



Distractor-dependent frontal neglect

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(Received 17 September 1996; accepted 23 January 1997)

Abstract—The effect of distractor load on visual search was examined in a patient with visual neglect following infarction of the right frontal lobe. The spatial extent of his left-sided neglect was modified greatly by changing stimulus attributes. When targets were highly discriminable compared to distractors, or distractor density was low, or when the subject was asked to cancel distractors as well as targets, he was able to direct his search to the extreme left of search arrays and there was little or no evidence of neglect. By contrast, similar changes in distractor load had little or no effect on the neglect of a patient with a fronto-parietal lesion. These findings suggest that distractability towards ipsilesional stimuli may be an important component of neglect in individuals with only frontal lobe injury. © 1997 Elsevier Science Ltd.

Key Words: neglect; frontal lobe; attention; visual search.

Introduction

Patients with unilateral visual neglect are unaware of objects contralateral to their lesion and fail to explore contralesional space [29, 54]. Neglect is commonly associated with large lesions involving both the parietal and frontal cortex of the right cerebral hemisphere. However, investigations of individuals with more focal injury have demonstrated that, amongst these patients, neglect is most severe following lesions of the inferior parietal lobe [62]. Patients with injury of only the frontal lobe have been reported but are comparatively rare (for a review, see [26]). Recent investigations have demonstrated that most patients with frontal neglect have lesions of the right inferior frontal lobe, a region which is part of the homologue of Broca's area [4, 24, 27].

It has been suggested that the neglect syndrome is a disorder of representing space [5, 9], of directing movement [19] or attention [33, 50, 52] into contralesional space. The attentional deficit has been attributed to either a bias to direct attention into ipsilesional space [33] or a direction-specific impairment in the ability to disengage attention and shift it towards contralesional space [50]. However, Bisiach [6] has recently suggested that the distinctions made between representational and attentional dysfunction may not be useful. Furthermore, it has been

argued that the posterior parietal cortex is involved not only in representing space and directing attention but also controlling eye and limb movements [23].

A number of authors have nevertheless proposed that the three functional impairments which have been associated with neglect result from lesions of specific brain regions. Thus, it has been suggested that injury to the posterior parietal cortex results in a disorder of spatial representation or directing attention, whereas frontal lesions lead to deficits in generating contralesional movements [7, 19, 42]. Presumably, patients with both frontal and parietal lesions should suffer from all three impairments.

We have been interested in characterizing the functional impairment in neglect associated with frontal lesions. Previous reports have demonstrated directional motor impairments—reduced amplitude, or slowed initiation or execution of contralesional movements—in patients with frontal lesions [7, 8, 10, 11, 20, 39–41, 58]. However, slowed initiation of contralesional movement may also occur with only parietal lobe lesions [20, 39], and some studies have failed to demonstrate a directional motor deficit following frontal lobe injury [28, 44].

Three recent investigations have demonstrated another association. Whereas neglect patients with predominantly frontal injury perform poorly on high-density cancellation tasks, their ability to bisect lines may be well preserved [4, 24, 37]. One interpretation of these results is that they reflect the relatively mild nature of frontal neglect. An alternative explanation is that patients

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with frontal injury experience a specific difficulty in directing visual search into contralateral space when confronted with a cluttered visual environment [24, 26].

In normal individuals, investigations of visual search usually employ brief displays and the subject's task is to determine whether a *single* target is present in an array. The time required to search a visual array decreases as the discriminability of a target is increased compared to distractors [13]. However, if targets are not highly discriminable, search time increases as a function of the number of distractor items in the array, i.e. with the degree of visual clutter [13, 60]. When patients with neglect have been assessed using tasks such as these, or variants in which all trials contain a target, they have demonstrated impaired detection of targets presented contralateral to their lesion [14, 21, 22, 53].

More commonly, visual search in patients with neglect is assessed using pen-and-paper cancellation tasks. In the simplest of these, patients are presented with a visual array consisting of only target items arranged evenly across a sheet of paper, e.g., short lines in Albert's test [1]. More complex tasks require patients to search for multiple targets embedded amongst distractor items, e.g., star [64] or shape cancellation [43]. Patients with neglect fail to search for targets on the side of the sheet contralateral to their lesion.

A number of studies, using either pen-and-paper cancellation tasks or reaction time paradigms, have demonstrated that the degree of spatial neglect may be reduced to some extent by decreasing the number of stimuli in the array (targets or distractors), by increasing the discriminability of a target compared to distractors or by cueing attention to the neglected side [14, 21, 22, 30, 32, 38, 51–53]. These results suggest that neglect can be modulated to some degree by changing the attentional demands of a task. Most of these reports have studied subjects with parietal lesions. A total of four patients with predominantly frontal injury were included in these group studies but details of their individual performances were not provided [14, 30, 38]. To date, there is no detailed report of visual search in a patient with frontal neglect.

Here, we describe a patient, AJ, who suffered a cerebral infarct confined largely to the right frontal lobe. He has left-sided neglect on standard cancellation tasks when distractors are present but no neglect on tasks without distractors. His performance on a number of novel control cancellation tasks demonstrates that his attention can shift to the extreme left of search arrays in the presence of distractors, but only if their density is low, or if targets are highly discriminable, or if both targets and distractors are discarded from visual search by overtly marking them after inspection. In short, his neglect is highly distractor-dependent.

For purposes of contrast, we present another patient, IP, with a large right fronto-parietal infarct. In her case, the degree of spatial neglect is little affected by altering target–distractor discriminability, the number of dis-

tractors or their location. Despite large changes in the visuospatial attentional demands of tasks, her search is consistently restricted to the right and she is unable to direct it to the extreme left of search arrays. The significance of attentional factors in modulating neglect and the role of the frontal lobe in directing attention and movement in cluttered visual environments is discussed.

Case reports

Case 1

AJ is a 67-year-old right-handed man with a history of hypertension, bilateral intermittent calf claudication and ischaemic heart disease. He presented to hospital following a sudden collapse at home. He was found to have a left-sided hemiplegia and it was noted he neglected objects to his left. Visual fields to confrontation were full and the patient was able to make saccadic eye movements toward the moving hand of an examiner when it was presented in the left visual hemifield. A computed tomography (CT) scan performed 8 hr after the collapse demonstrated a poorly-defined low attenuation area in the right frontal lobe. Ten weeks later, magnetic resonance imaging (MRI) demonstrated an area of infarction confined largely to the posterior and inferior aspects of the frontal lobe, but extending into the anterior portion of the parietal lobe, involving the postcentral gyrus. The posterior parietal lobe was not affected (Fig. 1).

