterior and posterior attentional systems. As proposed by Parasuraman and colleagues (Parasuraman & Haxby, 1993; Parasuraman & Martin, 1994), the attentional deficit in AD is caused by a disconnection of the cortico-cortical, anterior–posterior network. Functional imaging in healthy individuals (Donner et al., 2000) has corroborated this concept by showing that combined anterior (i.e., frontal eye field) and posterior (i.e., inferoparietal) regions are activated during a demanding conjunctive search. The integration of anterior–posterior components of the attentional system is also consistent with the theoretical approach of Wolfe (Chun & Wolfe, 2000; Wolfe, 1994, 2003), who proposed that a feedback between top-down and bottom-up strategies is used to guide a search even more efficiently. When a search is demanding, individuals attempt to label or categorize the information in order to minimize the processing demands, thus drawing on top-down strategies. One of our findings was consistent with this explanation, namely, that commission errors were correlated negatively with neuropsychological measures that represent top-down skills, such as access to semantic or organized categories (e.g., confrontation naming; category word generation). The common feature of the higher incidence of commission errors and the lower semantic skills may be a weakening of an underlying organizing ability; this, in turn, reduces a patient’s ability to draw on a useful directive or top-down strategy during a demanding search. It is also important to note that the stimuli in our current study were novel, and thus more demanding. Our findings produced significant numbers of commission errors not obtained in previous studies (Baddeley et al., 2001; Foldi et al., 1992). Those studies may have yielded nonsignificant findings, because there was still an opportunity to draw on existing, well-established representations such as letters or shapes. In summary, if patients with AD cannot draw on top-down strategies and hence cannot benefit from such resource-saving mechanisms, they must rely more heavily on less efficient bottom-up processing and must search in a serial item-by-item fashion; this strategy will be slower, more feature-oriented, and ultimately more prone to commission errors.

Speed of Search

Slower completion times in AD are another reflection of underlying inefficiency. The slower performance in the AD group could be construed as an exacerbation of slowing found in normal aging (Cerella, 1985; Salthouse, 2000), with the search strategy being the same. Our findings showed that the average time-per-cancellation score of the AD group was roughly twice as long on each cancellation (whether on a correct hit or on an incorrect distractor cancellation) as that of the age-matched control group. The methodology of the current study does not allow us to determine whether the speed differed when canceling a distractor as opposed to a target; future studies addressing this question would be needed. However, as the participants with AD did not show overt bradykinesia or slowed motor performance, and the total number of cancellations did not significantly differ from that of controls, the slower average completion time-per-cancellation in the AD group suggests that patients were involved in qualitatively different processes during each cancellation. Impaired eye movements during search (Rösler et al., 2000) clearly contribute to inefficiency and are one source of the slower completion times that age-matched controls do not show. A further interesting possibility is that eye-movement inefficiency could also be a consequence of compromised top-down directives.

Role of Omission Errors

Errors of omission were present in both groups, although more prevalent in AD patients, which is a common finding in the literature. For our AD group, the failure to detect a target correlated positively with measures of attention (e.g., Digit Span Forward and DRS Attention subtests) and working memory (e.g., Digit Span Backward), but there were no such correlations in the control group. This raises the possibility that, at least for participants with AD, omission errors may reflect their limited attentional capacity, whereas for participants in the control group, more automatic processing is still available and does not tax attentional resources.

Ideally, visual selection of items during daily activities occurs with minimal expenditure of attentional resources and with minimal interference from perceptually irrelevant stimuli. However, if surrounding stimuli are physically similar, more attentional resources are recruited. The current experiment utilized physically similar, nonmeaningful stimuli, and because they were artificial, one could argue that such a task might not be relevant to the real world, in which most objects are physically dissimilar and meaningful. However, our study highlights precisely the problems that patients with AD might be experiencing. That is, as AD progressively preempts a person’s ability to recognize items in the environment with neurobehavioral symptoms such as anosognosia and misidentification, and as top-down guidance from meaningful internal representations becomes less available, the person must increasingly rely on feature-oriented perceptual discrimination in order to select the item. Our findings may therefore explain selective attention impairment in AD in two ways. The first, as posited by Baddeley and colleagues (2001), is that total attentional resources are diminished in this disease. Thus, higher load demands of discrimination or density more easily compromise a patient’s limited resources. The second, as our study suggests, is that the access to viable, resource-saving search strategies is also compromised. Thus, whatever attentional capacity is available, it may be further depleted by allocating resources to inefficient strategies. The implication of this attentional impairment on everyday functional activities is not trivial, and it furthers our understanding of why patients with AD are so easily overwhelmed.

References


