



Alzheimer disease constricts the dynamic range of spatial attention in visual search

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Abstract

A cued visual search task was used to examine the dynamic range over which spatial attention affects target identification during visual search. Precues varied in validity (valid, invalid, or neutral) and in precision (cue size) of target localization. Participants were “young-old” (65–74 years) and “old-old” (75–85 years) elderly adults and individuals in the mild stage of dementia of the Alzheimer type (DAT). For all participants, search was speeded as the precision with which a precue surrounding the location of a subsequently appearing target increased (precue size decreased). The cue size effect was evident in both feature and conjunction search, but was greatly reduced in both old-old and DAT groups compared to the young-old. However, whereas all non-demented adults showed a progressive modulation of search efficiency over the entire range of cue sizes, the dynamic range of spatial attention was restricted to the most precise cue in the DAT group. The restriction in the dynamic range of spatial attention may represent an underlying component of the impairment in perceptual and memory functioning found in early-stage DAT. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

The early, mild stage of dementia of the Alzheimer type (DAT) is characterized by deficits in different attentional functions, most prominently in spatial and divided attention [42]. Understanding the characteristics of attentional impairment in DAT is important because these deficits accompany and may contribute to the memory loss that is considered the first presenting symptom of the disease [36,42,43,51]. Spatial attention, or the mechanism by which information at a given location in the visual field is selected for preferential processing, is particularly affected early in DAT. Parasuraman et al. [41] showed that although individuals with DAT could use a location cue to select a tar-

get in the visual field, they were markedly deficient whenever covert shifting of spatial attention away from an incorrectly cued location was needed in order to find the target. A similar deficit occurred (but with different time courses) for both reflexive shifts of attention driven by peripheral cues and for voluntary shifts initiated by central, symbolic cues.

This attention-shifting or “disengagement” deficit in DAT is similar to that exhibited by patients with hemi-neglect due to parietal-lobe damage [46]. Positron emission tomography (PET) also showed that the attention-shifting deficit in these DAT patients was correlated with the degree of hypo-metabolism of the superior parietal lobe [41]. Several subsequent studies have confirmed that spatial attention shifting is deficient in early-stage DAT ([26,30,31,38]; see also [12]) and is associated with lowered parietal-lobe metabolism [4].

The changes in spatial attention in DAT differ both

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qualitatively and quantitatively from those associated with healthy adult aging [17,20]. There is only modest slowing of voluntary attention shifting with healthy aging up to about 75 years, while reflexive shifting is unaffected [20,22]. However, both forms of attention shifting are impaired in the “old-old,” or in individuals 75 years and older [16]. Thus advanced age (over 75) and early-stage DAT have qualitatively (but not quantitatively) similar effects on attention shifting. This may possibly reflect the greater likelihood that some adults of advanced age are in a pre-clinical stage of DAT compared to “young-old” persons [52].

Shifts of attention across the visual field, whether stimulus-evoked or driven top-down by a search goal, provide selection mechanisms for many visual tasks [39]. However, the studies discussed earlier have mostly examined attention shifts to single objects in an otherwise empty visual field. In these studies spatial selection is involved in only a rudimentary way, given that the target is presented in isolation. Does such a mechanism also operate when there are many objects present, as in most of our visual experience, and when observers must search for a single object among distractors? In recent years a number of models of visual search have been proposed. Many of these models assume the existence of a covert spatial attention mechanism that underlies target identification in complex visual displays ([55,58]; but see [9]).

Search models differ in postulating differing conditions under which search for a target is fast and independent of distractors and when it is slow and dependent on distractors. In general, search is very efficient and is associated with the subjective phenomenon of “pop out” when targets are specified by a unique feature or when target/distractor feature overlap is minimal. Search is less efficient when targets are defined by a conjunction of features or if target/distractor discriminability is low. When search is distractor-dependent, displays with items such as letters or object forms can be searched at a rate of about 30–40 ms/item, which is consistent with the temporal characteristics of a covert attention mechanism [27].

Cognitive studies suggest that the spatial attention mechanism in visual search may be the same one that is involved in covert shifting of attention in response to location cues [40,48]. Furthermore, in a PET study, Corbetta et al. [6] found that in comparison to feature search, conjunction search was associated with activation of the superior parietal lobe in a region closely overlapping with the same region they had previously shown to be involved in covert shifts of attention. Arguin et al. [3] reported that brain-damaged individuals who showed deficits in covert orienting also had slower search rates in detecting targets defined by a conjunction of color and orientation, but that search was unimpaired for detection of either feature in iso-

lation. These results would suggest that individuals with DAT, who have prominent parietal lobe hypometabolism and show an attentional disengagement deficit [4,41] should be impaired when asked to perform a visual search task in which repeated shifts of spatial attention are required.