AJ was first assessed in detail 4 weeks after his stroke. He scored 68/146 on the conventional sub-tests of the Behavioural Inattention Test (BIT) battery, where the cut-off score is 130 [64]. He showed evidence of impairment on most sub-tests: on star cancellation he scored 13/54, on letter cancellation 9/40, on line bisection 6/9, on figure and shape copying 2/4, and on representational drawing 2/3. However, he appeared unimpaired on the line cancellation task, scoring 36/36. On the Mesulam shape cancellation task [43] he scored 9/60, marking targets on only the right side of the sheet. AJ was subsequently assessed on almost a daily basis over the next 6 weeks.

His performance on two of the cancellation tasks used in the BIT battery was assessed again on two different occasions using an ABBA sequence. Although he found a mean of only 15 targets (all on the right) out of a possible 54 on the star cancellation test ($n=4$), he was able to mark a mean of 35.5 out of 36 line segments on the BIT line cancellation test ($n=4$). Thus, whilst he appeared to have severe neglect on the star cancellation task, he showed no indication of neglect on line cancellation (Fig. 2).

Throughout admission, his visual fields to confrontation were considered to be full. However, when tested on the Humphrey perimeter he was found to have a marked constriction of the visual fields, with a bias towards detecting stimuli in the right hemifield (Fig. 3). The field defect within the left hemifield was not an absolute one, since he could on occasions detect stimuli presented there. The difference between confrontation and automated perimetry is probably due to the size and movement of stimuli: in the former we use a moving pin, whereas in the latter a small light stimulus is illuminated for only 200 msec.

Case 2

IP is a 71-year-old right-handed woman with a history of hypertension, who presented to hospital with sudden-onset left-sided weakness. On examination, she was found to have a left-

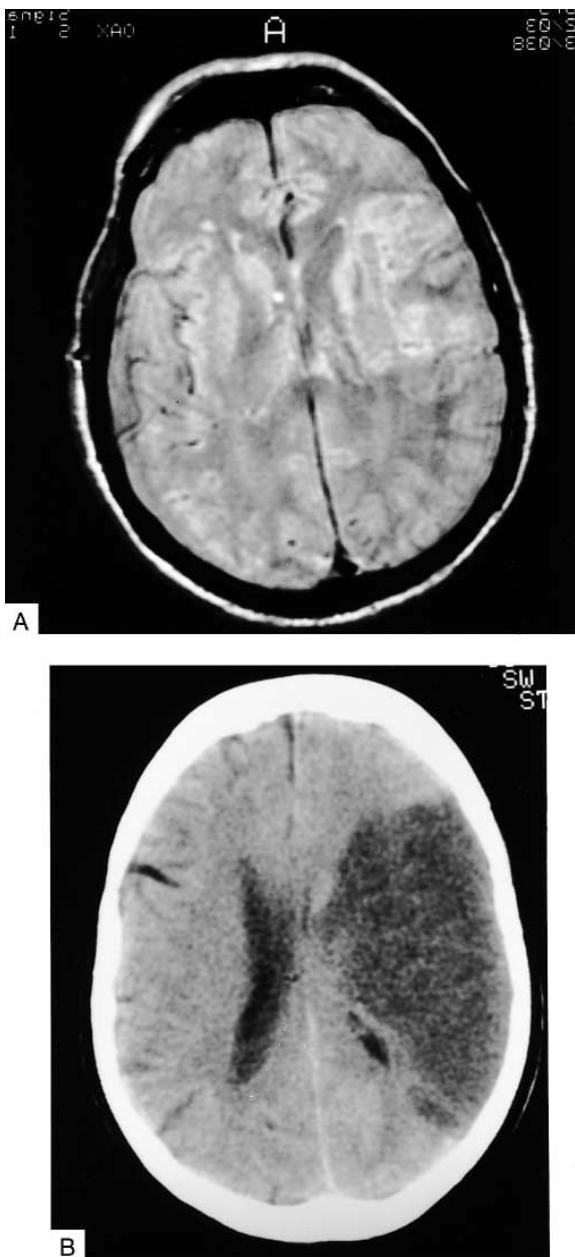


Fig. 1. (A) MRI of patient AJ, demonstrating a right frontal infarct. (B) CT of patient IP, demonstrating an extensive right fronto-parietal infarct.

sided hemiplegia and profound left-sided neglect. Assessment of visual fields to confrontation suggested she may also have a left homonymous hemianopia, but it was difficult to distinguish this from her neglect. During her admission, automated perimetry was attempted but the patient found the test distressing and was unable to perform more than a few trials.

A CT scan performed 3 days after admission demonstrated an extensive low-density area consistent with infarction in the territory of the middle cerebral artery. The infarct extended from the inferior parietal lobule to the inferior frontal lobe (Fig. 1). IP was first assessed in detail 10 days after the onset of her stroke. She scored 23/146 on the conventional sub-tests of the BIT battery. She showed evidence of impairment on all sub-tests: on star cancellation she scored 7/54, on line cancellation 10/36, on letter cancellation 4/40, on line bisection 0/9, on figure and shape copying 0/4, and on representational drawing 2/3.

On the Mesulam shape cancellation task she scored 2/60 (Fig. 4). IP was subsequently assessed for the next 8 weeks.

Experiment 1

AJ's near-perfect performance on line cancellation is in marked contrast to that on star cancellation. One important difference between the two tests is that the star task has targets embedded amongst distractor items, whereas the line task consists of only targets. However, the two tests also differ with respect to the shapes of the targets, as well as their number in the array. In order to control for these (and other) variables, we made a series of modifications to one standard cancellation array—the Mesulam shape cancellation task [43].

First, we produced a distractor-free version of this array. In the original version of the test there are 60 targets (circles with spokes with a diagonal line running through the centre) embedded amongst 312 distractor items (made up of 30 different types) on an A4 sheet of paper. In the distractor-free version the array consisted of only the targets in their original locations; we erased all the distractors. The original shape cancellation task and the distractor-free version were administered to AJ and IP on four separate testing sessions in alternating ABBA sequence (i.e. $n=8$ for each cancellation task).

AJ scored a median of 12.5/60 on the original task and all the targets he cancelled were on the right side of the sheet. However, when searching the distractor-free array he found significantly more (Fig. 2D), marking a median of 57/60 targets ($T^+=30$, $P=0.004$; Wilcoxon signed-ranks test for small samples). IP scored a median of 2/60 on the original version and 7/60 on the distractor-free task ($T^+=30$, $P=0.004$). All the targets she found were located on the extreme right side of the array (Fig. 4D). Although both patients marked more targets when distractors were absent, the absolute difference in the number of cancelled targets was significantly larger for AJ ($W_x=100$, $P=0.0001$; Wilcoxon rank-sum statistic). He demonstrated minimal signs of left-sided neglect in the distractor-free condition, whereas IP continued to show severe neglect, albeit slightly less pronounced, on this search task.

