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Visual Attention Deficits in Alzheimer's Disease: Simple Versus Conjoined Feature Search

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The authors investigated selective attention in patients with Alzheimer's disease (AD), using a well-known visual search procedure. In simple feature search, the deficit observed in AD patients represented a baseline shift in the median hit reaction time (RT). On the conjoined feature search task, the median hit RT for AD patients increased disproportionately with increasing array size, indicating an additional cognitive impairment on this task. Of particular importance, the cognitive deficit observed in conjunction search was more profound than that predicted on the basis of previous reports of global cognitive slowing in AD. There was some evidence that the performance of AD patients improved more than the performance of controls over the duration of the experimental test session. Patients also had more difficulty in detecting targets on the right side of hemispace and in more peripheral locations.

Until recently, there has been a relative paucity of experimental studies of attentional functions in Alzheimer's disease (AD). However, there have been recent suggestions in the neuropsychology literature that attention is impaired early in the course of AD (Haxby et al., 1990), and that deficits in sustained and spatial attention can be related to the characteristic neurochemical changes that occur in the disease (Lawrence & Sahakian, 1995). It has been further suggested that attentional dysfunction may mediate some of the other cognitive performance deficits observed in AD (Jorm, 1986; Nebes & Brady, 1989; Stuart-Hamilton, Rabbitt, & Huddy, 1988), and that attentional deficits in AD may correlate with impairments in activities of daily life (Alberoni, Baddeley, Della Salla, Logie, & Spinnler, 1992; Camicioli, Howieson, Lehman, & Kaye, 1997).

Among those studies that have reported attentional impairments, deficits have been revealed in a wide variety of attentional capacities and on a range of different tasks, including both auditory (Gearing, Graves, & Mohr, 1991) and visual (Grande, McGlinchey-Berroth, Milberg, & D'Esposito, 1996) selective processing, visual pursuit tracking (Hutton, Nagel, & Loewenson, 1984), visual search (Nebes & Brady, 1989), attention shifting (Filoteo et al., 1992), uncued reaction time (Gordon & Carson, 1990), divided attention (Baddeley, Bressi, Della Salla, Logie, & Spinnler, 1991; Greene, Hodges, & Baddeley, 1995; Nestor, Parasuraman, Haxby, & Grady, 1991), and the generation of antisaccadic eye movements (Currie, Ramsden, McArthur, & Maruff, 1991). Increases have also been noted in "attentional grasp" (Maruff & Currie, 1995) and inhibition of return (Fuentes, Langley, Overmier, Bastin de Jong, & Prod'Homme, 1998), and AD-related biases in attentional hemifield (Maruff, Malone, & Currie, 1995) have additionally been observed. Using a reaching task, Simone and Baylis (1997) observed exaggerated effects of interference in AD patients, whereas using a cued visual search task, Greenwood, Parasuraman, and Alexander (1997) found that the beneficial effects of location precues on target detection declined progressively with increasing age and the onset of AD.

It is not clear from those studies in which AD-related attentional deficits have been observed to date whether these impairments should be attributed to reduced target processing, to increased interference from distractors, or both. Some studies (e.g., Blackwood, St. Clair, Blackburn, & Tyrer, 1987; St. Clair, Blackwood, & Christie, 1985; St. Clair, Blackburn, Blackwood, & Tyrer, 1988) have identified impaired target processes in AD, although other investigations have found target enhancement to be preserved in AD (e.g., Balota & Duchek, 1991; Chertkow, Bub, & Seidenberg, 1989; Moscovitch, Winocur, & McLachlan, 1986;

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Sullivan, Faust, & Balota, 1995). Faust, Balota, Duchek, Gernsbacher, and Smith (1997) suggested that AD patients exhibit impaired inhibitory control, with relative preservation of facilitatory selective processes, as revealed by performance on a sentence comprehension task. This conclusion was supported by the findings of Spieler, Balota, and Faust (1996), who argued that there is an impairment of inhibitory control in normal aging, which is further exaggerated in AD. Problems in inhibiting the processing of distractor items have also been inferred in patients with AD from impaired performance in other experimental tests and on clinical measures such as the Stroop task, Trail Making Test, and Wisconsin Card Sorting Test (Foldi, Jutagir, Davidoff, & Gould, 1992; Grande et al., 1996; Greenwood et al., 1997; Koss, Ober, Delis, & Friedland, 1984; Massman et al., 1993; Nebes & Brady, 1989; Oken, Kishiyama, Kaye, & Howieson, 1994; Sahgal, Galloway, McKeith, Edwardson, & Lloyd, 1992; Sullivan, Faust, & Balota, 1995; Wright, Cremona-Meteyard, Geffen, & Geffen, 1994). These deficits may often take the form of impaired disengagement from distractor items. It has also been suggested that AD patients are unable to inhibit the activation of competing, prepotent responses (Maruff & Currie, 1995; Oken et al., 1994; Wright et al., 1994). It is therefore becoming increasingly clear that AD patients are less able than controls to ignore distracting information, but the dysfunctional processes underlying these effects have not yet been clearly identified. Inconsistencies in attributing AD-related deficits to reduced target or increased distractor processing in previous studies may be due to the possibility that AD patients are able to suppress weakly activated distractors efficiently, but less able to suppress more strongly activated distractors (see Sullivan et al., 1995).

Although the above studies have demonstrated an attentional impairment in AD, other studies have revealed no marked deficits. Patients appear to be unimpaired in detecting, shifting to, and engaging target items. Alertness and vigilance, as measured by the facilitation in responding to targets (occurring with varying degrees of frequency) provided by a prior warning stimulus (Nebes & Brady, 1993) or over time (Villardita, 1993), may be preserved in AD. In a study conducted by Nebes and Brady (1989), patients with AD were able to limit their visual search as well as controls to stimulus items sharing the relevant salient feature (see also Greenwood et al., 1997). Several studies have indicated that reported visual attentional shifting may be preserved early in the course of AD (Faust & Balota, 1997; Oken et al., 1994; Parasuraman, Greenwood, Haxby, & Grady, 1992; Sahakian et al., 1990; Wright et al., 1994), but deficits may be revealed in a more severe subgroup of AD patients (Sahakian et al., 1990). Sullivan et al. (1995) reported impaired negative priming in AD but a similar-size distractor interference effect on controls. Nebes and Brady (1989) concluded that there is no focused attention impairment in AD, although other researchers have reported that such an impairment does exist (Capitani, Della Sala, Lucchelli, Soave, & Spinnler, 1988; Parasuraman, Greenwood, & Alexander, 1995; Stuart-Hamilton, Rabbitt, & Huddy, 1988). In a covert selective attention task, Parasuraman et al. (1992) observed disproportionately poor performance in AD patients when they were invalidly cued and had to reorient their attention to another location in the visual field. However, patients in the mild to moderate stages of AD were generally able to use a valid cue to mobilize visuospatial attention efficiently toward an expected location. In contrast with Parasuraman et al.'s (1992) suggestion that disengagement mechanisms may be impaired in AD, Caffarra, Riggio, Malvezzi, Scaglioni, and Freedman (1997) reported no deficits in disengagement processes in AD: Compared with patients with Parkinson-dementia, Parkinson's disease, and matched controls, AD patients showed no differences in performance on the Posner paradigm of visuospatial attention. Using a stimulus detection task, Faust and Balota (1997) investigated inhibition of return in AD patients and elderly and young controls and found no AD-related deficits in inhibition. However, both an age-related and an AD-related increase in the facilitatory effect of a peripheral cue on target detection was observed. In a study that compared attentional processing in AD with Lewy body dementia (LBD), Sahgal et al. (1992) found that both AD and LBD patients were impaired, compared with matched controls, on an attentional set shifting task. However, on a visual search matching-to-sample task, the AD group performed at close to normal levels. Finally, there is also evidence that semantic attentional processing is preserved in AD (e.g., Balota & Duchek, 1991; Hartman, 1991).

There is therefore a continuing debate concerning the status of attentional functions in AD patients. It is against this background of somewhat mixed findings that the present investigation was conducted. A general objective of this study was to characterize further precisely which attentional capacities are impaired or preserved in AD. We were particularly interested in investigating the relationship between "controlled" (or effortful) and "automatic" (i.e., noneffortful) selective attentional capacities in AD (see Jorm, 1986). Many tasks of everyday life are so well practiced that they become automatic and require no or very few attentional resources. Other tasks, however, continue to require attention (i.e., their performance is controlled by attentional limits) no matter how well practiced they are. The capacity of selective attention involves focusing on some perceptual inputs while excluding other interfering stimuli. We tested patients at both a relatively early (mild AD group) and a later (moderate AD group) stage of the disease. In addition to providing insight into attentional functioning in AD, we sought to evaluate the question of whether attention may serve as a reliable cognitive marker for use in early-stage diagnosis of the disease. The status of attentional functioning in AD has other important practical implications, given that, for example, the postulated deficits in selective attention have previously been cited as contributing to increased risk of traffic accidents in AD (Parasuraman & Nestor, 1991).

In the present study, we used a computer-presented visual search task and investigated the effects of increasing the size of the distractor set presented on participants' reaction time (RT) to detect a target. We anticipated that there would be a specific, exaggerated effect of array size on target detection

performance in AD patients. In addition to examining whether an attentional deficit exists in AD, we also sought to investigate various other aspects of performance. Specifically, we examined detection by target location, which varied across peripheral, intermediate, and central regions of the computer screen, to evaluate whether there was any constriction in the size of the attentional window in AD (Coslett, Stark, Rajaram, & Saffran, 1996; Stark, Grafman, & Fertig, 1997). Target detection in the left and right hemifield was also examined by dividing the screen into a left half and a right half and determining the response latency in these two regions, to determine whether hemispatial bias was present in AD. According to the theory of the neural basis of attention proposed by Mesulam (1990; see also Corbetta, Miezin, Shulman, & Petersen, 1993; Heilman, Watson, & Valenstein, 1985; Nobre et al., 1997; Ojemann, Buckner, Corbetta, & Raichle, 1997), the right cerebral hemisphere (specifically, the right parietal region) is responsible for subserving attention to both the left and right hemispace, whereas the left hemisphere (in particular, the left parietal region) is responsible for the mediation of attention in the right hemispace only. (A related theoretical view of anatomically connected attentional networks has been proposed by Michael Posner and associates, who have argued that parietal regions are most important for orienting to spatial locations; see, e.g., Posner, 1992; Posner & Dehaene, 1994; Posner & Petersen, 1990.) Because pathology in the parieto-temporal region of the brain is a typical neurological feature of AD, there may therefore be greater likelihood of sparing of attentional function in the right hemifield of space than in the left in these patients. Furthermore, the findings of Corbetta, Shulman, Miezin, and Petersen (1995) and Ashbridge, Walsh, and Cowey (1997) implicate the superior parietal cortex (especially on the right) in the mediation of conjunction search tasks similar to that used in the present investigation, but not for preattentive search or "popout." The efficient performance of conjunction search, but not preattentive or simple feature search, is thought to rely on successive, serial shifts of spatial attention (Treisman & Gelade, 1980). We used both simple and conjoined feature search tasks in the present study. On the basis of the findings of Corbetta et al. (1995), Ashbridge et al. (1997), and others, we anticipated that the effect of array size on target detection speed would be most pronounced in AD patients on conjoined feature search compared with the simple feature task.

A further issue that we investigated concerns the degree of fluctuation in performance observed across the duration of testing. Increased variability in performance has been implicated in both pathological and nonpathological aging (Eustache, Desgranges, & Baron, 1995; Knopman & Gracon, 1994; Morse, 1993). Indeed, clinically, one of the most puzzling clinical aspects of AD concerns day-to-day fluctuations in behavior. However, there has been little formal, systematic research on AD patients' ability to sustain task performance over the duration of a test session. As mentioned earlier, impaired vigilance has been implicated in AD (Alexander, 1973; Sahakian & Coull, 1993; Sahakian, Jones, Levy, Gray, & Warburton, 1989; Sunderland et al., 1987), although differential changes in performance over time have not typically been evaluated in previous studies. Furthermore, although inconsistency in performance has often been treated as a secondary issue in those AD studies in which it has been examined, it may be more appropriate to treat variability as a critical feature of task performance that needs to be targeted and investigated in its own right (see Stuss et al., 1994, for a presentation of categorically dissociable but experimentally amenable forms of variability).