Individuals with DAT can use location information to select a visual hemi-field for selective processing [41]. However, the spatial scale of attention is an important factor in visual selection, particularly if fine target discriminations have to be made at the attended location and when the number of items to be searched is large. Non-demented adults can voluntarily adjust the effective area of the attentional focus from large to small or vice versa but, just like a “zoom lens,” resolving power must be traded off against the size of the attended area [11]. An alternative conceptualization is that observers can distribute their spatial attention along a “gradient” that peaks at the attended location, with the falloff from the peak being relatively sharp or diffuse [28]. Either of these views predicts that spatial cues that vary in their precision of localization should affect search efficiency. In particular, a small, target-sized cue should facilitate search compared to a larger-sized cue because of its greater precision.

In order to examine these effects of spatial scale in search, we combined the standard orienting and search paradigms to develop a cued visual search task that directly manipulates the spatial scale of attention [19,40]. Participants searched for feature or conjunction targets as in the typical visual search task. However, the search display was preceded by a cue that varied in size and therefore in its precision of spatial localization. The cue enclosed an area that subsequently contained only a single letter or three letters in the search array. This allowed for an assessment of the role of shifts of spatial attention in complex visual processing independent of factors such as display size. Individuals with DAT and healthy, age-matched controls searched the display for a target characterized by a single feature (color) or by a conjunction of features (color + letter). The small and large cues provided localizing information of varying precision. Effects of cue size on reaction time (RT) for feature search were similar in a DAT group and in controls. For conjunction search, however, whereas controls were markedly faster at target identification with the small compared to the large cue, the DAT group showed very little benefit with the small, precise cue. These results suggest an impairment in DAT in the ability to adjust the spatial scale of attention during visual search.

The present study examined the influence of DAT and advanced age on the dynamic range over which spatial attention affects target identification during visual search. In our previous study [19], cue precision was manipulated using only two cue sizes, and so the

dynamic range over which attention can be scaled could not be determined. In the present study we used five cue sizes, which also allowed us to compute a slope for the RT-cue size function. Comparing slope values between groups allows an examination of the effective range of variation of the spatial scale of attention and the effects of DAT and advanced aging on that range. Furthermore, in contrast to the previous study by Greenwood et al. [19] we also varied cue validity, including neutral cues in addition to valid and invalid cues. This allowed us to compute separate benefits and costs of spatial cueing, as is commonly done in simple visual orienting studies [41,44].

As the precision with which a precue surrounds a subsequently-presented search target increases (cue size decreases), search speed is facilitated. We predicted that this facilitation would be seen over a large dynamic range of cue sizes in non-demented adults. We hypothesized that the dynamic range over which the spatial scale of attention could be adjusted would be markedly reduced in individuals with DAT, and reduced to a lesser extent in individuals of advanced age.

2. Methods

2.1. Participants

There were 42 participants, divided into three groups: 15 non-demented “young-old” adults (<75 years), 15 non-demented “old-old” adults (>75 years), and 12 individuals in the early stages of DAT. The young-old and old-old groups were recruited by newspaper notices and paid for participation. They were screened for health status and medication usage that could adversely affect attentional functions [15]. Individuals with major psychiatric, neurological or cardiovascular disease, alcoholism, or drug abuse were excluded. The DAT group consisted of nine patients who met the National Institute for Neurology, Communicative Disorders and Stroke — Alzheimer Disease and Related Disorders Association (NINCDS-ADRDA) diagnostic criteria for “probable” and three for “possible” Alzheimer disease [34]. Patients were either referred by their physicians or were contacted independently. None had focal abnormalities as revealed by MRI or any other current disease that could compromise brain function. Several other procedures, including neurological examination, neuropsychological testing, psychiatric interview, physical examination, and blood chemistry profile were carried out to exclude individuals with dementia due to other causes. (For further details of the clinical and neuropsychological testing procedures, see [1,23].)

Participant demographic variables are summarized

in Table 1. The DAT group consisted of individuals in the mild to moderate stages of dementia (mean Mattis Dementia Rating Scale=116; range 97–142). The young-old group was matched in age to the DAT group. There were no significant differences in years of education between the three groups. There were significant group differences in both the immediate ($F(2,39)=28.6$, $P < 0.0001$) and the delayed ($F(2,39)=30.3$, $P < 0.0001$) versions of the Logical Memory subtest of the Wechsler Memory Scale. The DAT group had significantly lower scores on both measures than the other two groups, who did not differ significantly from each other.

All procedures were approved by institutional review and informed consent was obtained from all participants.