Experiment 2

Apart from the presence of distractors, the original shape cancellation test and the distractor-free version differ in one other respect: the number of stimuli in the array. The distractor-free task consists of only 60 targets, whereas the original task contains a total of 372 elements (60 targets and 312 distractors). It is possible that the large difference in AJ's performance on these two tests is due to the *overall* density of stimuli. In order to control for this, a version of the shape cancellation test was made in which all 312 distractors were replaced by targets. The original 60 targets were retained in their positions so that the new array consisted of a total of 372 targets. The overall stimulus density was exactly the same as that of the standard task. The original shape cancellation task and the 372-target version were administered to AJ and IP on four separate testing sessions in alternating AB sequence (i.e. $n=4$ for each cancellation task).

When given the 372-target task AJ began, as previously, by marking targets on the right edge of the array, but the extent of his subsequent leftward search was greatly increased and he was able to cancel a median of 369/372 or 99% of targets (Fig. 5A). On the original shape test, AJ's cancellation continued to be confined to the right side of the array and he marked far fewer targets, finding a median of only 14/60 or 23% ($T^+=10$, $P=0.06$; comparison of percentage targets detected). These results demonstrate that overall stimulus density does not deter-

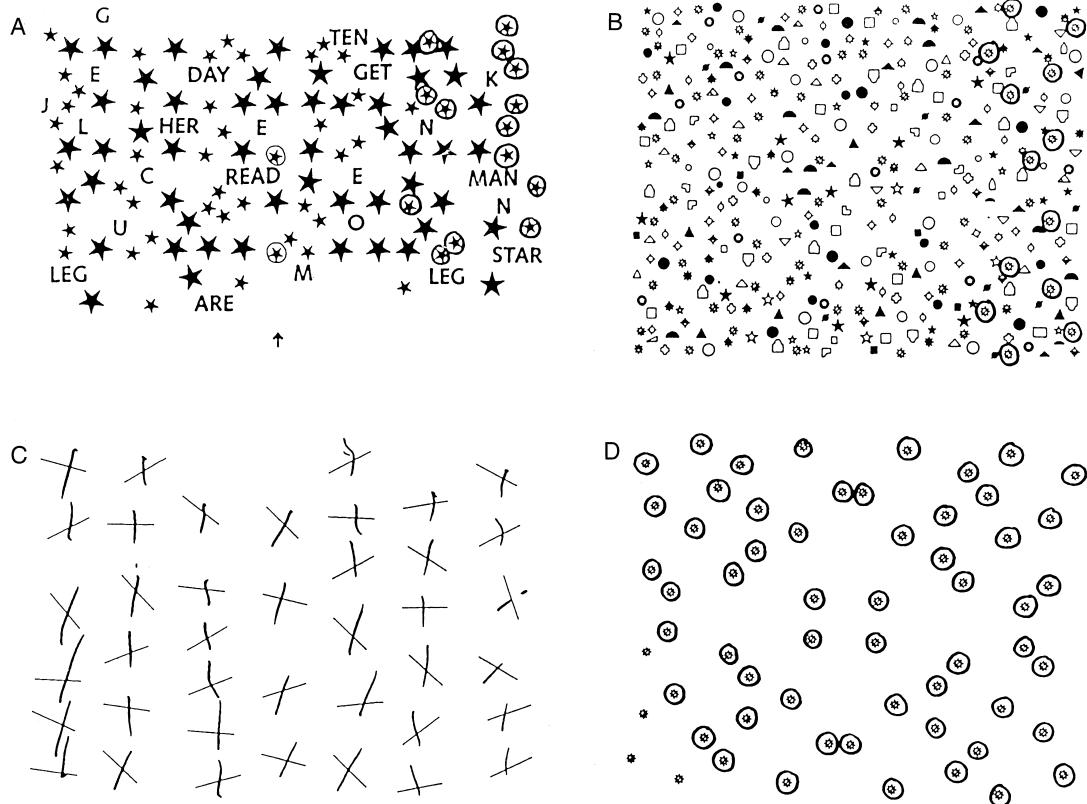


Fig. 2. Visual search performance of AJ on BIT star cancellation (A), Mesulam shape cancellation (B), BIT line cancellation (C) and a distractor-free variant of the Mesulam shape cancellation task (D). Notice the severe neglect in A and B, but minor or no neglect in C and D.

mine the extent of AJ's leftward search. Rather, the presence of distracting elements appears to be a key factor in modulating the degree of contralesional search. In marked contrast, on the 372-target test IP found a median of only 18.5/372 targets, or

5%, all of them located on the right side of the array (Fig. 6A). Her cancellation on the standard shape cancellation test was also confined to the right edge and she marked a median of only 3/60 targets, or 5% ($T^+ = 8$, $P = 0.19$).

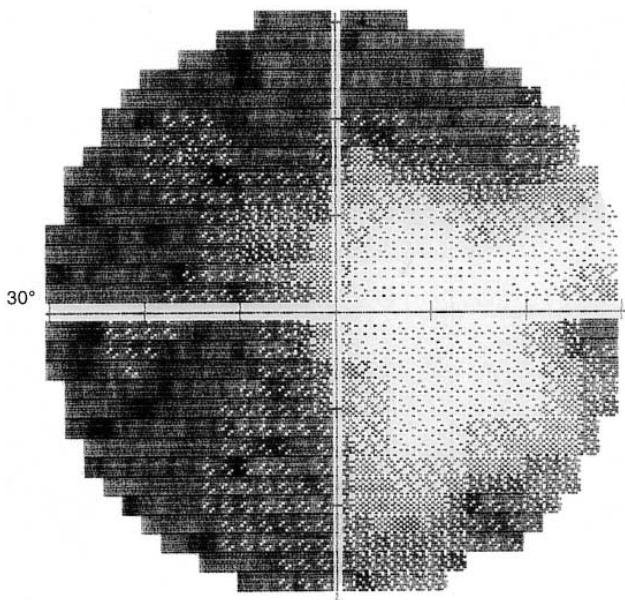


Fig. 3. Greyscale representation of AJ's central (30° radius) visual field as determined on the Humphrey perimeter. Note the constricted field of vision directed to the right of fixation, and the relative field defect to the left.

Experiment 3

The results of the previous experiments demonstrate that AJ's cancellation is confined to the right of the array when distractors are present. Furthermore, high stimulus density (as assessed by modifying *target* density) is not the critical factor which determines the extent of leftward search. In this experiment we examined the influence of *distractor* density on the extent of leftward search. Two further variants of the shape cancellation test were made.