An important theoretical issue that we examined is the extent to which any deficits observed were truly specific to attentional function or instead were a product of generalized cognitive slowing, manifesting itself in the particular cognitive domain being examined (Birren, 1974; Birren, Woods, & Williams, 1980; Cerella, 1985; Cerella, 1990; Salthouse, 1985). This central issue has not been addressed by many previous studies of visuospatial attention in AD, but it is possible to do so using chronometric measurement, as used in this study (see also Nebes & Brady, 1992; Nebes & Madden, 1988; Nestor, Parasuraman, & Haxby, 1991, for a consideration of cognitive slowing in AD). If processing in any given psychological task is qualitatively similar for AD patients and controls, but AD patients are slowed by a constant amount for each cognitive operation, a simple linear chronometric function might be expected to characterize the response data: RTAlzheimer = mRTOld, where m is a multiplicative slowing factor significantly greater than 1. On the other hand, if the degree of slowing observed in a particular study is greater than that predicted by this function, this indicates that there is a specific deficit in the cognitive domain being examined, beyond that predicted on the basis of generalized cognitive slowing.

In summary, the study reported here examined the performance of patients with AD and matched controls on simple and conjoined feature visual search tasks to provide valuable information concerning possible AD-related deficits in performance. We investigated performance with respect to a number of factors. First, we investigated target detection across stimulus arrays of increasing size to determine whether there was differential slowing in AD patients as the number of distractors was increased. We expected exaggerated effects of array size on performance in AD patients compared with controls, especially on the conjoined feature task. Second, by systematically varying the location of the target, we examined whether there was an AD-related constriction of the perceptual window or hemispatial bias evident in performance on either visual search task. Third, we investigated changes in performance across the duration of testing to determine whether there were significant AD-related increases in variability across testing. Finally, the possibility that global cognitive slowing represented the critical mechanism underlying intergroup differences in performance was also evaluated.

Method

Participants

Three groups of English-speaking participants, between 55 and 85 years of age, took part in the study. There were two groups of

AD patients (mild group [n = 9], moderate group [n = 11]) and a group of age-matched elderly control participants (n = 20). Neurological exclusion criteria were applied in participant selection; none of the participants had, either at the time of testing or in the past, a significant neurological illness (other than AD) or psychiatric disorder. No participants had experienced a severe systemic illness or history of alcoholism or substance abuse. Participants meeting *Diagnostic and Statistical Manual of Mental Disorders* (3rd ed., rev.; American Psychiatric Association, 1987) criteria for depression were excluded from the study. Reference is also made here to the performance of a fourth group of participants, the young control participants; these were normal young participants (age range 18–30 years inclusive), who were tested in a previous study under identical experimental conditions (Foster, Behrmann, & Stuss, 1995) and whose performance provided a benchmark against which other comparisons could be made.

Although medication could not be controlled in the AD groups, participants who used neurotropic drugs were specifically excluded from the study. All participants had intact visual fields and normal visual acuity (with or without correction), the latter being determined at the fixed viewing distance (40–50 cm) that was used in the experimental tasks. Consent was obtained from all participants following appropriate procedures.

AD patients were diagnosed as having probable dementia of the Alzheimer type, based on the National Institute of Neurological and Communicative Disorders and Stroke and Alzheimer's Disease and Related Disorders Association criteria (McKhann et al., 1984). Before patients were included in the study, concordance of two independent diagnoses was required. All patients had a computerized tomography (CT) scan of the brain, EEG, and biochemical tests for serum B12 and folate level, thyroid function studies, Venereal Disease Research Laboratory (VDRL), renal function tests and evaluation of liver function, complete blood count, ESR, and serum calcium and phosphorus levels. The CT scans were normal or showed only atrophy. The EEGs were normal or showed only generalized slowing. The biochemical blood tests were all normal.

We recognized that the selection criteria that we used can include patients with neurodegenerative dementias other than AD, such as frontal dementia, and we therefore used recognized clinical criteria to exclude these patients (Neary, Snowden, Northen, & Goulding, 1988). We followed all patients for approximately 18 months before deciding whether to include them in the final analysis. One of the patients originally tested was excluded because the provisional diagnosis of AD could not be confirmed.

Demographic data for the participants in each of the groups are presented in Table 1. There was no significant difference in age between AD patients and controls, $F(1, 38) = 0.02$, $p = .97$. All participants had received a relatively high level of education (M = 14.2 years), and there was no significant difference in the number of years of education received across AD patients and controls, $F(1, 38) = 0.51$, $p = .48$. Both AD and control participants were given the following psychometric tests as part of the study: the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975), the National Adult Reading Test (NART; Blair & Spreen, 1989), the Mattis Dementia Rating Scale (DRS; Mattis, 1976), and the Vocabulary subtest of the Wechsler Adult Intelligence Scale—Revised (WAIS–R; Wechsler, 1981). Significant group differences were observed on all of these measures. The group means and standard deviations of scores are shown in Table 1.

For all patients, the Mattis DRS score was less than 123 and the modified Hachinski score was 2 or less (Hachinski et al., 1975; Rosen et al., 1980). Patients were further defined as having mild (n = 9) or moderate (n = 11) AD, according to their performance on the DRS. Mild patients were defined as scoring between the cutoff (123) and 1 *SD* below the cutoff (116) on the DRS. Moderate patients were defined as scoring below 116 on the DRS. This grouping was also compatible with the mild and moderate categorization of severity using the Global Deterioration Scale of primary degenerative dementia (Reisberg, Ferris, de Leon, & Crook, 1982). The distinction between the mild and moderate groups was upheld by the findings on the MMSE, $F(1, 38) = 49.48$, $p < .001$, the DRS, $F(1, 38) = 55.96$, $p < .001$, and the WAIS–R Vocabulary, $F(1, 38) = 21.39$, $p < .0001$, where the mild and moderate groups differed significantly from each other as well as from the control participants. (Of note, these group differences were upheld by performance on the Memory subscale of the DRS, $F[1, 38] = 152.5$, $p < .0001$, but not by performance on the Attention subscale, $F[1, 38] = 0.29$, *ns;* this distinction may be important when considered in the context of the overall findings of this study, and when reflecting on the diagnostic value of different components of the DRS.)

The elderly control participants (n = 20) were matched as closely as possible to the AD patients in age, gender, handedness, years, type (e.g., academic, technical) and level of education, and their scores on the NART (Blair & Spreen, 1989). Controls all scored above 123 on the Mattis DRS.

Apparatus

The stimuli were presented on a Macintosh Plus computer with a monochrome screen using Psychlab experimental software (Bub & Gum, 1988). RT and accuracy were recorded using a response relay system. Participants pressed the mouse button to indicate their responses. Stimulus arrays consisted of 1–13 items (target plus

Table 1
Demographic Information for the Three Groups in the Experiment and Scores on the NART, WAIS–R Vocabulary, MMSE, and DRS

	Age (years)		YOE		NART		WAIS–R Vocabulary		MMSE		DRS (Total)		DRS Attention		DRS Memory	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Control	72.3	7.1	14.7	2.7	116.5	7.2	61.2	9.2	28.5	1.4	137.8	5.6	36.2	1.4	23.6	1.5
Mild AD	71.0	6.9	14.0	3.3	110.0	9.1	50.4*	11.1	23.3**	2.7	119.4**	9.7	35.8	1.3	15.5**	3.7
Moderate AD	73.2	7.9	13.9	3.6	104.4**	10.2	37.1	12.6	16.24	5.3	95.2	15.4	33.3**	2.8	10.3	3.1

Note. NART = National Adult Reading Test; WAIS–R = Wechsler Adult Intelligence Scale—Revised; MMSE = Mini-Mental State Examination; DRS = Mattis Dementia Rating Scale (total scores and scores on Attention and Memory subscales); YOE = years of education; AD = Alzheimer's disease. Where a difference is indicated between mild AD patients and controls, a significant difference also exists between moderate AD patients and the control group.
*$p < .05$. **$p < .001$.

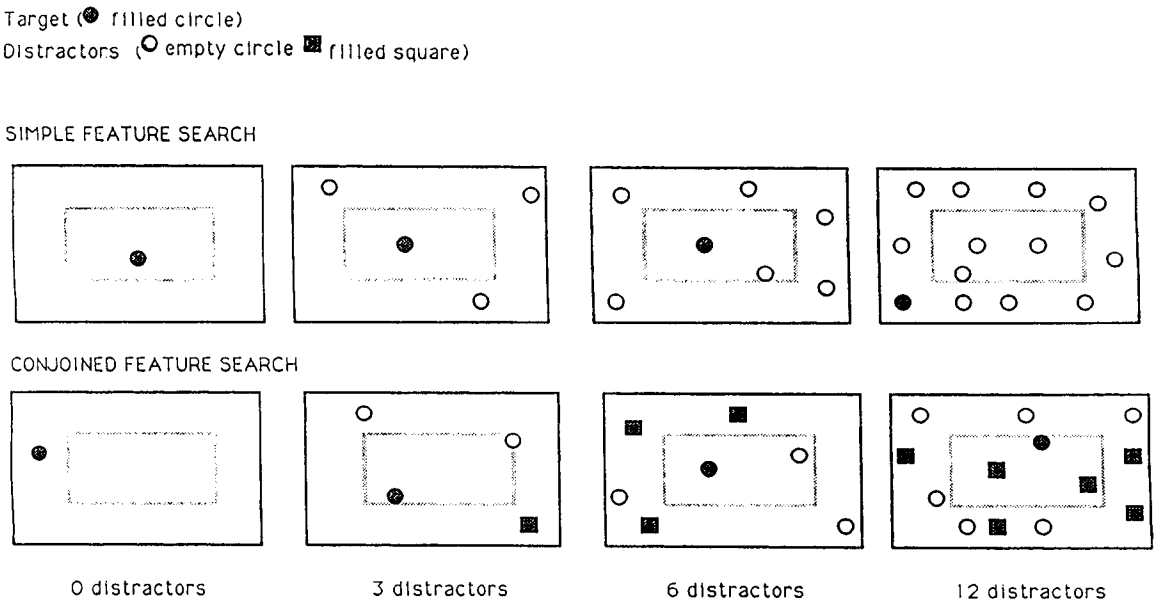

Figure 1. Positive trials in the 0-, 3-, 6-, and 12-distractor conditions in the simple and conjoined feature tasks. Negative trials were as depicted for positive trials but without the filled circle (except for the 0 target absent condition, in which either an empty circle or a filled square alone was shown). The central rectangle was not visible to participants and is shown for the purpose of exposition only.

0–12 distractors) of circles and squares arranged quasirandomly on the computer screen (18.5 cm wide × 14 cm high) around a central fixation point. Examples of these stimuli are shown in Figure 1. The diameter of each circle and the length of the side of each square were 0.7 cm, subtending approximately 0.9° of visual angle. The target stimulus was always a circle filled with a checkered pattern, and the distractors (each embodying individually the two dimensions of shape and shading of the target stimulus) were either an empty circle or a filled square. The whole screen subtended approximately 9° of arc in the vertical axis and approximately 12° in the horizontal axis, with participants seated at a distance of 45 cm from the screen.

The screen of the computer was divided into left and right halves by bisecting the width of the screen: Trials in which target stimuli were presented to the left of this line were defined as left probe trials, and trials in which targets fell to the right of this line were defined as right probe trials. The screen was also divided into central, intermediate, and peripheral regions. The central region encompassed exactly the central half of the computer screen (dimensions of central rectangle = 9.25 cm × 7 cm), and therefore subtended approximately 4° 30′ of arc in the vertical axis and 6° in the horizontal axis. Targets located entirely within the central rectangle were defined as central, those appearing entirely outside this internal region were defined as peripheral, and targets that straddled the line defining these two regions were defined as intermediate.