2.2. Cued-visual search task

The display for the task consisted of a centered array of 18 letters arranged in three rows of six colored letters each (see Fig. 1). The array items consisted of the letters G, R, and N, drawn in one of three colors, green, pink, or blue (shown in Fig. 1 as gray, outlined white, or black, respectively). The order and position of the letters comprising the array were chosen randomly. The participant’s task was to make a speeded decision about the presence or absence of a target, a pink R, in the array. The target was present on half the trials and absent on the remaining half. The array was always preceded by a location precue that varied in precision and validity. Following a fixation point presented for 1 s, a rectangular precue was shown for 500 ms before the array of letters was presented. The use of a 500 ms stimulus onset asynchrony (SOA) was based on previous work showing that this SOA was optimal for cue effects on search tasks of this type [18].

The size of the cueing rectangle varied, such that the

Table 1
Participant characteristics^a

Characteristic	Group		
	Young-old	Old-old	DAT
Number	15	15	12
Gender	10F/5 M	9F/6 M	6F/6 M
Age	69.4 ± 0.6	79.5 ± 0.9	74.7 ± 3.6
Education (years)	14.7 ± 0.6	15.1 ± 0.7	15.0 ± 0.8
Logical memory (WMS)			
Immediate	11.4 ± 1.0	13.3 ± 1.0	3 ± 0.9
Delayed	10.5 ± 1.0	11.3 ± 1.1	1.2 ± 0.6

^a Values shown are means and standard errors; F=female; M=male; DAT=Dementia of the Alzheimer type; WMS=Wechsler Memory Scale.

precue enclosed the space subsequently occupied by 1, 4, 6, 9, or 12 letters in the search array. The location precue also varied in validity. Cues were valid on 60% of the trials, invalid on 20%, and neutral on 20%. A cue was valid when it enclosed a space that subsequently contained the target. As indicated, cue precision was systematically manipulated across five levels, from high (1 letter) to low (12 letters) by varying the size of the rectangle cue. The cue was invalid when the cued area did not subsequently contain the target. Finally, a neutral cue consisted of a rectangle that enclosed all 18 letters of the array, and thus did not provide any information on target location. Fig. 1 shows the five cue sizes used in the valid and invalid conditions (Fig. 1a–e), plus the neutral cue (Fig. 1f). (Valid cues are indicated in Fig. 1a–c, invalid cues in Fig. 1d–e).

2.3. Search conditions

There were two search conditions, feature and conjunction search. In both conditions, participants searched for the presence or absence of the same target, a pink R. In the feature search condition, the target could be distinguished from distractors on the basis of a single feature, color (pink). In the conjunction search condition, the target properties of color

(pink) and form (letter R) appeared with equal frequency among distractors but only jointly in the target. Examples of displays of the cued-visual search task for the conjunction condition are shown in Fig. 1.

2.4. Procedure

The task required a speeded decision about the presence or absence of a feature or conjunction target (pink R) embedded in a 18-letter array. On each trial, following a 500 ms centered fixation cross, a location precue appeared with a 500 ms SOA before array onset. This rectangle was empty during the SOA and varied in size. After the 500 ms SOA, the search array appeared superimposed over the precue so that 1, 4, 6, 9 or 12 letters were enclosed. Both precue and search array remained present until the participant responded or the end of the trial at 2000 ms. The target was present in the search array on 50% of trials. All combinations of search task, SOA, cue size and cue validity were randomized into six mixed blocks. Participants had the opportunity to take a brief break after each block, with a more substantial break required at the end of the first three blocks.

2.5. Data analyses

After eliminating all RTs associated with error trials and RTs of less than 100 ms, target identification accuracy scores and median RTs for correct responses were computed for each condition. These data were submitted to repeated-measures, mixed-factorial analyses of variance (ANOVA). Analyses were first carried out for validly cued trials to assess the effects of group (young-old, old-old, DAT), search condition (feature, conjunction), and cue size (five levels). Given that separate analyses of cue benefits and costs can be justified theoretically from previous work [19,44], additional analyses were carried out for RT benefits (neutral RT–valid RT) and RT costs (invalid RT–neutral RT). The slopes of the RT/cue size function were also analyzed. A slope value was computed for each subject from the slope of the best-fitting (minimizing least squares) linear fit of RT to cue size. In all ANOVAs, repeated measures *F* values were corrected for violations from sphericity by adjusting degrees of freedom using the Huyhn-Feldt procedure [25]. Post-hoc contrasts were computed using the Student-Newman-Keuls test.