First, we controlled for distractor heterogeneity by replacing the 30 *types* of distractor (which make up the total of 312 distractors), with only one type chosen from this set. This distractor (a circle with spokes, with the lower half of the circle coloured black) closely resembles the target. The original 60 targets were unchanged. Thus, this test has the same overall density as the standard task and consists of 60 targets and 312 distractors, all of the same type. We refer to this as the standard density task. Our second variant consists of the same number and type of target and the same type of distractor, but with half the overall distractor density. These two tests were performed by AJ and IP in alternating ABBA sequence on three different test sessions (i.e. $n = 6$ for each test).

On the standard density test, AJ scored a median of 7.5/60 marking targets on only the right side (Fig. 5B). When overall distractor density was reduced by half, he cancelled a median

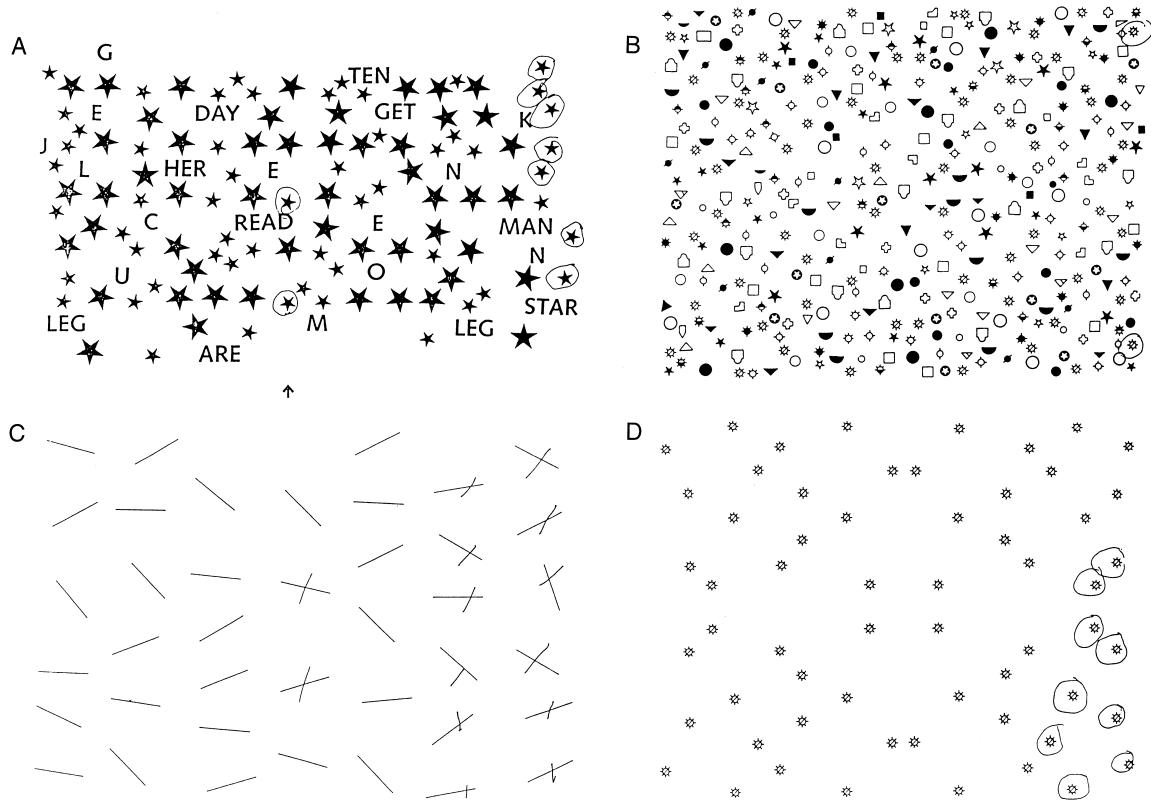


Fig. 4. Visual search performance of IP on BIT star cancellation (A), Mesulam shape cancellation (B), BIT line cancellation (C) and a distractor-free variant of the Mesulam shape cancellation task (D). The central stars (in A) and lines (in C) were marked, according to the instructions of the BIT, by the examiner to demonstrate what was required.

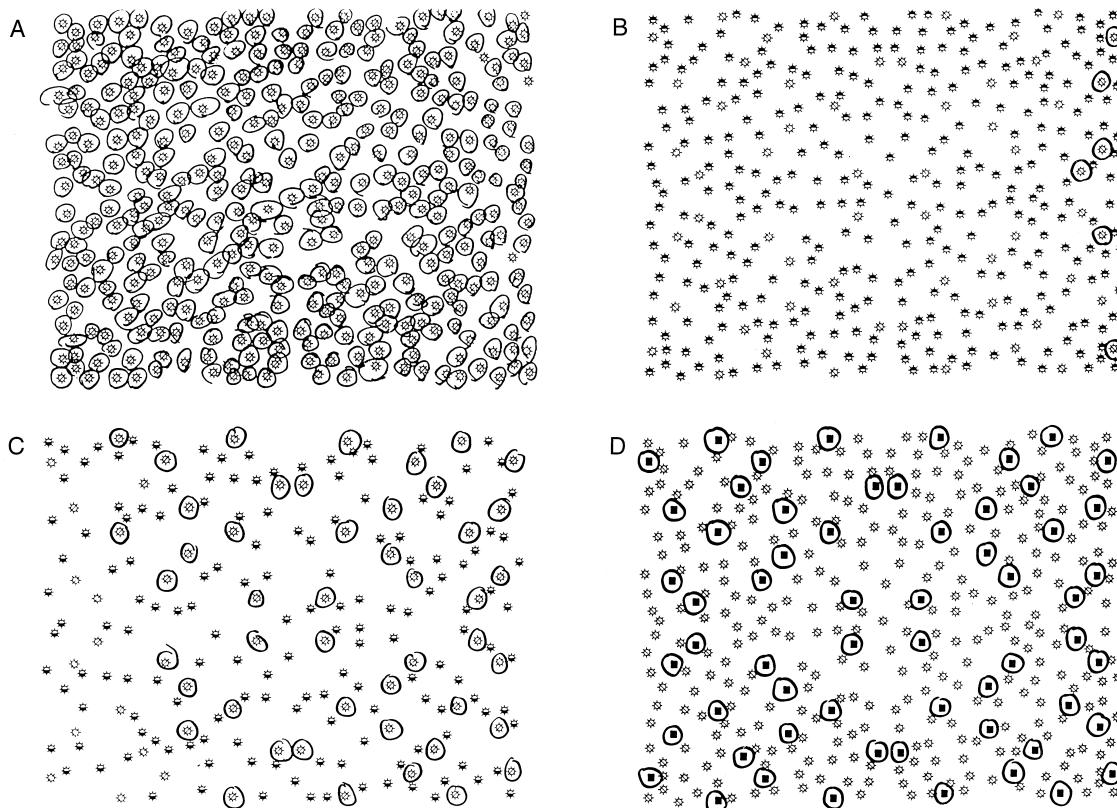


Fig. 5. Visual search performance of AJ. (A) On the all-target (372-target) task he showed no evidence of neglect. (B) Profound left-sided neglect was apparent when 60 targets were embedded amongst 312 distractors (all of the same type). (C) A significant improvement occurred when the distractor density was halved, or (D) when targets (in this case, black squares) were highly discriminable compared to distractors.