Design and Procedure

The experiment was described to participants and then they completed the consent forms. Immediately thereafter, participants were given the preliminary psychometric tests (MMSE, NART, DRS, and WAIS–R Vocabulary).

Participants then completed the experimental phase of testing. This was composed of two target detection tasks (i.e., simple and conjoined feature search). The instruction in both tasks was for the participant to respond as quickly as possible by pressing the mouse key whenever a target stimulus was present and to withhold responses when no target was present. In both tasks, the target was represented by a filled circle (see Figure 1), and there was an equal probability of the target being present or absent on any one trial. The two tasks differed from each other with respect to the nontarget elements comprising the distractor array. In the simple feature task, the distractors were empty circles, differing from the checkered circle target by texture only. In the conjoined feature task, two types of distractors were present, but all shared one of the critical dimensions with the target; whereas the target stimulus was a filled circle, the background distractors were either empty circles (sharing shape) or filled squares (sharing texture). It is important to note, then, in contrast to the feature search in which the target and distractors differed by a single feature, in the conjunction search, the target represented a conjunction of two features, both of which were present in the background array.

In both tasks, there were four array sizes of 0, 3, 6, or 12 distractors. At each of these array sizes, there were 20 target-present and 20 target-absent trials, making a total of 80 positive (target present) and 80 negative (target absent) trials per task. On positive trials, the distractor set accompanied the target stimulus, whereas on negative trials, only the distractors appeared on the screen. When present, the location of the target varied between the left and right sides of the screen and across the central, intermediate, and peripheral regions of the screen (with the probability of presentation at each of these locations weighted 1:1 [left:right] and 2:1:2 [central:intermediate:peripheral]). Therefore, within each of the 20 positive trials at each of the four array sizes, there were five target presentations in each quarter of the screen, two of which occurred in the central portion of the screen, two in the peripheral zone, and one in the intermediate zone. The 20 positive trials were randomized prior to the presentation of each block together with the 20 negative trials.

A single trial proceeded as follows: The word *ready* appeared in the center of the screen for 3 s, followed by the stimulus display,

which remained on the screen until a response was made or for a further 3 s. No feedback was given during the experimental tasks. Participants responded with their dominant hand. RTs and errors (omission and commission) were recorded and were calculated as a function of array size, and side (left or right) and location (central, intermediate, or peripheral) of the target. Prior to testing, explicit instructions and practice trials were given to all participants. In the practice instructions, both the speed and the accuracy of participants' performance were emphasized, and verbal feedback was given. For the experimental trials, the speed and accuracy of performance were stressed prior to each block of testing.

The order of the simple feature task and the conjoined feature task was counterbalanced across subjects. Within each task, a series of four blocks was administered, with each block containing 40 trials, 20 of which were positive and 20 negative, with a full crossing of the experimental variables in each block. Short breaks of 1–2 min duration were provided between blocks of testing. Both the simple and conjoined feature search tasks were completed within a single test session and participants were then debriefed about the purposes of the study.

Statistical Analyses

Analyses were performed on both the error data and the RT data, with the median correct RTs calculated for each participant on target present trials. Analyses of variance (ANOVAs) were conducted on both errors and median RTs to examine differences between the three groups (mild, moderate, and elderly control) as a function of task and array size. Linear regression lines were plotted for each group with RT set against array size to derive separate intercept and slope values for the simple and conjoined feature search tasks. Group differences were also examined as a function of target laterality (left or right of screen) and of location (central, intermediate, or peripheral zones). All interactions were broken down using Tukey's honestly significant difference post hoc tests, with $p < .05$, to determine significant pairwise differences. Only the significant post hoc results are presented.

In addition to the analyses on the median RTs, we also analyzed variability in RT. Increased variability in performance has been previously reported in studies of normal aging (Botwinick & Thompson, 1968; Fozard, Thomas, & Waugh, 1976), and we were interested to investigate whether there would be an even greater increase in variability in patients with AD. We used a robust statistical index of variability, namely the natural logarithm of the variance ($ln[s^2]$), to examine consistency of individual performance within and across blocks of testing. (To complement the variability analysis, we also evaluated changes in the mean level of group performance across blocks of testing; however, because there were no revealing block interactions on the mean measures of task performance, and for reasons of length, we do not report the results of these analyses below.)

Results

We report the analyses using the error data first and then the analyses conducted on the RT for the correct target-present trials. These latter analyses are discussed in terms of the effects of (a) array size (including median RT, variability, and Brinley analyses), (b) target laterality (left or right), and (c) target location (central, intermediate, or peripheral).

Errors

As intended in the design of the study, all groups performed well and relatively few errors were made. In particular, no participant made errors exceeding 5% of the total trials on either the simple or conjoined feature tasks. This indicated that the level of task difficulty was appropriate for investigating the visual search abilities of AD patients.

ANOVAs conducted to examine the two within-subject variables of task (simple or conjoined feature) and array size (0, 3, 6, or 12 distractors) and the one between-subjects variable (group) on the number of errors (omissions and commissions, analyzed separately) revealed a difference in error performance across the three groups: There were significant main effects of group on both omission, $F(2, 37) = 5.45$, $p < .01$, and commission errors, $F(2, 37) = 3.72$, $p < .05$. There were no two-way interactions between group and task nor between group and array size for either dependent measure, and the three-way interaction (Group × Task × Array Size) was not significant for either omission or commission errors.

For the omission errors, when the main effect of group was analyzed further, post hoc tests showed that on the simple feature task, the moderate AD patients (mean errors per participant = 4.0) made significantly more errors than both the mild AD patients (mean errors = 0.56) and the elderly controls (mean errors = 0.53), who did not differ significantly from each other. This same pattern approached significance on the conjoined feature search task (mean omission errors = 5.54 for moderate AD, 0.89 for mild AD, and 0.63 for elderly controls).

For the commission errors, when the main effect of group was analyzed further using the same post hoc tests, there were no significant differences between groups on the simple feature task (mean errors = 2.00 for moderate AD, 0.22 for mild AD, and 0.20 for elderly controls), although the pattern of errors was similar to that reported for omission errors. On the conjoined feature search task, the post hocs indicated that moderate AD patients (mean errors = 4.00) made a significantly greater number of commission errors than the elderly controls (mean errors = 0.40), although the moderate AD patients did not differ significantly from the mild AD group (mean errors = 1.56).

Effect of Array Size on Task

Median RT as an index of performance. To evaluate the critical effect of array size on the three groups as a function of type of task, we performed an ANOVA with two within-subject variables (array size and task type) and one between-subjects variable (group). The dependent measure was median correct RTs. The most important finding was the presence of a significant Task × Group × Array interaction, $F(6, 111) = 2.80$, $p < .025$. This is illustrated in Figures 2 and 3, which show the means of the median values at the various array sizes for the three groups for the simple and conjoined feature tasks, respectively. Note that the *y*-axis is

scaled differently for the two figures to reveal more clearly the significant effects.

Post hoc analyses conducted on the significant three-way interaction from the global ANOVA showed that there were no differences across increasing array size on the simple feature search task for any of the groups, as evidenced by the relatively flat functions shown in Figure 2. The major characteristic of the data from the simple feature task was a baseline shift in the median hit RT in AD patients, which was statistically independent of the number of background distractors. The degree of this AD-related baseline shift in RT on simple feature search was related to disease severity, and was probably due to generalized psychomotor slowing.

By contrast, there was a linear increase in RT on the conjunction task. RTs slowed as array size increased in all three experimental groups on conjunction search. However, the extent of the slowing differed across the three groups. More specifically, in the conjunction task, differential increases in RT were observed in AD patients as array size increased, superimposed on increases in intercept in AD patients similar to those observed on the simple feature task. In detail, comparing the 3-distractor to the 0-distractor condition, the elderly control group was 64.4 ms slower, the mild AD group was 109.2 ms slower, and the moderate AD group was 127.6 ms slower. We saw similar differences on conjunction search when comparing the 6- and 3-distractor conditions: The elderly controls were slowed by 89.5 ms, the

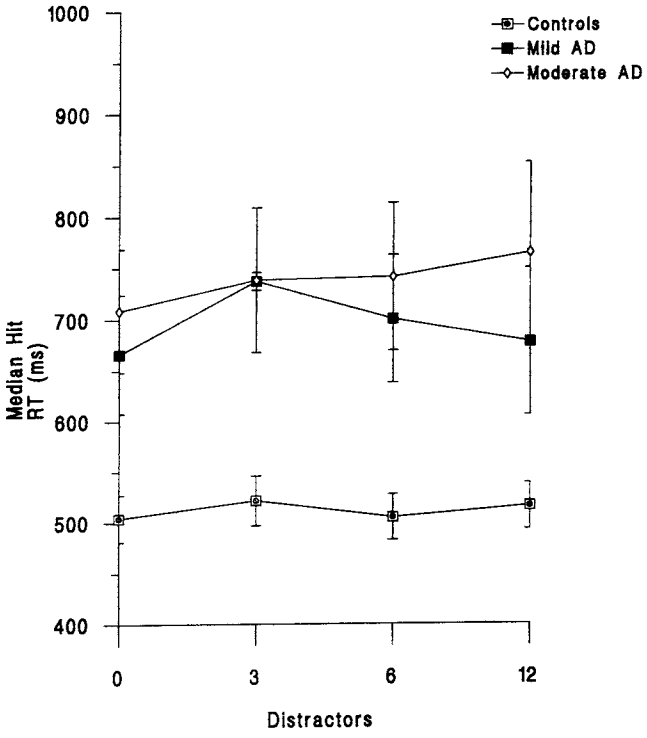

Figure 2. Median hit reaction time (RT) for the three groups of participants (controls, mild Alzheimer's disease [AD], and moderate AD) as a function of number of distractors on the simple feature search task. Vertical bars represent ±2 *SEM*s for the performance of that group.

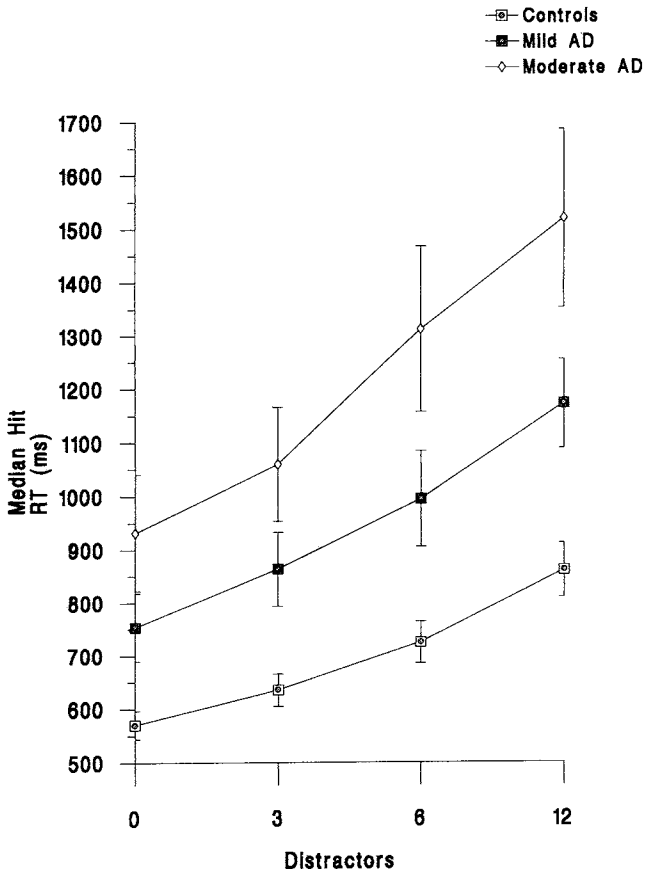

Figure 3. Median hit reaction time (RT) for the three groups of participants (controls, mild Alzheimer's disease [AD], and moderate AD) as a function of number of distractors on the conjoined feature search task. Vertical bars represent ±2 *SEM*s for the performance of that group.

mild AD group by 131.4 ms, and the moderate AD group by 252.0 ms. Finally, the same pattern emerged in the difference between the 12- and 6-distractor conditions, although the increment for the moderate AD group appeared to be reaching a plateau relative to the size of the increase between 3- and 6-distractors: The elderly control group was slowed by 136.3 ms, the mild AD group by 176.6 ms, and the moderate AD group by 207.0 ms. To summarize, on the conjoined feature task, the systematic increment as array size increased was seen in all three groups, but the slope of the increment was most dramatic in the moderate AD group (see below for slope values).