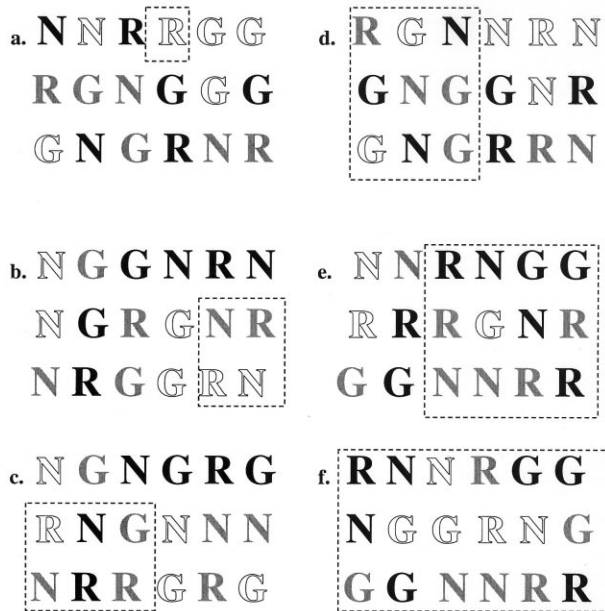


Fig. 1. Examples of the cued visual search task in the conjunction search condition. Participants were required to search for a pink 'R' target among distractors in an array of 18 letters drawn in one of three colors, green, pink, or blue (shown in the figure as gray, outlined white, or black, respectively). Spatial precues (represented by dashed lines) varied in precision of target localization by enclosing 1, 4, 6, 9, or 12 letters. The valid cue condition is shown in (a–c), invalid cues in (d–e), and the neutral cue in (f).

3. Results

3.1. Accuracy

Mean target identification accuracy scores for the

three groups and for the feature and conjunction search conditions are shown in Table 2. All three groups had relatively high accuracy scores. Furthermore, all participants with DAT could understand and complete all task conditions with quite high accuracy. However, their accuracy was significantly lower (mean = 83.4%) than either the young-old (95.8%) or old-old (96.3%) groups, who did not differ from each other (main effect of group, $F(3,39) = 7.1$, $P < 0.005$). In addition, the task \times group interaction was significant, $F(2,39) = 42.3$, $P < 0.0001$, indicating that reduced accuracy in the DAT group compared to the other two groups was greater in the conjunction search condition (mean = 80.0%) than in the feature search condition (mean = 86.8%). No other effects were significant.

3.2. RT for valid cues

The dynamic range of spatial attention effects was assessed by computing median RTs for validly cued trials as a function of cue size. Fig. 2 shows the RT-cue size function for the feature and conjunction search conditions. ANOVA gave significant effects for group, $F(2,39) = 21.2$, $P < 0.0001$: The DAT group was significantly slower (mean = 854 ms) than the young-old (mean = 585 ms) and old-old (mean = 592 ms) groups, who did not differ significantly from each other. Also, feature search (mean = 579 ms) was faster than conjunction search (mean = 749 ms), $F(1,39) = 90.9$, $P < 0.0001$.

As Fig. 2b indicates, search RT decreased as cue size decreased, i.e., as the precision of cueing increased, particularly for conjunction search. This was indicated by a significant effect for cue size, $F(4,156) = 19.5$, $P < 0.0001$. However, the effect of cue precision was markedly reduced in the DAT group, particularly in comparison to the young-old group (group \times cue size, $F(8,156) = 3.6$, $P < 0.01$). Moreover, the reduced influence of cue size was more marked for conjunction than for feature search, as reflected by significant interactions of search condition and cue size, $F(4,156) = 9.0$, $P < 0.0001$ and of group, search condition, and cue size, $F(8,156) = 2.3$, $P < 0.05$ (see Fig. 2b).

To examine these interactions further, ANOVAs

Table 2
Target identification accuracy scores (%) in the feature and conjunction search tasks for each group

Search condition	Group		
	Young-old	Old-old	DAT
Feature	97.6 \pm 0.3	98.0 \pm 0.2	86.8 \pm 1.7
Conjunction	94.1 \pm 0.7	94.6 \pm 0.4	80.0 \pm 1.6

were computed separately for feature and conjunction search. The main effect of group was significant for both feature, $F(2,39) = 17.3$, $P < 0.0001$, and conjunction search, $F(2,39) = 17.8$, $P < 0.0001$. Similarly, the main effect of cue size was significant for feature search, $F(4,156) = 8.8$, $P < 0.0001$, as well as conjunction search, $F(4,156) = 16.3$, $P < 0.0001$. However, the group \times cue size interaction was significant only for conjunction search, $F(8,156) = 3.3$, $P < 0.01$, and not for feature search, $F(8,156) = 1.6$, $P > 0.12$. Group differences in the effects of cue precision were thus confined to the conjunction search task. As Fig. 2b shows, search RT increased progressively with cue size across all cue sizes for both the young-old and old-old groups. This was confirmed by simple-effects analyses of cue size for each of these groups separately (young-old: $F(4,56) = 21.8$, $P < 0.0001$; old-old: $F(4,56) = 6.1$, $P < 0.01$). In contrast, Fig. 2b shows that for the DAT group only the smallest cue size facilitated RT (cue size 1 vs cue size 4: $F(1,11) = 4.9$, $P < 0.05$). RT remained relatively flat and did not change signifi-