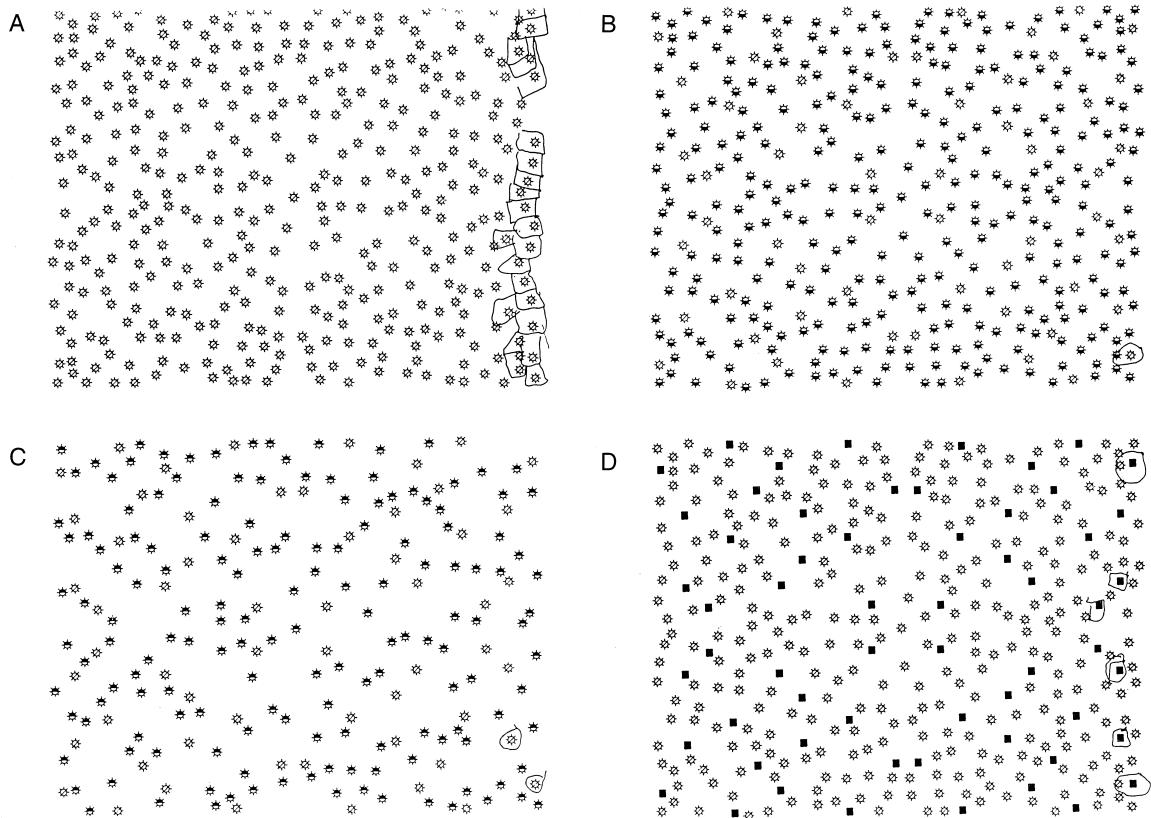


Fig. 6. Visual search performance of IP, who showed severe left-sided neglect on all tasks. (A) All-target (372-target) task. (B) Sixty targets embedded amongst 312 distractors (all of the same type). (C) As in B, but with half the distractors. (D) Targets (black squares) highly discriminable compared to distractors.

of 41/60 targets (Fig. 5C). Thus, reducing distractor density had a significant effect on the degree of leftward search ($T^+ = 21$, $P = 0.02$). In contrast, IP scored a median of 1/60 on the standard density test and 3/60 on the half-density task ($T^+ = 17$, $P = 0.11$). In both cases, her cancellation was confined to the extreme right edge (Fig. 6B, C). These results show that halving distractor density improves the degree of leftward search for AJ but has no significant effect for IP.

Experiment 4

In Experiment 3, the discriminability of the target compared to the distractor was low, since the two resembled each other closely. In this experiment we examined whether the degree of leftward search improved if targets and distractors were less similar in form. The standard shape cancellation test was modified to produce a variant which consisted of 60 black square targets embedded amongst 312 distractors, all of the same type (circles with spokes and a diagonal running through each). The targets in this array are highly discriminable compared to the homogeneous array of distractors.

AJ and IP were given this cancellation test and the original Mesulam shape cancellation test in alternating ABBA sequence on four and two different occasions respectively. AJ found a median of 59.5/60 targets on the new test (Fig. 5D), compared to 11/60 on the original task. Thus, a highly discriminable target significantly improved the extent of his leftward search ($T^+ = 36$, $P = 0.004$). In contrast, IP found a median of 6/60 of black square targets (Fig. 6D), compared to 2/60 on the original shape cancellation test ($T^+ = 10$, $P = 0.06$). All the targets she cancelled were on the right of the array. Changes in target-

distractor discriminability therefore made only a modest difference to the degree of leftward search for IP.

Experiment 5

AJ's search performance appears to depend upon the density of distractors and the discriminability of targets compared to distractors. But does the location of distractors have an effect on the extent of leftward search? In order to examine this issue we first removed all the distractors from the standard Mesulam shape cancellation task except for those occupying the right-hand quarter of the sheet. Thus, in this array distractors are present in only the extreme right-hand quarter strip. At a viewing distance of 50–60 cm this region subtends approximately 7° of visual angle.

Next, we made three further quarter-strip versions with the zone of distractors occupying the extreme left-hand quarter, mid-left quarter or mid-right quarter of the array. The targets of the original shape cancellation task were not altered. These four arrays were administered in a random sequence on different test sessions ($n = 5$ for each task for AJ; $n = 6$ for each for IP). Both AJ and IP always first started to cancel targets on the right side of the array, irrespective of the location of distractors. However, they differed with respect to the extent of leftward search.