In addition to the three-way interaction, there were a number of significant two-way interactions. There were differences in overall RT for the three groups on the simple feature and conjoined search tasks, $F(2, 37) = 5.89, p < .01$. On simple feature search, the post hoc tests revealed that the elderly control group responded significantly faster than the two patient groups, which did not differ significantly from each other (see Figure 2). By contrast, on the conjoined feature search task, the response latency of the moderate group of AD patients was significantly longer than that of the

mild group, which was, in turn, significantly slower than that of the elderly control group (see Figure 3). There were therefore more pronounced differences in overall target detection time between groups on the conjoined feature task.

The groups also differed in RT across the different array sizes, with the moderate AD patients slowest on the displays with the larger arrays, $F(6, 111) = 5.32, p < .0001$. This is a corollary of what was noted earlier (in the context of the three-way interaction [between group, task, and array]) concerning group differences on conjunction search.

Finally, collapsed across groups, performance across the arrays varied for the simple feature and conjoined search, $F(3, 111) = 36.41, p < .0001$. On the conjoined but not simple feature task, post hoc tests indicated that there was a significant difference between the average response latencies at each of the array sizes, with participants responding progressively more slowly as the number of distractors was increased (see Figure 3). This two-way interaction is consistent with what was noted earlier, regarding the linear increase in RT on the conjunction task, when analyzing the source of the Group × Task × Array three-way interaction.

In addition to these two-way interactions, there were main effects of group, $F(2, 37) = 16.55, p < .0001$, of array, $F(3, 111) = 81.91, p < .0001$, and of task, $F(1, 37) = 62.99, p < .0001$, all of which were consistent with what was noted earlier when conducting more detailed analysis of the two- and three-way interactions.

A number of standard indices have been developed to better characterize the nature of visual search functions. One such index involves deriving the value of the slope of the function across array size. The typical functions are less than 4 ms per distractor for simple feature search and approximately 30 ms per distractor for conjoined feature search in healthy young participants (Treisman, 1988; Treisman & Gelade, 1980).

We obtained intercept (in milliseconds) and slope (in milliseconds per distractor) values from linear regression analyses with median correct RT set against the array size for each group on the two tasks. These values are shown in Table 2. The amount of variance accounted for by the line of best fit was also calculated and is included in the table.

Treisman (1988; Treisman & Gelade, 1980) postulated that central cognitive resources are not required to effect the feature extraction that is postulated to be necessary for target detection on the simple feature task. As is evident from Table 2, although there were severity-related increases in the intercept in AD groups, the slopes (which reflect the central cognitive demands of the task) for the three groups on the simple search task were all close to zero, consistent with Treisman's (1988; Treisman & Gelade, 1980) data. There was a slight tendency for the moderate participants to have a steeper slope (4.25 ms per item). This may be suggestive of some impairment in feature extraction in this group, although note that all three slope values (0.53, 0.71, and 4.25 ms/distractor) fell within or very close to the normal range in pop-out performance previously observed by Treisman and her colleagues (1988; Treisman & Gelade, 1980). Note also that the amount of variance accounted for by the regression for the mild participants on simple feature search was small, probably due to the unusual increase in RT for the three-distractor condition. Why this slight increase occurred in this particular condition is not clear but it does not seem to be of obvious theoretical significance. Small effects of cue size on simple feature search have also been noted in previous studies (see, e.g., Greenwood et al., 1997), and these observations would appear to be consistent with recent evidence that suggests that simple and conjoined feature search may lie at opposite extremes of a parallel–serial search continuum, rather than being categorically different (Duncan & Humphreys, 1989; Nakayama & Silverman, 1986).

Table 2
Intercept, Slope, and r^2 Values for the Three Participant Groups on the Simple and Conjoined Feature Tasks

Group	Intercept	Slope	r^2
Simple feature search task			
Control	507.8	0.53	10.4
Mild AD	609.0	0.71	1.3
Moderate AD	715.9	4.25	90.1
Conjoined feature search task			
Control	568.8	24.50	96.8
Mild AD	762.1	34.90	99.3
Moderate AD	941.1	50.25	99.7

Note. AD = Alzheimer's disease.

In contrast with the simple feature task, on the conjoined search task, substantial increases in both intercept and slope were observed in both AD groups, with both increases occurring in proportion to the severity of the illness. According to Treisman (1988; Treisman & Gelade, 1980), central resources are required to perform this task to conjoin the features (here, shading and circularity) by which the target can be defined. The slopes for all three groups are much steeper than for the simple feature task, indicating a significant requirement of central processing resources. This is again consistent with Treisman's (1988; Treisman & Gelade, 1980) own findings. Moreover, the variance accounted for by a linear regression was large, indicating that the linear functions derived accounted well for the data. Of especial note, both the elderly control and mild AD group functions show slopes that are broadly in the range of normal participants (30 ms per item for normal young participants), but the slope for the moderate AD group was substantially steeper. That the linear increment in RT with number of distractors in the conjoined search but not simple feature search task was largest for the moderate AD group, followed by the mild AD group and the elderly control group, clearly reflects the nature of the attentional deficit in AD and its scaling by disease severity.

Taken together, these findings indicate that the performance of mild-to-moderately impaired AD patients may be relatively well preserved on less resource-demanding tasks such as simple feature search, although there is a hint (from the slightly greater slope observed in the moderate AD patients on the simple feature task) that deficits may emerge once patients have progressed to a more severe level of impairment. By contrast, when substantial central cognitive

resources are required, such as in conjoined feature search, impaired performance may be evident in AD. These impairments then become particularly apparent as the central processing demands of the task are increased.

Variability as an index of performance. In addition to analyzing the group differences using the median RT, we examined the variability in individual performance on the two tasks using the natural logarithm of the variance ($ln[s^2]$) as the dependent measure. Increased variability in performance has been reported in studies of normal aging (Botwinick & Thompson, 1968; Fozard et al., 1976), and we were interested here in investigating whether there would be a greater increase in variability in patients with AD. The natural logarithm of the variance was used as the measure of variability because of its capacity to correct for the potentially powerful effects of outliers on the magnitude of the variance and to highlight patterns of consistency over the course of the experiment. To capture the variability over the four blocks of each task, we included block as a variable in the ANOVA, with ($ln[s^2]$) as the dependent measure.

The main finding of the variability analyses indicated that individuals in the two AD groups manifested more variable performance compared with the elderly controls, but that this increased variability decreased in relative terms over blocks of testing in the more severe AD group. The relevant data are presented in Table 3.

In the four-way ANOVA (Block × Task × Array × Group), with the first three variables as within-subject variables and group as a between-subjects variable, there was a significant three-way interaction between task, group, and array, $F(6, 111) = 3.67$, $p < .005$. Post hoc tests indicated that variability increased progressively as the array size increased on the conjoined feature task, and that this was most pronounced in the AD groups. This finding is complementary to the previous data, which used median hit RT as the dependent measure. (However, note that the error bars shown in Figure 3 illustrate interindividual variability, which is a distinct form of variability from the intraindividual variability reported in this section.)

The three-way interaction between group, block, and task also approached significance, $F(6, 111) = 2.17$, $p = .06$. When this interaction was analyzed further, it became apparent that, on the conjoined feature task, the moderate AD patients initially showed a higher level of variability in their responding (Block 1), but there was a differential reduction in the level of variability in this group relative to the elderly control group and the mild AD group on this task over blocks of testing. As an illustration of this effect, at Block 1, the level of variability in performance across groups (collapsed over array size) was 12.08 (moderate AD) against 10.96 (mild AD) against 9.94 (elderly controls). At Block 4 of testing, these values had changed to 11.36, 11.01, and 9.85, respectively. Therefore, the order of the three groups was preserved across blocks, but the relative difference between the groups changed. One interpretation of this effect is that the moderate AD patients were showing a much slower practice effect on the conjoined feature task than participants in the other two groups (although note that participants in all three groups made very few response errors on this task). From a practical perspective, this finding suggests that the effects of practice may, under some circumstances, outweigh the negative effects of fatigue on variability of performance in participants suffering from a more advanced form of AD. However, if participants had been tested over a much longer time scale, then the more severe AD patients may have shown a greater level of variability in performance over time. This remains an open empirical question that should be investigated in the future, given its possible relevance for activities of daily living in AD.

In addition to the three-way interaction, as expected there was a significant two-way interaction between task and array size, $F(6, 111) = 3.67$, $p < .005$. This reflected the fact that performance became more variable on the conjoined feature task as array size was increased. As expected, too, there were significant main effects of group, $F(2, 37) = 12.11$, $p = .004$, array size, $F(3, 111) = 42.27$, $p = .001$, and task, $F(1, 37) = 46.58$, $p = .002$. That is, variability was greater in the two AD groups than in controls, it increased as a function of

Table 3
Variability Data for the Three Participant Groups on the Single and Conjoined Feature Tasks

Group and array	Block 1	Block 2	Block 3	Block 4
	Simple feature search task			
Control				
0	8.87	7.99	8.48	9.37
3	9.48	8.55	7.75	7.78
6	8.03	8.73	8.03	8.22
12	9.19	8.45	8.00	8.33
Mild AD				
0	9.81	10.24	9.92	9.44
3	9.93	9.90	10.08	9.20
6	9.52	10.51	8.63	8.91
12	9.98	9.05	9.83	9.11
Moderate AD				
0	9.72	10.18	10.69	9.76
3	9.61	10.10	9.70	10.55
6	9.84	9.30	9.89	9.94
12	10.32	10.08	9.90	10.55
	Conjoined feature search task			
Control				
0	9.01	8.14	8.66	8.69
3	9.02	9.30	9.76	9.45
6	10.46	10.29	10.17	10.06
12	11.26	11.20	11.17	10.89
Mild AD				
0	10.14	11.11	9.43	10.88
3	10.58	10.97	10.85	10.49
6	11.42	10.85	10.79	10.89
12	11.75	12.48	12.15	11.41
Moderate AD				
0	10.70	9.86	10.05	9.74
3	12.96	11.32	10.67	11.75
6	12.03	10.84	11.55	11.50
12	12.62	12.10	12.35	11.78

Note. AD = Alzheimer's disease. The natural logarithm of the variance ($ln[s^2]$) is given in the table by group, across stimulus array size, and across the four blocks of testing.

array size, and it was greater on the conjoined feature task than on the simple feature task.

Evaluation of slowing in search function. The findings thus far suggest that in both median RT and in the distribution of the data (indexed by variability) there were important differences across the search functions for the three groups and that these functions differed for the simple and conjoined feature tasks. An important question is whether these differential group-related effects merely reflected generalized cognitive slowing or instead indicated a disproportionate deficit in the AD patients. To evaluate this, we constructed Brinley plots in which we compared the performance of the elderly control, mild AD, and moderate AD groups against the performance of younger participants (Brinley, 1965). Over the past 30 years, this procedure has been widely adopted in the cognitive aging literature (although its exact applicability is still subject to some debate; see Cerella, 1994; Myerson, Wagstaff, & Hale, 1994; Perfect, 1994) and it has also begun to be used in studies of AD patients (see Nebes & Brady, 1992). The critical feature of the Brinley plot is that, by plotting the findings from elderly or clinical groups against those of healthy, young controls, we can obtain lines of best fit. If there were no differences between these groups and the young controls, the slopes would be equal to 1. The standard finding is that normal aging participants show an increased slope of roughly 1.5–2 times the magnitude of the slope of the function characterizing the performance of young participants (Cerella, 1985), and this is attributed to the generalized cognitive slowing associated with aging. To the extent that, on a given task, a further increase in RT is observed in elderly participants above and beyond this degree of slowing, one can interpret the pattern of performance as being specifically associated with the demands of the task and possibly unique to the cognitive domain under investigation (see Foster, Behrmann, & Stuss, 1995). Furthermore, in AD patients, if additional slowing is related to the disease process, then one would expect to observe an increase in slowing with the level of severity of the illness.