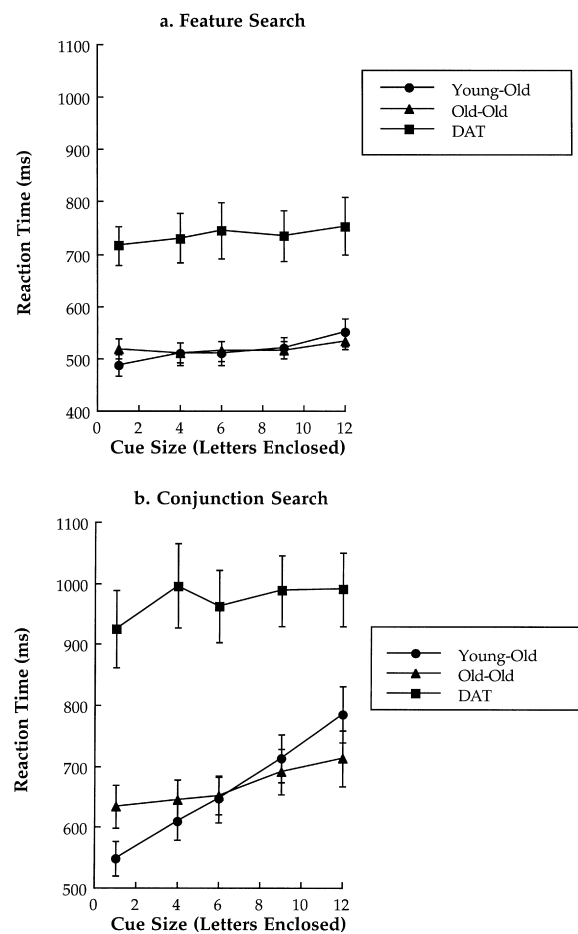


Fig. 2. Mean of median RTs (ms) for target identification during visual search as a function of cue size for the young-old, old-old, and DAT groups. a: Feature search. b: Conjunction search.

cantly with further increases in cue size (cue sizes 4–12: $F(3,33)=0.4$).

The slope of the RT-cue size function shown in Fig. 2 represents an index of the degree of facilitation provided by cue precision: the greater the slope, the greater the facilitation. Analyses of slope values were carried out to compare the overall effects of cue size on search efficiency across groups. Fig. 3 gives the mean slopes for the three groups and the two search conditions. ANOVA gave significant effects for group, $F(2,39)=4.2$, $P < 0.05$, search condition, $F(1,39)=13.6$, $P < 0.001$, and their interaction, $F(2,39)=3.4$, $P < 0.05$. Tests of the simple effects of group for each search task separately showed that slopes did not differ significantly for feature search, but did for conjunction search, $F(2,39)=4.3$, $P < 0.05$. As Fig. 3 shows, the mean slope for the young-old group was greater than that for the old-old and DAT groups. Post-hoc tests revealed that the young-old group differed significantly from both the old-old and DAT groups, who did not differ significantly from each other.

To examine the effects of age on dynamic spatial attention independent of dementia, a correlational analysis was also carried out on the data of all non-demented subjects ($n = 30$). The correlation was computed between age and the slope measure, for conjunction search only. This correlation was significant ($r = -0.4$, $P < 0.05$). The scatter plot is shown in Fig. 4. This analysis confirmed that the effect of cue precision on search efficiency began to decline in the seventh decade. Prior to that age decade slope values tended to be higher. With one exception (the rightmost point in Fig. 4 for a 85-year-old participant), the highest slope values occurred in the youngest elderly participants.