AJ detected a median of 12, 23, 47 and 57 targets on the right-hand quarter, mid-right quarter, mid-left quarter and left-hand quarter tasks respectively (Fig. 7A–D). The extent of his leftward cancellation was significantly affected by the location of the distractor zones ($KW = 17.0$, $P = 0.007$; Kruskal–Wallis test). He cancelled targets which were to the right of or within

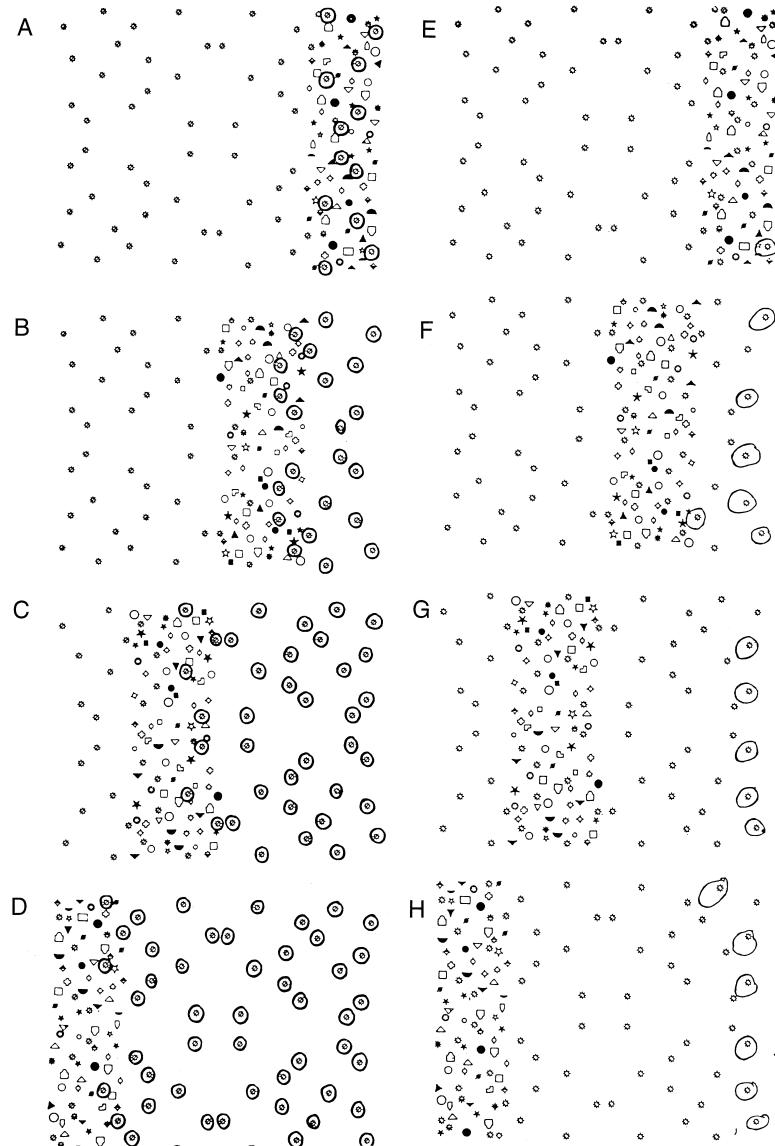


Fig. 7. Cancellation of AJ (A–D) and IP (E–H) on the distractor strip tasks. For AJ, cancellation of targets improves systematically with leftward shifts of the distractor strip.

a distractor zone, but never to the left of a distractor zone, regardless of where it was located. IP detected a median of 1.5, 6.5, 8.5 and 7.5 targets on the right-hand quarter, mid-right quarter, mid-left quarter and left-hand quarter tasks respectively (Fig. 7E–H). There was a significant difference between conditions ($KW = 10.5, P = 0.01$), but this is due to the difference between her performance when the distractor zone occupied the right-hand quarter and all other conditions. Thus, a shift of the distractor zone away from the extreme right to the mid-right improves her search but further leftward shifts of distractor zones do not.

A further modification of the Mesulam shape cancellation task was made by erasing all the distractors except those occupying the extreme right one-eighth of the array (subtending $\sim 3.5^\circ$ of visual angle). This cancellation task was given to AJ ($n = 5$) and IP ($n = 6$) on three different days. AJ found a median of 59/60 targets (Fig. 8A), whereas IP marked significantly fewer, cancelling a median of only 2/60 targets (Fig. 8C), all on the right edge ($W_x = 40, P = 0.004$). The performances on this task demonstrate that AJ is able to search to the extreme left of the array if the number of distractors on the right side is

small. However, for IP this manipulation makes little difference: she continues to confine her search to the extreme right.

Experiment 6

Taken together, the results of Experiments 1–5 suggest that for AJ distractors play an important role in modulating the extent of his spatial neglect. In the final experiment we asked our subjects to cancel distractors as well as targets. We reasoned that if distractors make a significant contribution to neglect, marking them (as well as targets) would allow them to be overtly discarded from search and enable attention to shift leftwards.

For our experimental task we chose our most difficult high-density cancellation array, where targets closely resemble the distractor (Experiment 3). The instructions to the patient were alternated in ABBA sequence: in one condition the subject was asked to mark only targets; in the next, the subject was asked to cancel distractors as well as targets. Each subject was tested on two different testing sessions (i.e. $n = 4$ for each task). AJ