In their meta-analysis of cognitive performance in AD patients, Nebes and Brady (1992) noted that the Brinley functions characterizing the AD data are highly linear, and specify this as an important criterion for whether a Brinley analysis should be conducted. In the present experiment, this criterion was met for the conjoined feature Brinley data but not for the simple feature Brinley data. Specifically, the linear regression lines (or Brinley plots) that were fitted to the conjoined feature data accounted for 97.9% (elderly control), 97.4% (mild AD), and 93.2% (moderate AD) of the variance in RT (r^2), respectively. Furthermore, the slope on the simple feature search task was no different across the three experimental groups for the simple feature task, but was considerably greater for the AD patients on the conjoined feature task (see Figure 4). We therefore focus on the Brinley plot for the conjoined feature task to investigate further the mechanisms underlying the increased Brinley slope for the conjoined feature search data in AD patients.

Adopting the standard Brinley procedure, we plotted the RT values for the three groups (elderly control, mild AD, and moderate AD) on the ordinate against the RT for the reference young control group on the abscissa, across the range of values of the independent variable (i.e., 0–12 distractors). The data for the young group (young controls) were taken from another experiment, which examined the effects of normal aging on the performance of these tasks under identical experimental conditions (Foster et al., 1995). As shown in Figure 4, the regression slopes of the Brinley plots for the conjoined feature task indicate a degree of slowing ranging from substantial to severe: 2.55 (elderly control) to 3.64 (mild AD) to 5.19 (moderate AD). Therefore, relative to unity (by definition, the slope of the Brinley function describing the data derived from the young participants, plotted against themselves), the AD patients showed a much steeper slope than the elderly controls on the conjoined feature task. Furthermore, the degree of slowing in the AD patients relative to the performance of young controls was well scaled by the degree of patients' functional impairment. (By contrast, on the simple feature task, there was no systematic trend in the Brinley slope values across the three groups.)

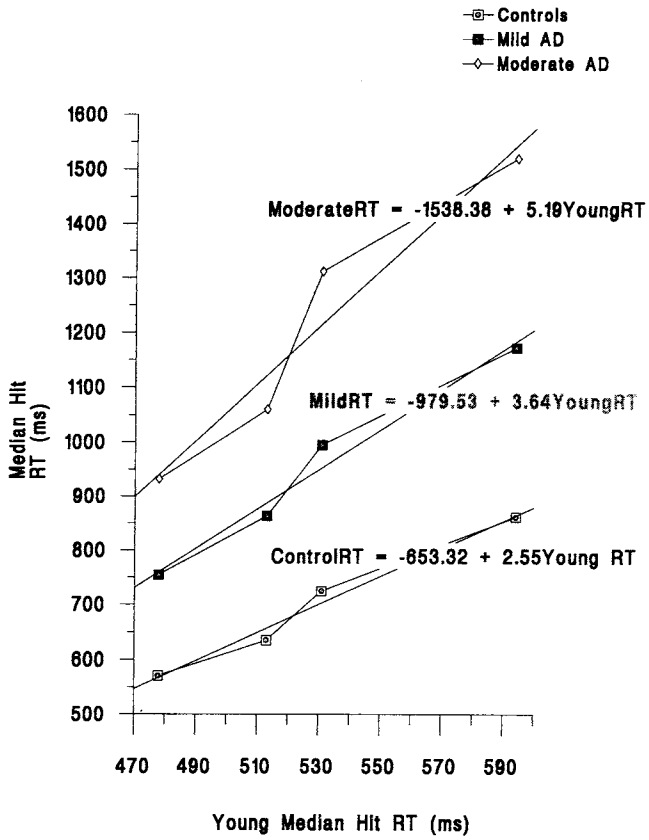

Figure 4. Brinley plots for the conjoined feature search task, illustrating target detection time in the three older groups of participants (controls, mild Alzheimer's disease [AD], and moderate AD) as a function of detection time among young participants on feature conjunction. (The values on the abscissa refer to data obtained in a complementary study that investigated the performance of young healthy controls on the same task; see Foster, Behrmann, & Stuss, 1995). RT = reaction time.

In a review of their data, Nebes and Brady (1992) reported Brinley slope values of 2.26–2.48 for AD patients performing batteries of different cognitive tests. (The precise slope value reported by Nebes and Brady was determined by the specific cognitive tests included or excluded from their analyses.) This overall range in slope values breaks down further according to Nebes and Brady's categorization of patient severity (mild AD: DRS $\geq$ 119, moderate AD: DRS $\leq$ 118) as follows: mild AD slopes = 1.87–1.97, moderate AD slopes = 2.56–2.94. (Here, the ranges of values cited refer to precisely which participants were included or excluded from the analyses conducted by Nebes and Brady, 1992.) Therefore, the slope values observed on the conjoined feature task in the present study (mild AD = 3.64, moderate AD = 5.19) are considerably greater than those observed by Nebes and Brady (1992). Note that this also seems to apply to the slope value of 2.55, which we observed for the elderly controls (cf. Nebes & Brady, 1992: elderly controls showed slopes, compared with young controls, in the range of 1.36–1.39 on their range of tasks). This is consistent with our previous findings using this paradigm in a larger sample of elderly participants (Foster et al., 1995). Therefore, there are attentional deficits elicited by the central cognitive demands of the conjoined feature task over and above those anticipated on the basis of generalized cognitive slowing in (a) elderly controls (compared with young controls) and (b) AD patients (compared with age-matched controls).

To summarize, the most important theoretical implication of our present findings is that the disproportionate slowing observed in the AD patients on the conjoined feature task is, according to the criteria espoused by Salthouse (1985) and Nebes and Brady (1992), indicative of a specific cognitive impairment that cannot simply be accounted for in terms of a linear function describing generalized slowing. In line with the theoretical significance of this finding, the degree of slowing observed in the present study (relative to that observed in other cognitive domains) is a subject that is addressed further in the Discussion.

Effect of Target Laterality on Search

A four-way ANOVA (Task × Side × Array × Group) was conducted to examine the effect of side of target presentation on task performance. These data are shown in Table 4.

As anticipated, many of the statistical effects that were observed echo those that have been previously reported in the *Median RT as an index of performance* section. For the sake of brevity, and to avoid redundancy, only statistical effects that relate to the novel variable of side, or interactions that incorporate this variable, are therefore reported in this section.

There was a significant Side × Task × Group interaction, $F(2, 37) = 7.78$, $p < .005$, and a significant Side × Task interaction, $F(1, 37) = 15.70$, $p < .005$. As anticipated, there were no significant side-related effects on target detection time for the simple feature search task, indicating equivalent levels of processing on both sides of the midline of the computer screen. However, on the conjoined feature task, the post hoc tests showed that participants were faster in detecting a target presented on the left side of the screen, and this effect was more pronounced in the moderate AD group than in the mild AD group or in the elderly controls. This observation casts doubt on the notion of relative preserva-

Table 4
Median Hit Reaction Time (in Milliseconds) for the Three Groups of Participants as a Function of the Side (Left or Right) of the Target on the Simple and Conjoined Feature Search Tasks

Group and side	0 distractors	3 distractors	6 distractors	12 distractors
		Simple feature search task		
Control				
Left	512.8	517.0	491.9	527.5
Right	494.1	501.5	498.5	497.7
Mild AD				
Left	678.1	722.5	709.2	665.8
Right	690.3	733.5	710.4	687.6
Moderate AD				
Left	699.1	757.1	765.4	744.8
Right	738.2	714.5	749.8	794.5
		Conjoined feature search task		
Control				
Left	559.7	635.7	715.3	818.0
Right	566.0	635.8	709.0	910.8
Mild AD				
Left	730.7	882.9	972.3	1,174.7
Right	748.3	867.7	1,018.5	1,219.2
Moderate AD				
Left	936.3	1,061.5	1,296.5	1,640.0
Right	995.6	1,203.2	1,598.0	1,740.4

Note. AD = Alzheimer's disease.

tion of visuospatial attention to the right side of space (as might be predicted from Mesulam, 1990; see also Corbetta et al., 1993; Heilman et al., 1985; Nobre et al., 1997; Ojemann et al., 1997) following the occurrence of bilateral parietal brain damage, as typically present in AD.

Rather, this pattern of findings could be due to AD-related problems in disengaging and then shifting attention from the "resting" left side of space in patients compared with controls. (Attention may "rest" on the left side of space because of Western reading habits developed over a lifetime.) The post hoc tests show that the superiority for left targets emerged for the elderly control group only at the largest array, whereas for the mild AD group it was observed at Array Size 6, and for the moderate group it emerged at Array Size 3, clearly reflecting the joint effects of task, group, side, and array size.

Consistent with the three-way Side × Task × Group interaction, there was also a significant two-way interaction between side and group, $F(2, 37) = 4.01$, $p < .05$, with moderate AD patients disproportionately slower to detect targets on the right side of the screen. As expected, there was also a main effect of side, $F(1, 37) = 7.86$, $p < .01$, and a main effect of array, $F(3, 111) = 41.79$, $p < .001$, on task performance. The effect of side indicated that, overall, targets were easier to detect on the left side of the screen, although, as indicated by the Side × Task interaction, this was the case for the conjoined feature search task only.

Effect of Target Position on Search

As before, many of the statistical effects that were observed echo those that have been previously reported in the *Median RT as an index of performance* section. Again, for the sake of brevity, and to avoid redundancy, only statistical effects that relate to the novel variable of position, or interactions that incorporate this variable, are therefore reported in this section.

A four-way ANOVA (Task × Position × Array × Group) was conducted to examine the effect of location of target presentation on task performance. The relevant data are shown in Table 5. The four-way interaction just failed to reach significance, $F(1, 22) = 1.79$, $p = .07$. There was a significant Task × Group × Position interaction, $F(4, 74) = 2.75$, $p < .05$. (Note the difference in y-axes across the different groups, although this is held constant across the two tasks for each group.)

Somewhat surprisingly, post hoc tests indicated that the location of the target (central, intermediate, or peripheral) influenced performance significantly on the simple feature task, with faster overall detection for central targets relative to intermediate and peripheral targets. The latter two locations did not differ significantly from each other. The four-way interaction approached significance because these differences in the effects of target location were much more

Table 5
Median Hit Reaction Time (in Milliseconds) for the Three Groups of Participants as a Function of the Location of the Target on the Simple and Conjoined Feature Search Tasks

Group and location	0 distractors	3 distractors	6 distractors	12 distractors
		Simple feature search task		
Control				
Central	500.7	501.0	498.0	497.0
Intermediate	501.1	507.1	487.4	503.7
Peripheral	495.8	521.5	506.7	524.4
Mild AD				
Central	651.4	719.3	692.4	658.9
Intermediate	758.6	676.3	755.8	664.6
Peripheral	688.2	835.0	704.8	749.3
Moderate AD				
Central	689.2	701.9	687.6	731.7
Intermediate	748.2	701.0	837.4	902.9
Peripheral	803.3	859.7	754.0	779.6
		Conjoined feature search task		
Control				
Central	571.7	585.9	652.9	747.8
Intermediate	559.1	656.3	724.9	862.9
Peripheral	575.1	689.0	813.0	969.3
Mild AD				
Central	725.9	828.0	945.9	1,095.9
Intermediate	788.4	886.7	931.2	1,288.4
Peripheral	764.2	895.9	1,121.3	1,242.2
Moderate AD				
Central	925.2	1,057.5	1,524.4	1,403.7
Intermediate	861.2	1,101.6	1,847.7	1,777.8
Peripheral	997.6	1,192.9	1,472.0	1,698.1

Note. AD = Alzheimer's disease.

pronounced in AD patients than in elderly controls (see also Foster et al., 1995).

There was a significant two-way interaction between group and position, $F(4, 74) = 2.75$, $p < .05$. As noted above, in the context of the three-way Task × Group × Position interaction, the overall effects of target location were most noticeable in AD patients. There was also a main effect of location, $F(2, 74) = 7.31$, $p < .01$: As anticipated, target detection was significantly faster overall at the central target location.