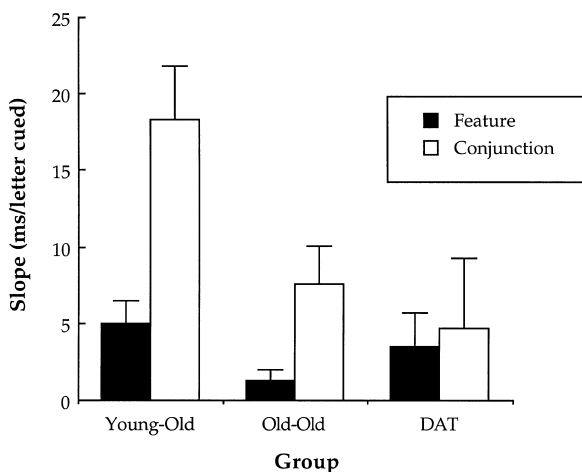


Fig. 3. Mean slopes of the RT-cue size function for feature and conjunction search tasks for the young-old, old-old, and DAT groups.

3.3. RT benefits

Fig. 5 shows the mean RT benefits as a function of cue size for the three groups and for both search tasks. There were no significant effects due to group. There was a significant effect of cue size, $F(4,156)=23.6$, $P < 0.0001$, showing that the benefit of cueing on RT decreased with increased cue size (reduced cue precision). The smallest, most precise cue led to the greatest facilitation of search speed, particularly for conjunction search (see Fig. 5b). This effect differed with group (group \times cue size, $F(8,156)=3.5$, $P < 0.05$) and with search condition (search condition \times cue size, $F(4,156)=6.1$, $P < 0.001$). Because the group \times search condition \times cue size interaction approached significance, $F(8,156)=2.1$, $P < 0.06$, ANOVAs were computed for each search task separately. Although the effect of cue size remained significant, the group \times cue size interaction was significant only for conjunction search, $F(8,156)=3.3$, $P < 0.01$. This interaction confirms the previous slope analysis in showing that the beneficial effect of cue precision on target identification speed was markedly reduced in the DAT and old-old groups.

3.4. RT costs

Table 3 gives the mean RT costs as a function of cue size for each search task. ANOVA gave significant effects for search task, $F(1,39)=31.9$, $P < 0.0001$, cue size, $F(4,156)=4.4$, $P < 0.01$, and their interaction, $F(4,156)=3.5$, $P < 0.05$. RT costs showed non-linear changes with increased cue size. The function was U-shaped for conjunction search. Costs were high for the

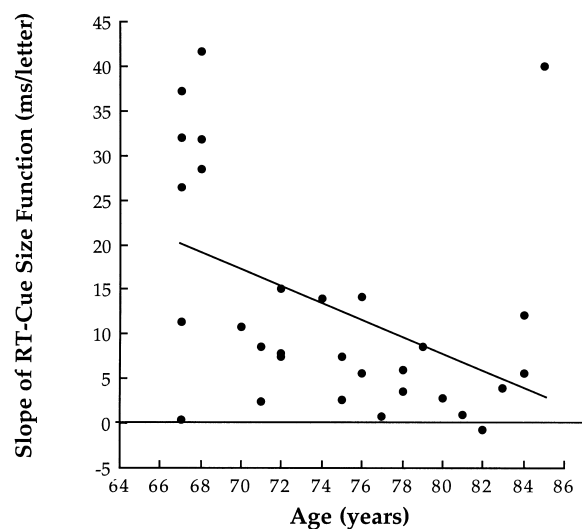


Fig. 4. Scatterplot of slopes of the RT-cue size function as a function of age for conjunction search for all non-demented older adults.

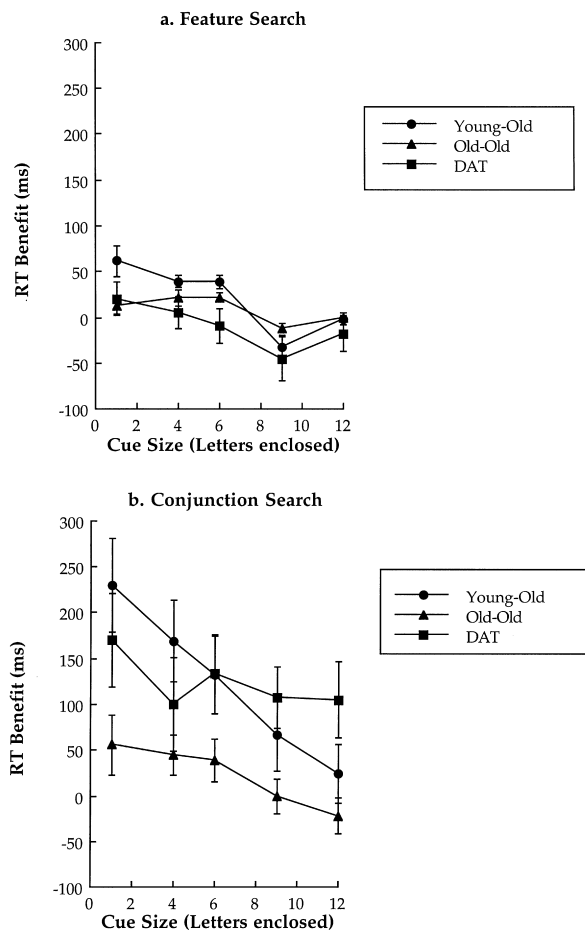


Fig. 5. Mean of median RT benefits (neutral cue RT–valid cue RT) for target identification during visual search as a function of precue size for the young-old, old-old, and DAT groups. a: Feature search. b: Conjunction search.