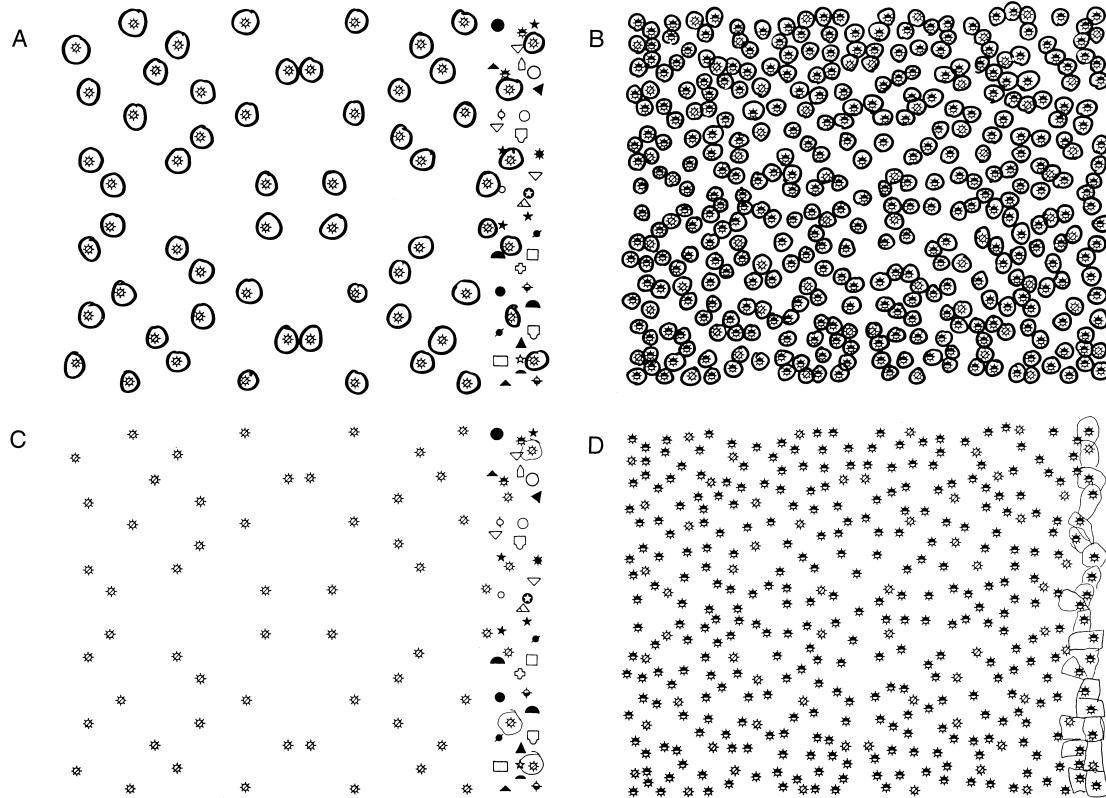


Fig. 8. Visual search performance of AJ (A, B) and IP (C, D). When the distractor strip was confined to the extreme right one-eighth of the sheet, AJ had no neglect (A), whereas IP continued to neglect targets on the left (C). When AJ was instructed to cancel targets as well as distractors, he showed no neglect (B), whereas IP continued to neglect targets and distractors to the left (D).

found a median of 12.5/60 targets when asked simply to cancel all the targets he could see, but when he was asked to mark distractors as well as targets, he was able to search the entire array (Fig. 8B) and marked a median of 60/60 targets ($T^+ = 10$, $P = 0.06$). In contrast, IP found a median of 3/60 targets when asked to mark distractors as well as targets (Fig. 8D), compared to 1.5/60 targets when asked to cancel only targets ($T^+ = 10$, $P = 0.06$). For both subjects, performance on the same task varied with the instructions given, but the difference in numbers of targets cancelled between the two conditions was significantly larger for AJ ($W_x = 26$, $P = 0.01$).

Discussion

The two cases of left-sided neglect reported here show remarkably different performances on both established visual cancellation tasks and novel ones made for the purposes of this investigation. Whereas AJ (a patient with a lesion confined largely to the right frontal lobe) shows great variation between tasks depending upon their visuospatial attentional demands, IP (a patient with a large right fronto-parietal lesion) has profound left-sided neglect, which is little affected by modulations in attentional demands. AJ is able to direct his search to the extreme left of arrays if targets are highly discriminable compared to distractors (Fig. 5D), if distractor density is low (Fig. 2C, D, Fig. 5C), or if distractors are marked and overtly discarded from search (Fig. 8B). For IP, these

manipulations have only a modest influence on the extent of her leftward search.

One interpretation of these results is consistent with the hypothesis that representations of contralesional hemisphere are destroyed by lesions of the posterior parietal cortex [5], but are intact in neglect associated with only frontal injury. Thus, objects in the neglected hemisphere may not be represented in a form sufficient to evoke visual awareness in parietal neglect. In cases with parietal or parieto-frontal lesions such as IP, therefore, changing ipsilesional attentional demands should have little effect on the degree of neglect. Conversely, in neglect associated with only frontal injury, parietal representations of contralateral hemisphere are intact. Therefore, objects in contralesional hemisphere may be represented but may not reach awareness because attention is drawn towards objects in ipsilesional hemisphere. Reducing ipsilesional attentional demands in cases such as AJ should therefore allow attention, and gaze, to shift towards objects in contralesional hemisphere.

Of course, this account is not completely satisfactory. The two patients reported here differ not only with respect to damage to the posterior parietal cortex, but also the overall extent of their lesions. And rather than invoke a qualitative functional difference between them, one could simply suggest IP has a more severe neglect than AJ, perhaps because more of the distributed network responsible for representing space or directing

attention has been damaged. Furthermore, it has been shown by a number of investigators that neglect in patients with parietal lesions can be modulated by changing attentional demands [14, 21, 22, 30, 32, 38, 51–53].

The role of distractors in frontal neglect

Is there then anything unique about frontal neglect? A number of investigators have suggested that it arises from a failure to generate exploratory or premotor components of attention [7, 19, 42]. In support of this hypothesis, directional hypokinesia, hypometria or bradykinesia have been shown to be more common following lesions which include the frontal lobe.

For example, Bisiach *et al.* [7] have employed a pulley device to dissociate direction of visual attention from direction of hand movement. They found that leftward hypometria contributed to the subjective rightward displacement of the midline in patients with lesions which included the right frontal lobe. Similarly, Tegnér and Levander [58], and more recently Bisiach *et al.* [8], have used a 90° angle mirror to examine cancellation. They reported that some subjects with lesions including the right frontal lobe failed to move their hands into left hemispace to cancel targets which appeared in their ipsilesional hemifield in the mirror. Patients with left-sided neglect and lesions including the frontal lobe also have increased movement times when directing their hands to visual targets on the left [39, 40]. However, the results of other investigations suggest that frontal injury need not be associated with a deficit in directing contralesional movements [28, 44].

A slightly different, but related view, of frontal neglect has been advanced by Làdavas *et al.* [35]. They have suggested that it is due to an inability voluntarily to direct attention toward contralateral hemispace, whereas parietal neglect is due to an impairment in the mechanisms which automatically direct attention to novel stimuli located there. There is some evidence in favour of this proposal from investigations of 'endogenous' and 'exogenous' orienting of attention using central or peripheral cueing [35]. Clearly, this hypothesis is very close to the 'premotor' one, but it need not make a mandatory connection between voluntary orienting of attention and operations which direct eye or limb movements to visual targets.

Recently, Berti *et al.* [3] tested five left-neglect patients on novel line bisection tasks in which distractors irrelevant to the task were placed either to the left, right or on both sides of space. Four of the patients had fronto-temporal lesions; one had suffered a fronto-temporal-parietal stroke. Line bisection in two of the fronto-temporal patients shifted to the left when distracting stimuli were placed on the left. This did not occur in the patient with the fronto-temporal-parietal lesion. The authors considered their findings in the context of Làdavas' hypothesis. They suggest that stimuli in the contralesional

hemispace may fail automatically to capture the attention of neglect patients with lesions involving the parietal lobe. In frontal neglect patients without parietal injury, mechanisms which automatically direct attention to stimuli in contralesional hemispace should be intact, so stimuli on the left may attract attention toward them and hence lead to a leftward shift in line bisection.