The finding of faster detection for central than for intermediate and peripheral targets on the simple feature search was somewhat unexpected given the "parallel" nature of the visual processing thought to mediate performance on this task. However, this difference was much less evident in the elderly control participants than in the AD patients. The differential impairment of AD patients in detecting peripheral targets on the simple feature search task was proportional to the severity of the illness and suggests some constriction of the perceptual window, necessitating shift and refixation across the computer screen.

By contrast, on the conjoined feature search task, although, as expected, there was a main effect of location, further analysis of the data indicated no differential group-related effect of position on target detection time. This appeared to be due to detection performance being slow in the moderate AD group, even when the target was presented centrally. (This may have been due to participants in this group failing, despite cuing with the *ready?* signal, to recenter their gaze appropriately between trials.) This possibility requires further investigation in future studies.

Discussion

This article reports a detailed study of operationally separable components of visuospatial attention. A visual search paradigm composed of simple and conjoined feature search tasks was used to evaluate the level of attentional functioning in patients with varying degrees of severity of AD and matched controls. Whereas in the first simple feature task, the target differed from the background distractors by a single feature, in the conjoined task, the target was differentiated from the background distractors by a conjunction of two features, each of which was embodied by a subset of the distractors.

This paradigm has previously been used extensively in the cognitive psychology literature (Driver, McLeod, & Dienes, 1992; Poisson & Wilkinson, 1992; Pollmann, 1996; Quinlan & Humphreys, 1987; Theeuwes & Kooi, 1994; Treisman & Gelade, 1980), and as a marker for the nature of visual search for different target types and for different clinical populations (Arguin, Joanette, & Cavanagh, 1993; Grabowecky, Robertson, & Treisman, 1993; Robertson, Treisman, Friedman-Hill, & Grabowecky, 1997), as well as a robust index of visuospatial attention (Treisman, 1988; Treisman, 1993).

In this study, we compared the performance of elderly control, mild AD, and moderate AD groups across simple and conjoined feature search tasks with the primary goal of characterizing the nature of visual search in the AD groups. Error rate, RT, and variability were examined across the two tasks as a function of number of distractors in the display and, using Brinley plots, we plotted these data against a group of young controls to determine the degree of increased RT compared with that expected by generalized cognitive slowing. We also examined effects of laterality (left vs. right) and location (central vs. intermediate vs. peripheral) on target detection performance.

The most important finding was that AD patients had significant deficits in visual attention, as revealed by their differentially slowed target detection speed on the conjoined feature task. The facts that this differential impairment was observed only in the conjoined feature task and that the degree of the impairment was directly related to the level of the independent variable (i.e., size of distractor set) enable us to rule out the possibility that this finding was due to a fundamental motivational, sensory, or motor deficit in the AD patients. Given that parietal lobe dysfunction is a typical pathological characteristic of AD, our finding of impaired conjoined visual search is consistent with previous work that indicated that the superior parietal cortex is specifically involved in mediating conjunction search (Corbetta et al., 1995). Other possibly relevant brain regions are the anterior cingulate (thought to be involved in selecting target information from distracting information; see Posner, 1992; Posner & Dehaene, 1994; Posner & Petersen, 1990) and the frontal lobes (thought to be involved in resolving response conflict), both of which may also be dysfunctional in AD. Interestingly, less resource-demanding capabilities, tapped by the simple feature search, remained relatively preserved in AD. Of note, it has been suggested that the basal ganglia (which seem to be relatively unaffected in AD) may mediate the fundamental ability to detect salient targets (see Posner, 1992; Posner & Dehaene, 1994; Posner & Petersen, 1990).

An important theoretical point from the present investigation derives from the analysis of the Brinley plots. These revealed that the differential slowing observed on the conjoined feature task in the AD patients was greater than that which could be attributed to the existence of a generalized cognitive impairment. Moreover, the deficits in visual search that were observed in the AD patients increased with the severity of the disease. We saw consistent patterns in the variability analysis. Furthermore, there was some evidence from the variability analysis that more severely impaired AD patients may be facilitated more than controls by the beneficial effects of practice on task performance. However, our overall finding of an absence of pronounced differential AD-related changes in variability in performance over time is consistent with the one previous study that systematically evaluated time-related task performance in AD patients (Nebes & Brady, 1993). The central finding from the location analysis in the present study was that targets on the left were detected better than those on the right, and this became even more evident as the array size increased and as AD became more severe. There was also evidence from the simple feature search data that AD patients may have problems in detecting even highly salient items when they are presented in more peripheral regions of space.

The difference in performance that we observed between the AD patients and controls, with the greatest impairment in the moderate AD patients, was observed in the error data as well as the RT data, and this was especially the case for the conjunction search task. Although the error rates were low overall (as intended, given the simplicity of the task), moderate AD patients made more omission and commission errors than mild AD patients and elderly controls (the latter two groups not differing considerably).

Taken together, the implications of our findings are significant. They imply that AD patients have substantial and specific problems with visual attention when the target item shares common features with other stimuli in the background. These problems seem to be more exaggerated if the target is presented on the right rather than the left side of space. Where the visual target is more distinct with respect to the background, target detection is better preserved in AD, although even salient targets may be relatively poorly detected by AD patients if they are presented in more peripheral regions of space. These findings have important implications for the design of optimal visual environments for people with AD. Our variability data indicate that the problems that AD patients have with visual search may attenuate to a degree, given sufficient task-specific practice. However, these findings are somewhat tentative and require replication.

Until relatively recently, there have been relatively few systematic, experimental investigations into attentional functioning in AD. Those experiments that have been conducted have tended to examine only one independent variable, whereas in the current study, we examined several variables simultaneously, namely, task, array size, target laterality, and target location (in addition, we examined a further variable by manipulating the complement of distractors in the conjoined feature search task [where array size = 3 items], although this manipulation revealed no significant group-related effects and is therefore not reported). It is important to note that this multifactorial approach permits one to interrelate performance differences following systematic manipulation of several different experimental variables. Moreover, as we see from the discussion that follows, a marked weakness of previous experiments is that they have largely examined attentional function in isolation, without attempting to relate attentional capacity in AD to the level of functioning in other cognitive domains, that is, to consider the domain specificity of significant effects that are observed (by, e.g., using the Brinley plot approach that we applied in the current investigation).

With this proviso in mind, we now consider the findings of the most relevant previous studies, and how they may inform and constrain our own findings. The most closely related previous study is that of Parasuraman et al. (1995). Using a similar visual search task, these researchers reported a finding similar to our own for simple feature search, that is, that AD patients were cognitively unimpaired, although they had slower overall search RTs. On conjoined feature visual search, a main effect of group was also reported by Parasuraman et al. (1995). There was further evidence that AD patients were unable to direct their conjoined feature search as well as controls according to the location of a previously presented spatial cue. However, in contrast to our findings, there was no evidence in the Parasuraman et al. (1995) study that AD patients became differentially worse at conjoined feature search as the size of the distractor array increased. The discrepancy between these and our findings clearly requires further investigation, particularly given the comparability of participant group sizes across the two studies. (Note, however, that Parasuraman et al., 1995, used a task requiring the conjunction of different features—color plus letter—from those used in the present investigation, and which involved the use of precues and only two different stimulus array sizes [10 and 15 items]; in addition, all patients in the Parasuraman et al., 1995, study were categorized as being in the mild stage of the disease at the time of testing.)

In another relevant study, Simone and Baylis (1997) examined the ability of young adults, elderly adults, and elderly individuals suffering from AD to perform a selective reaching task. They found that normal aging did not increase the degree of interference caused by distractors on this task. Their finding is similar to the performance that we have previously observed on the simple feature task in elderly individuals (but not on the conjoined feature task, where aging did differentially affect performance; see Foster et al., 1995). However, Simone and Baylis (1997) demonstrated exaggerated effects of interference in AD patients, similar to the findings in the present study of a greater effect of distractors on conjoined feature search in AD patients. (Problems with interference in AD have also been suggested by studies reporting difficulties in resolving stimulus–response conflict, using both experimental [e.g., Foldi, Jutagir, Davidoff, & Gould, 1992; Greenwood et al., 1997; Massman et al., 1993; Nebes & Brady, 1989; Oken et al., 1994; Sahgal et al., 1992; Wright et al., 1994] and psychometric [Koss et al., 1984] measures.) Simone and Baylis interpreted their findings in terms of AD patients' inability to use inhibitory processes, which increased with the severity of AD. This conclusion was supported by Faust et al. (1997), who observed impaired inhibitory control in AD patients on a sentence comprehension task, and Spieler et al. (1996), who observed impaired inhibitory functioning in AD on the Stroop task.

Is the notion of reduced inhibition in AD relevant for explaining our current findings on conjunction search (see also Grande et al., 1996, and Sullivan et al., 1995, for further evidence of reduced inhibition of distractor items in patients with AD)? By contrast with the findings of Simone and Baylis (1997), Faust et al. (1997), Spieler et al. (1996), and others, Faust and Balota (1997) reported no AD-related deficits in inhibition. These researchers used a simple detection task to examine covert orienting of visuospatial attention in AD. There was both an age-related and an AD-related increase in the facilitatory effect of a peripheral cue on target detection. These findings provide an interesting contrast with the data obtained in the current investigation, insofar as our data indicated that, on the simple feature task, peripheral targets were detected more poorly by AD patients. However, this did not apply to our conjoined feature data.

Therefore, the nature of the target and the processes mediating its identification may well have some bearing on whether the stimulus is detected or can be used efficiently by AD patients in different regions of space. Faust and Balota noted equivalent inhibition of return (i.e., a slowing in response to previously cued locations) in AD patients and young and elderly controls. By comparison with the findings of Simone and Baylis (1997), these findings of preserved inhibition of return suggest that there may be fractionation of impairment in inhibitory subprocesses in AD. The findings of Faust and Balota also seem to provide some evidence against the notion that the AD-related deficits in conjoined feature search observed in the present study were necessarily due to impaired inhibitory processes. As we see below in more detail, other studies have, by contrast, noted problems in AD with target enhancement (e.g., event-related potential studies conducted by Blackwood et al., 1987; St. Clair et al., 1985; St. Clair et al., 1988; although, note that some other studies have found target enhancement to be preserved in AD: Balota & Duchek, 1991; Chertkow et al., 1989; Moscovitch et al., 1986; Sullivan et al., 1995).

As noted, the pattern of findings observed by Simone and Baylis (1997) with AD patients is similar to the findings observed in the present study using the conjoined feature task. One theoretical interpretation of the Simone and Baylis findings is that a task that draws on "automatic" functioning in elderly controls may be subserved by "controlled" processing in AD patients. There was the suggestion of a similar effect in our data, with performance slowing somewhat in the moderate AD patients at the 12-distractor array size on the simple feature search task (see Figure 2). However, in other respects, the AD patients who participated in the present study did not manifest cognitive impairment on the automatic simple feature search task. Rather, they showed a pattern more exaggerated than that observed in the previous normal aging study (Foster et al., 1995), namely, cognitive impairment that was focused on the controlled conjoined feature search task. This finding of generally preserved automatic attentional functioning but impaired controlled processing in AD would seem to conflict somewhat with the findings of a recent positron emission tomography study (Nobre et al., 1997) that indicated that these two capacities may be mediated via a similar network of anatomical regions. The key issues here may be regional specialization, and the extent to which the controlled and automatic systems show graceful degradation following brain damage; that is, although mediated by similar anatomically distributed sites, the network of structures and processes mediating automatic processing may be more resilient following brain damage.

Other relevant recent studies have examined the question of interhemispheric balance in AD; for example, Caffarra et al. (1997) used the Posner paradigm to investigate "disengagement" processes in AD. In contrast to our findings, these authors observed no deficits in visuospatial attention in AD: Compared with patients with Parkinson-dementia, Parkinson's disease, and matched controls, AD patients showed no differences in performance, and no significant effects were observed across hemifields. These authors concluded that AD patients show no deficits with attentional disengagement, and discuss their findings in terms of Kinsbourne's (1978) framework of interhemispheric balance. These findings have an important bearing on our data: If AD patients do indeed manifest no impairments on attention disengagement processes, then the deficits that we observed in the present study on the conjoined feature task may be due to problems in processing the stimulus items themselves, rather than in disengaging from distractor items. On the other hand, accounts of our data in terms of impaired processing of target items and reduced disengagement from distractor items are, of course, not necessarily mutually exclusive.