smallest cue and for the large cues, with a decrease for the intermediate-sized cues. However, there was no significant effect of group and group did not interact with either cue size or search condition. Hence these effects were not analyzed further.

Table 3
Reaction time costs (ms) of invalid location cues as a function of cue size for feature and conjunction search^a

Cue size	Search Task	
	Feature	Conjunction
1	32.4 ± 9.0	90.0 ± 17.8
4	23.1 ± 6.4	76.2 ± 12.4
6	17.5 ± 6.8	68.3 ± 16.0
9	-29.2 ± 8.5	84.8 ± 16.3
12	-6.1 ± 6.3	74.6 ± 15.8

^a Values shown are means and standard errors.

4. Discussion

4.1. Dynamic spatial attention and visual search

The speed of detection of a target among distractors increases as the precision of a spatial cue preceding the search target increases (i.e., as the size of the precued area decreases). This effect was found both for targets defined uniquely by color (feature search) and by a conjunction of features. We predicted that this facilitation would be seen over a large dynamic range of cue sizes in non-demented adults. This prediction was corroborated by the linear decrease in search RTs as cue size was systematically decreased over five levels, from 12 letters to one letter.

These findings point to a major controlling role for dynamic spatial attention in target identification during visual search. The greater sensitivity of conjunction search to cue size effects, compared to feature search, also supports the view that search for conjunctions of features is particularly affected by the allocation of spatial attention [40,48,54]. Nevertheless, the finding that the speed of both feature and conjunction search was influenced by cue size is consistent with the view that feature and conjunction search tasks primarily differ on a continuum of search difficulty rather than defining qualitatively different types of search [10]. Although the top-down effects of cue size we observed were smaller under conditions of feature search, they were nevertheless consistently present, as in our previous studies [18,19].

The speed of visual search can be modified by top-down information about target size and location. On 60% of trials cues provided correct information about the region of the array where the target would appear. It could therefore be argued that cues of differing size merely provided strategic information, allowing search to be conducted initially within the cued region. However, we have previously reported that effects of precue size on search emerge over time as the SOA increases from 200 to 500 ms [18]. Were effects of cue size attributable only to strategic factors operating at the time of appearance of the array, the amount of time available to process the cue would be irrelevant. Therefore, it can be concluded that top-down information concerning the size and location of target events is provided automatically in the course of visual processing.

4.2. Dynamic spatial attention in DAT and advanced aging

We hypothesized that the dynamic range over which the spatial scale of attention could be adjusted would be markedly reduced in individuals with DAT, and reduced to a lesser extent in individuals of advanced

age. The prediction for DAT patients was strongly supported. DAT patients showed a significant benefit with spatial cueing, but this benefit was obtained only for cues with high spatial precision. In fact, the reduction in the dynamic range of spatial attention was so marked that only the smallest cue (out of five possible cue sizes) facilitated search speed in the DAT group. In contrast, non-demented elderly, including the old-old, showed continuous modulation of search speed over the entire range of cue sizes. These group differences in the effects of cue size were obtained for the conjunction search condition. Thus the range of dynamic scaling of spatial attention is restricted in DAT to only the most precise location information. This finding parallels evidence of a highly localized and small attentional focus in a case-report of two DAT patients ([8]; see also [53]), although those patients were characterised as variants of DAT due to their additional and perhaps unique visual processing deficits.

The *overall* effects of cue size were similar in the old-old and DAT groups. Compared to the young-old, both groups showed a reduced ability to benefit from precue precision to target location. This deficiency may underlie the distractibility that characterizes both DAT and healthy elderly individuals [14]. However, although both the old-old and DAT groups showed reduced cue size effects, the groups did differ in the range over which such effects were found. The dynamic range of spatial attention spanned the entire range of cue sizes in the old-old group. In contrast, dynamic spatial attention in the DAT group was restricted to only the most precise cue.