The findings of the Caffarra et al. (1997) study also bear on a related issue concerning the effect of target laterality on detection speed. Recall that, on the conjoined feature task, we observed a left-field advantage for target detection that was most pronounced in AD patients (similar to the pattern observed in our previous studies of the normal elderly, compared with young controls; Foster et al., 1995). Furthermore, in the present study, the left-field advantage was scaled by disease severity. However, Caffarra et al. reported no differences in task performance between AD and other groups and between left and right hemifields. Our finding that AD patients are disproportionately slowed in detecting a target on the right side of the midline on conjunction search may indicate that AD patients have particular problems disengaging and then shifting their focus of selective attention from the left to the right side of space. (Note that there may be a relevant distinction here between disengaging from distractor items and disengaging from the left side of space; these two forms of disengagement may rely on distinct cognitive processes.) However, by contrast with the findings reported here for conjunction search, using a Posner cued visual search task, Buck (1997) observed that AD patients showed a greater deficit for left-sided than right-sided invalidly cued targets (i.e., they were slower to detect a target on the opposite side of space when the invalid cue had been presented on the right rather than the left). When Buck examined the single photon emission computerized tomography scans of the participants in this study, it appeared that the asymmetry in target detection times (left > right) was correlated with the absolute severity of bilateral parietal damage (see also Buck, Black, Behrmann, Caldwell, & Bronskill, 1997).

One possible reason why right-handed AD patients were slower to respond to right-sided targets in the present study is because of interhemispheric transfer of visual information necessary for the identification of left-sided targets in right-handed individuals. There may then be differentially slowed processing of right-sided targets in a disease like AD, because of the callosal atrophy that often occurs in the disease (see, e.g., Parasuraman & Haxby, 1993, for a consideration of the hypothesis that AD is best considered as a disconnection syndrome). Furthermore, as AD patients typically experience bilateral pathology involving both the left and right parietal lobes, especially as the disease progresses, their attentional deficits may be more similar to those of patients with Balint's syndrome, many of whom

experience simultagnosia, bilateral attentional impairment, or both (Pierrot-Deseilligny, 1994; Robertson et al., 1997), rather than the left-sided attentional deficits often reported in patients with unilateral parietal lobe dysfunction.

Moreover, although the pathology present in AD is typically bilateral, significant stable asymmetries have been reported across AD patients, and this too may have influenced our findings (see Grady et al., 1988; Haxby et al., 1990; Parasuraman et al., 1992). For example, Maruff et al. (1995) classified the AD patients that they studied into three different subgroups, according to their abnormally slow attentional biases: Compared with matched controls, the first group showed a significant slowing of RT to all left-sided targets, the second group was significantly slowed to right-sided targets, and the third group showed a significant slowing of RT to both left- and right-sided targets. These findings indicate a considerable degree of interindividual heterogeneity in hemifield-related attentional biases in AD (which may well be related to the acknowledged heterogeneity that exists in AD neuropathology across individuals; see, e.g., Grady et al., 1990), and this may help to explain the different outcomes reported in the extant literature.

As predicted, we saw no group-related difference in target detection across hemifield, or main effect of hemifield, on the simple feature task. These findings are in line with those of Caffarra et al. (1997), and indicate that specific task demands (i.e., feature extraction vs. feature conjunction) may also have an important bearing on hemifield differences in target detection between AD patients and controls.

The findings of Caffarra et al. (1997) also relate to another study that we have conducted (in collaboration with researchers at the University of Sheffield) investigating visual search performance in Parkinson's disease. Using the same tasks, patients with Parkinson's disease were indistinguishable from matched controls on the simple and conjoined feature tasks. By contrast, Parkinson's disease patients with evidence of concomitant frontal lobe dysfunction were globally slower on both tasks (Berry, Nicolson, Foster, Behrmann, & Sagar, in press). These findings suggest that the outcome of Caffarra et al.'s investigation of visual attention in Parkinson's disease patients may have been different if they had also tested a group of Parkinson's disease patients with frontal lobe symptomatology. However, note also that, in further contrast to the findings of Caffarra et al., E. L. Berry (personal communication, November 25, 1998) has observed a similar pattern of performance to that reported here for AD patients in a group of Parkinson's disease patients with concomitant dementia. So, it may be that task, rather than patient differences, represents the crucial distinguishing factor in these experimental outcomes. This question clearly requires further investigation.

In another relevant recent study, Greenwood et al. (1997) used a cued visual search task to manipulate the size of attentional focus in AD. This task was related to that used in the present study (i.e., simple and conjoined feature search), although Greenwood et al. (1997) used precues to indicate (with varying validity) the size and location of the area to be searched. Greenwood et al. (1997) found that location precues exerted the strongest effects on conjunction search and the weakest effects on simple feature search. Moreover, as the size of the invalid cues decreased, conjunction search was facilitated. These findings are consistent with the notion that simple feature search may occur in "parallel" (with no or minimal eye movements), whereas conjoined feature search takes place in "series" (with saccadic eye movements occurring from one stimulus to the next). In the Greenwood et al. (1997) study, the effects of precuing declined progressively with increasing age and the onset of AD. Indeed, the greatest group differences were observed when the precue was small and precise (which benefited the elderly and AD patients considerably less than young controls). Greenwood et al. (1997) interpreted their findings as indicating that both AD and, to a lesser extent, advanced aging reduce control of the spatial focus of attention (see also Parasuraman et al., 1995). These authors also argue that the performance of AD patients is preserved on visual search tasks that require the conjunction of stimulus features (the effects of precues notwithstanding). This clearly conflicts with our own present findings and may well have been due to methodological differences; for example, there were only two different array sizes (10 or 15) in the Greenwood et al. (1997) study, the region of space within which the stimulus arrays were located subtended a smaller visual angle, there were eight different possible types of distractor (rather than the three different types in the current study), and the AD patients were all in the early stage of the disease.

The findings of Greenwood et al. (1997) are consistent with those observed in the present study, and in our previous investigation (Foster et al., 1995), in showing a broad functional continuity between attentional deficits observed in AD and normal aging (with the performance of old–old participants falling between that of young–old and AD participants in the Greenwood et al., 1997, study). Moreover, the findings of Greenwood et al. (1997) suggest one explanation for our present findings: If AD patients (and, to some degree, elderly controls) have problems in controlling the focus of their attentional "window," then they may have searched the stimulus array in our conjoined feature search task suboptimally, while still being able to process stimuli efficiently on simple feature search (see also Coslett et al., 1996; Stark et al., 1997). Specifically, AD patients (and, to a lesser extent, elderly controls) may have problems in modifying the focus of attention sufficiently to process stimuli efficiently. If an impaired reduction in the size of the attentional window also leads to a reduced signal-to-noise ratio within the engaged region of space, this may also explain the higher level of inappropriate responding to distractor items that has been reported in AD (e.g., Simone & Baylis, 1997; see also our own error data, which indicated that AD patients made a larger number of omission and commission errors). A lack of flexibility in visual attention could also explain our observation of differentially slowed detection of targets on the right side of the midline in AD patients on the conjoined feature task. Recall that we also observed severity-related slowing of target detection in more peripheral regions on the simple feature task. For more

peripheral targets, it may well be necessary to widen the window of visual "grasp" in parallel search. If AD patients again lack this flexibility, this could explain why they were differentially worse in the present study at detecting more peripheral targets on simple feature search.

Another relevant finding obtained by Greenwood et al. (1997) concerns these researchers' "combined search" condition, in which—to perform efficiently—participants were required to restrict their search within a subset of array items sharing a salient feature with the target. It has been shown that young controls are able to perform this restricted search well (Egeth, Virzi, & Garbart, 1984), presumably by first selecting out a subset of items sharing the relevant shared property (e.g., color or form), and then searching for the target within this subset of items. Plude and Doussard-Roosevelt (1989) noted that this ability was retained in older adults, and indeed we have replicated this finding among the healthy elderly in a previous study (Foster et al., 1995). Greenwood et al. (1997) argued further that this restricted search capacity is also preserved in AD patients. For reasons of length, we do not discuss our findings in detail here, but we also observed this to be the case in the present investigation, that is, we replicated the findings of Greenwood et al. (1997): In the present investigation, although globally slower, AD patients were not differentially affected by manipulations of the proportion of particular target features among the items of the distractor array. Greenwood et al. (1997) also made an attempt at relating their findings to the explanatory concept of cognitive slowing (Cerella, 1990). They concluded that, because more precise cuing (which they argue should have made the visual detection task less complex) actually made AD patients perform differentially worse relative to controls, this militates against the cognitive slowing explanation. However, it should be noted that Brinley plots were not used in the Greenwood et al. (1997) study, in order to evaluate the cognitive slowing hypothesis more rigorously. Furthermore, the cognitive slowing hypothesis may require refinement before it is evaluated in the context of a task using differentially sized valid and invalid cues. Indeed, Greenwood et al. (1997) accepted that "It is possible that adjustment of the attentional focus itself occurs more slowly in advanced age and with the onset of DAT [dementia of the Alzheimer type], and such an explanation would be consistent with general cognitive slowing" (p. 9).

In another relevant study (Parasuraman et al., 1992), cue-directed shifts of spatial attention were applied to a letter-discrimination task in mild-to-moderate AD patients and age-matched controls. Spatial cues varied in terms of their validity and were presented either centrally or peripherally. RT benefits for valid cues did not differ between the AD group and the controls, whereas RT costs incurred by invalid cues were significantly greater in the AD group than in the controls, suggesting problems in disengaging from an invalid cue. Very similar findings have been reported by Oken et al. (1994) using a closely related disengagement task, and the number of perseverative responses recorded by AD patients in a study reported by Scinto et al. (1994) are also suggestive of problems with disengagement. In contrast with the later findings of Greenwood et al. (1997), Parasuraman et al. (1992) concluded that focusing of attention to location is intact in early AD, but that the disengagement of visuospatial attention is impaired. Indeed, in a complementary study of normal aging (Greenwood, Parasuraman, & Haxby, 1993), it was postulated that, whereas normal aging has only a weak effect on voluntary attention shifts, dementia affects both voluntary and involuntary modes of attentional shifting. Parasuraman et al. (1992) further argued that intact focusing and impaired disengagement of visuospatial functioning in AD may be linked to dysfunction in the early stage of the disease of cortico-cortical attentional networks linking the posterior parietal and frontal lobes (indeed, other researchers have suggested that the parietal lobe—which is typically dysfunctional early in the course of AD—may be intimately involved in the disengagement of spatial attention; see, e.g., Posner, 1992; Posner & Dehaene, 1994; Posner & Petersen, 1990). However, the findings of Parasuraman et al. (1992) clearly conflict with those of Caffarra et al. (1997) and other studies (Faust & Balota, 1997; Wright et al., 1994), which indicate that disengagement processes are not impaired in AD.

The ability to shift appropriately the spotlight (Broadbent, 1970) of selective attention (once it has been adequately disengaged from a previous location) appears to be well preserved in AD (Faust & Balota, 1997; Oken et al., 1994; Parasuraman et al., 1992; Wright et al., 1994). However, there is also some uncertainty concerning deficits in the engagement of attention in AD. The same studies of shift processes cited above also indicate preserved attentional engagement processes in AD (Faust & Balota, 1997; Oken et al., 1994; Parasuraman et al., 1992; Wright et al., 1994). However, taken together with the somewhat contrasting later findings obtained by Greenwood et al. (1997), the findings of Parasuraman et al. (1992) indicate that evidence for impairments in the engagement of focused attention in AD may depend critically on the type of task used: When cued targets are presented in one of several possible locations, and are preceded by cues of different levels of spatial resolution, deficits in engagement in AD may emerge. Impairments in the degree of cue and target engagement have also been suggested using event-related potentials (Wright et al., 1994), although patients and controls did show similar patterns of brain activity. In another study that compared attention in AD and LBD, Sahgal et al. (1992) found that mild AD patients were impaired, compared with matched controls, on one visual task (an attentional set shifting task), but that on another visual task (match-to-sample search) the AD group performed at close to normal levels. Matched mild LBD patients were significantly impaired on both tasks. From a clinical perspective, the findings of Sahgal et al. (1992) indicate that, by carefully choosing appropriate tests of visual attention, one may be able to develop reliable psychological instruments for distinguishing between AD and LBD. Theoretically, this study highlights the fractionation of different components of attentional engagement. Overall, then, in terms of processing of the target, previous experimental findings seem to indicate preserved ability to

shift the spotlight of spatial attention in AD but small deficits in the ability subsequently to engage target locations.