There are several possible explanations for the pattern of dynamic spatial attention effects in DAT and advanced aging obtained in the present study. One explanation for the partial similarity between the old-old and DAT groups is that some of the individuals in the old-old group may have been in a very early, pre-clinical stage of DAT. Such individuals have been shown to have lower scores on neuropsychological tests [50] and on PET-based measures of parietal lobe metabolism [24]. While such an explanation cannot be completely ruled out, the fact that the old-old group had higher mean values and similar standard errors for the Wechsler Memory Scale (Table 1) and higher accuracy in the search task (Table 2) compared to the young-old group makes this explanation less likely.

Another possible explanation is that declining ability to scale spatial attention is a characteristic of old age, rather than of DAT per se. The old-old group were on average five years older than the DAT patients. By this view, aging could reduce dependence on top-down information in search so that DAT, at least in the early stages, may have little additional effect. Considered in light of our

previous findings that effects of precue precision *increase* in young-old adults in the sixties and early seventies compared to young individuals [18], it would appear that aging has a biphasic effect, first increasing, then decreasing, dependence on top-down information about target size.

That the young-old and old-old differ qualitatively is also suggested by the relation of age to effects of cue size. The scatterplot of slopes of the cue size/RT functions on conjunction search (Fig. 4) suggests that in the seventh decade there begins a decline in effect of cue size on search speed, reflecting reduced scaling of spatial attention. Prior to that point slope values tend to be higher, although some lower values are evident as well. With one exception, the highest slope values occurred in the youngest elderly participants. This suggests that an age-related change may become evident in the seventies, even in individuals who are apparently cognitively intact, which reduces efficiency in scaling the attentional focus and that this process may occur either before or concurrently with the onset of DAT.

On the other hand, reduced ability to scale spatial attention may be a characteristic both of DAT and of those individuals destined to develop DAT. If so, then the reduced scaling ability in the old-old group could be due to the inclusion of some individuals who are currently non-demented but at increased risk of DAT. Among the several genetic risk factors that have been examined in relation to dementia, possession of the $\epsilon 4$ allele of the apolipoprotein E gene (apoE) has been associated with increased risk and earlier age of onset of DAT [7]. In addition, apoE $\epsilon 4$ has also been linked to decreased neuropsychological test performance in healthy individuals [49] and non-demented Down syndrome adults [2], and to hypo-metabolism of temporal and parietal cortices in non-demented adults, particularly when homozygous individuals are examined [50]. However, if the old-old group in the present study contained some individuals possessing at least one $\epsilon 4$ allele, this group should have shown some signs of cognitive decline: however, the neuropsychological test performance of the old-old group was superior to that of the young-old group. Unfortunately, apoE typing was not available in the individuals examined in the present study. However, in another study, we have recently found that individuals possessing at least one apoE $\epsilon 4$ allele exhibited reduced effects of precue precision during visual search while those with no $\epsilon 4$ alleles did not [21]. Therefore it remains possible that some part of the decrease with age in effects of precue size beginning in the seventh decade in the present study (Fig. 4) could be attributed to the presence of apoE $\epsilon 4$ positive individuals.

4.3. Neural mechanisms

Aging and DAT can be distinguished by the absence of neuronal cell loss in healthy aging (reviewed in [37]) and by the far greater number of neurofibrillary tangles in DAT [47]. However, cortical metabolism is reduced in parietal, temporal and prefrontal regions both in unselected but healthy individuals [32] and in those who are non-demented but homozygous for the apoE ϵ 4 [50]. Spatial attention is mediated by a distributed network of cortical and subcortical regions [35,45]. An important component of this network is the parietal cortex. There is substantial evidence linking the shifting of visuospatial attention to superior parietal lobes [5] and we have shown an association between metabolism in superior parietal lobes and measures of shifting visuospatial attention in early DAT [41]. The cortical regions mediating the dynamic scaling of spatial attention remain relatively unstudied. However, brain imaging studies of perceptual tasks requiring either global or local processing [13,33] suggest that hypo-metabolism of the parietal and temporal cortices may also contribute to the deficit in dynamic spatial attention in DAT found in the present study.

Finally, the constriction of the spatial scale of attention in DAT may be mediated, at least in part, by the depletion in acetylcholine that is a hallmark of the disease. There is a massive loss in Alzheimer disease of cholinergic projections from the nucleus basalis of Meynert in the basal forebrain to neocortical areas, including the parietal lobe [56,57]. In the present study, DAT patients had an overall marked reduction in the effect of cue size but were able to narrow the attentional focus to the element-sized cue. In a recent pharmacological study, we found that scopolamine, a centrally active muscarinic cholinergic antagonist, selectively and strongly impaired this very ability [29]. In fact, scopolamine completely eliminated the cue size effect in a DAT group for a visual search task very similar to the one used in the present study. This result points to the importance of the cholinergic system for the ability to narrowly scale dynamic spatial attention in visual search.

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