To summarize previous findings that are relevant to the present study, the ability to resolve stimulus–response conflict seems to show early impairment in AD. This appears to be consistent with our error data. Previous studies indicate that decreased distractor inhibition is less severely affected than stimulus–response conflict resolution in AD, yet more significantly than reduced target enhancement, for which there appears to be the least evidence in the existing AD literature (see also reviews of changes in attention in AD presented by Parasuraman & Haxby, 1993; Spinnler, 1991). These findings help in the interpretation of some aspects of our findings: It seems that problems in inhibiting distractors may be more likely to mediate the deficits that we observed than impaired target processing. However, regarding the eye movements underlying conjoined visual search, there does not appear to be a consensus from the existing literature indicating whether our findings should be predominantly interpreted in terms of impaired movements toward the target or a deficit in disengagement from distractors. From an anatomical perspective, it has been predicted, on the basis of a proposed theory of anatomically linked attentional networks (Posner, 1992; Posner & Dehaene, 1994; Posner & Petersen, 1990), that there should be impaired disengagement processes in AD (corresponding to damage in the parietal region), with preserved shift and engagement processes (because of limited neuropathology in AD in the superior colliculus and pulvinar, respectively). However, although some findings suggest that the ability to disengage attention is selectively impaired in AD, with preservation of shift and engage capacities, other experiments indicate that attentional deficits in AD are not limited to disengage processes. At least some of the confusion in the extant literature may be due to the fact that, unlike in the present study, few previous studies have attempted to determine whether apparent deficits in disengagement, shift, or engagement processes transcend problems due to global cognitive slowing. In addition, it seems from previous studies that deficits in disengagement are more likely to be revealed on tasks that require stimulus discrimination rather than stimulus detection and that therefore require a more complex decision to be made for efficient task performance. Finally, at least some of the apparently conflicting findings in the existing literature may be due to heterogeneity in the neuropathology present across different AD patients (see Grady et al., 1990).

It is clear that selective attention is not a unitary process, and only certain specific components of attention are likely to be impaired in AD, at least in the early stages of the disease. Our own findings indicate deficits in AD patients in conjoining features, especially on the right side of hemispace, in detecting salient targets in more peripheral regions, and in determining when it is appropriate to respond. In the future, the precise attentional mechanisms that are affected in AD need to be studied more rigorously using additional well-established experimental paradigms, designed to tease apart specific component processes mediating task performance.

Generalized Slowing

Are the deficits in visual search that we observed in this study specific to selective attention function, or can they be interpreted as reflecting a more general decline in cognitive function? As mentioned above, a common feature of many previous studies of attention in AD is a failure to apply a Brinley plot approach to the data. Without the use of such a technique (adopted from the normal aging literature), one is unable to attribute any deficits reported specifically to the domain of attention. This is because, in the absence of a Brinley plot, one is unable to discount the possibility that the effects that one is observing are merely indicative of a general cognitive decline or slowing, which (because it is putatively universal) is being manifested in the cognitive domain under investigation.

Although a consideration of the construct of global slowing is less well established in the neuropsychology literature than in studies of normal aging, we believe that this represents a fundamental oversight in previous experimental studies of visual attention in AD (and in several other clinical populations). Because of its theoretical importance, we therefore now return to consider the question of whether "generalized cognitive slowing" can account for the data that we report here.

In a meta-analysis of their investigations into cognitive functioning in AD, Nebes and Brady (1992) directly addressed this issue. The authors plotted a Brinley function of the performance of both normal older participants and patients with AD, compared with young controls, on a range of psychometric and experimental tests. They proposed that one could validly infer that a particular psychological task was selectively impaired only if the data points representing performance on this task lay two or more standard deviations from the regression line which they fitted to their complete data sample.

This has been interpreted as a stringent criterion for selective impairment (see Parasuraman & Haxby, 1993). However, when our data are superimposed on the Brinley-type regression function derived by Nebes and Brady (1992), there is evidence for significant deviation on the conjoined feature search task. In the mild AD group, this is notable at the largest array size, whereas in the moderate group, such a deviation is apparent at all array sizes, with the extent of this deviation increasing approximately in proportion to the number of distractors. The DRS scores of the mildly demented and moderately demented patients evaluated in the Nebes and Brady (1992) review were similar to those in the mild and moderate AD groups tested in the present study, indicating the plausibility of our comparison. Furthermore, when we constructed Brinley plots from our data, the slopes of the Brinley functions relating young participants' RTs to the AD patients' RTs on the conjoined feature search task were systematically greater in the mild group, and greater still in the moderate group, than the slope of the function derived for AD patients given by Nebes and Brady (1992).

Thus, whereas Nebes and Brady (1992) found that the best regression line showed a slope of 1.87–1.97 (mildly

demented) to 2.56–2.94 (moderately demented) when comparing the performance of AD patients with young controls, in the present investigation this range was exceeded by both sets of AD patients (see Figure 4): Mild AD patients showed a slope of 3.64, whereas moderate AD patients showed a slope of 5.19. One may, therefore, legitimately interpret these figures as reflecting the specific central processing demands of the conjoined feature task. Moreover, we saw an even greater increase in the moderate than the mild AD group, suggesting that the slowing in target detection in conjoined feature search was specifically related to AD. Note also that the degree of slowing of old control participants (slope = 2.55) from the relevant Brinley plot on the conjoined feature search task (see Figure 4) was considerably greater than that predicted from the normal cognitive aging literature (<2.0), as we have observed previously, in a larger sample of healthy elderly (Foster, Behrmann, & Stuss, 1995).

Overall, the findings of our Brinley analyses indicated that selective attention is affected in AD patients above and beyond the degree of impairment expected according to the notion of generalized cognitive slowing. The Brinley analyses also indicated that the AD patients studied here showed a much steeper slope on the conjoined feature task than observed in normal aging, and that the extent of the deficit observed in AD patients was well scaled by severity of the disease.

Diagnostic Considerations

Early studies of attentional function in AD tended to use small groups of patients in the early stages of the disease. Important questions have therefore been raised concerning the nature and degree of attentional dysfunction in more advanced stages of AD, and whether findings obtained with small numbers of relatively mild patients will generalize to AD patients as a whole.

The patients studied here all fell within either the mild or moderate categories of AD, according to the criteria of the Global Deterioration Scale used. However, most of the mild patients appeared to fall within Categories 2 or 3 of the Global Deterioration Scale, whereas the majority of the moderate patients seemed to fall within Level 5; that is, within each of the main categories of mild and moderate, patients were located toward the more severe end of the diagnostic spectrum. Although it would have been preferable to have tested more mild patients, the number of patients that were tested raises a genuine problem in the field: Diagnosis of AD is currently probabilistic and made by exclusion, so that it is much more difficult to find clearly diagnosed AD patients in the earliest stages of the condition to participate in research. This, in turn, raises problems in attempting to define early "cognitive markers" for the disease, and in conducting follow-up studies across the widest possible spectrum of symptom severity. We here preferred to be as accurate as possible in the initial diagnosis.

In the present study, analysis of the performance of individual participants indicated that there was a significant amount of intragroup variability on both the simple feature and conjoined feature search tasks (see error bars in Figures 1 and 2). Furthermore, there was a substantial amount of overlap both between the performance of participants in the mild and moderate AD groups, and between all AD patients and control participants. These findings therefore preclude the use of performance on these tests as definitive cognitive markers for the occurrence and level of severity of AD. However, these visual search tasks may prove to be of considerable utility when used in the context of other standardized psychometric tests and a full clinical workup and/or when the level of attentional function is of particular diagnostic significance. Of note, whereas attentional differences were noted between AD patients and controls in the present study on the conjoined feature task, no significant group differences were noted on the Attention subscale of the DRS (although significant differences between AD patients and controls were noted on the global DRS score and on the Memory subscale). This finding indicates that the conjoined feature task is detecting a decline in attentional functions to which the DRS is insensitive.

In conjunction with our previous observations, these findings suggest that there is some functional continuity between normal aging and AD in the domain of visual attention; that is, the differences observed between AD and normal aging in the current study and the previous investigation (Foster, Behrmann, & Stuss, 1995) are quantitative rather than qualitative. However, for both AD patients and elderly controls studied across the two investigations that we have conducted, the central slowing seen on conjoined feature search is specific, in that it exceeds the degree of impairment predicted on the basis of a generalized cognitive slowing impairment (see the previous section). These distinctions between quantitative versus qualitative differences and specific versus global cognitive impairments are important to grasp, in order to fully appreciate the theoretical implications of our data.

Concluding Comments

This study indicates that AD patients have cognitive impairments on a resource-demanding visual search task. The severity of this deficit was greater than that expected from an analysis of the degree of impairment reported in previous cognitive studies of AD. There was also some indication in this study that more severe AD patients may begin to show deficits on a noneffortful visual search task. The performance of AD patients was more variable than controls on both search tasks, but more severe AD patients benefited more from extended practice on effortful visual search. The performance of AD patients was facilitated more than for controls from left-sided target presentation on conjunction search, and on simple feature search, AD patients experienced more difficulty than controls in detecting more peripherally located targets.

Our findings therefore indicate that AD affects attentional abilities. This deficit may have important knock-on effects for individual performance in other cognitive domains. However, there was no suggestion in the current investigation that AD patients performed the conjoined feature search

task in a qualitatively different manner than controls; indeed, the data largely indicated a functional continuity between the performance of patients with AD and normal older participants on both of the visual search tasks that were studied (see also Foster et al., 1995).

Several questions for future research were raised by this study. For example, is the differential reduction in intraindividual variability in the performance of the moderate AD patients on the conjoined feature task over time maintained over longer periods of testing and when using other cognitive measures? Would the use of pretarget cues permit AD patients to compensate for the difficulties that these individuals apparently experience in detecting targets located on the right-hand side of the midline (in conjunction search) or in peripheral regions of space (in feature search)? What is the mechanism underlying the somewhat paradoxical finding (given the array size effects) that AD patients are not differentially impaired in detecting more peripherally located targets on the conjoined feature task? Future investigations should also consider in more detail the possible mechanisms underlying the deficits observed on conjoined feature search in AD patients. For example, by monitoring participants' eye movements, it should be possible to determine whether the deficits observed in AD patients are predominantly due to difficulties in moving attention between stimuli, or in processing stimuli once they have been engaged. More generally, future longitudinal follow-up studies will also enable researchers to specify in more detail the nature of the attentional changes taking place in AD. Participants also need to be rigorously classified according to disease stage, severity, and the local versus global nature of their clinically manifested impairments, so that attentional performance may be examined as a function of disease stage in a carefully controlled manner both within and across individuals.

The findings that we have reported here on the simple and conjoined feature search tasks indicate specificity in the attentional performance of AD patients relative to task demands and severity of the disease. In general terms, these findings are consistent with other studies of attention in AD, which have indicated that dementia may impair some attentional processes while sparing others (see Graf, Tuokko, & Gallie, 1990; Parasuraman & Haxby, 1993; and Spinnler, 1991, for reviews). Our results also indicate AD patients are as effective as normal elderly or young participants in using a physical feature to restrict their processing of information (see Nebes, 1992), so long as that feature uniquely defines the item of interest, and it is not presented in a peripheral region of space. In addition to their theoretical significance, our findings may have significant practical implications for the management and level of functioning of AD patients in the home, in the clinic, or on the hospital ward.

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