This interpretation is open to debate, but the results do suggest that neglect patients with lesions which involve the frontal lobe, but spare the parietal cortex, may be automatically attracted by distractors. Changes in distractor load may therefore modulate the extent of their neglect. Patients with only parietal injury may not be influenced by distractors because they suffer an impairment in automatic orienting of visual attention.

That distractors may have a significant role in frontal neglect is also suggested by the performance of AJ on the search tasks used in this study. The extent of his left-sided neglect was altered greatly by manipulating distractor variables. First, he showed little or no evidence of neglect in tasks which have only targets, irrespective of the density of targets (Experiments 1 and 2; Figs 2 and 5A). Second, on cancellation tasks in which distractors were present, reductions in distractor density or improvements in target discriminability compared to distractors allowed him to search further leftwards (Experiments 3 and 4; Fig. 5B–D). Third, when the location of distractor zones was systematically altered, he was able to find targets to the right but not to the left of these distractor strips, regardless of whether these were placed to his left or right (Experiment 5; Fig. 7A–D). Finally, when asked overtly to cancel distractors as well as targets in high-density arrays, he showed no evidence of neglect (Experiment 6; Fig. 8B).

These results show that the presence of distractors are critical in impeding leftward search in this patient with frontal neglect. Attention can shift to the left in the presence of distractors, but only if their density is low, or if targets are highly discriminable, or if distractors are discarded from visual search by overtly marking them. But why should distractors on the right impede search to the left? One possible explanation is that there is difficulty in disengaging attention from visual stimuli on the right and shifting it to the left. There is evidence that this may occur in some individuals with parietal injury [45, 50]. More recently, we have shown that difficulty in attentional disengagement may also occur in patients with frontal neglect, even when spatial shifts of attention are not required [27].

An alternative explanation is that attention inadvertently revisits distractors which have already been inspected. That is, there is difficulty in discarding from search those distractors which have already been scrutinized because of a failure to remember which locations have already been searched. This could result from an impairment of visuospatial working memory [2] or of a failure of mechanisms which normally inhibit attention from revisiting locations during visual search, so-called

inhibition of return [34, 48]. Finally, the inability to discard distractors on the right of cancellation arrays may be due to an inability to select motor programmes which direct gaze and search to the left.

In cluttered visual environments, any one of these factors may cause significant difficulty in re-orienting attention, and our experiments do not allow us to distinguish between these possibilities. However, they clearly show that distractor load is an important factor in the case of frontal neglect presented here. On the other hand, the presence of distractors appeared to make far less difference to IP's performance, suggesting that they have much less significance for her neglect.

Interestingly, a number of recent studies have reported that patients with frontal neglect perform poorly on high-density cancellation tasks such as Mesulam's, but have relatively preserved line bisection [4, 24, 37]. Patients with parietal injury appear to be poor on both [4], although at least one parietal case with normal bisection and abnormal cancellation has been reported [18]. The two tasks differ in many respects, but one fundamental difference is that cancellation tasks have distractor elements, whereas line bisection is performed on an uncluttered field. The pattern of performance of frontal neglect patients suggests that visual search in the presence of distractors may be significantly more impaired than the processes mediating judgement of line length in these subjects.

A slightly different interpretation of the results we have presented is that the performances of the two patients, AJ and IP, represent two extremes of a continuum. From this perspective, the differences between them do not represent qualitative differences but simply quantitative differences in the severity of neglect. Bisiach and Vallar [9] have proposed that each cerebral hemisphere is responsible for directing a gradient of attention across visual space, with maximal attention being directed into the contralateral hemisphere. It is possible that the steepness of these gradients varies after different forms of brain injury and this, in turn, may lead to different degrees of neglect arising from the same underlying mechanism.

In addition to these spatial gradients, the study of visual search in normal individuals has suggested to some investigators that this process may be conceived of in terms of a 'search surface' [13]. The degree to which attention is attracted to an object, regardless of its location, depends upon its discriminability amongst distractors and also upon the degree of similarity between distractors. The search surface describes the magnitude of these effects, and it is possible that the gradients of these surfaces too may vary between individuals with different types of brain injury.

There is little doubt that, as assessed on standard cancellation tasks, IP's neglect is worse than that of AJ, but this does not mean that the functional disorder in both these individuals is the same. In our view, one reason for considering that there are fundamental differences in the mechanisms underlying neglect in these two patients is

their performance in Experiment 6. Despite being given an opportunity overtly to discard distracting stimuli (by cancelling them as well as targets), IP was unable to direct her search much further to the left. In contrast, this manoeuvre greatly improved AJ's performance and he was able to direct his search to the extreme left of the array. Thus, distractor dependence appears to be a major component of his neglect and have little significance for that of IP.

It is possible to argue that, despite marking the distractors, IP's attention continued automatically to be captured by these stimuli. If this were the case, there would still be a fundamental difference between AJ and IP: in the former distractability could be overcome by cancelling distractors, whereas in the latter it could not. This is an interesting issue since it suggests there may be different types of distractability in visual neglect. It also suggests that distractability may not be unique to neglect associated with only frontal injury.

Clearly, the performances of the two patients presented here are very different, but it is not possible to conclude definitely from our investigation that AJ is sensitive to modulations in distractor load *because* of his frontal lesion. Similarly, it is not possible to conclude that the insensitivity of IP to changes in distractor load is attributable to parietal injury. It remains a possibility that the modulatory effect of distractors is directly related to severity of neglect and/or extent of lesion. So, patients with only focal parietal lesions and mild neglect may also be sensitive to distractor load.

The role of a biased focus of attention

The results of the distractor strip investigations (Experiment 5, Fig. 7) suggest that, apart from distractability toward objects in ipsilesional space, there are two other significant components of neglect. When the distractor zone (which subtends approximately 7° of visual angle) was on the extreme right of the array, the performance of both patients was the same as if the whole array were full of distractors. They could not search left beyond the distractor strip to the salient targets lying in the distractor-free zone: the local distribution of targets and distractors on the extreme right is therefore sufficient to account for their performance when distractors were present throughout the cancellation array.

This suggests that the spatial extent of the aperture or 'spotlight' of attention is highly focused. There is evidence to suggest that the aperture of attention can narrow or widen like a zoom lens [15]. In AJ it appears unable to expand to detect targets beyond distractor zones ~7° wide. However, he was able to detect targets beyond distractor strips which were ~3.5° wide, suggesting that his aperture of attention may be 3.5–7° in diameter. IP's performance suggests an even more focused aperture of attention directed towards the right hemisphere, because her search did not improve even when the distractor zone

was reduced to $\sim 3.5^\circ$ of visual angle. So, in this respect, neglect in AJ and IP may share a focused aperture of attention as one similar underlying mechanism.

A second mechanism which may be common to both is suggested by their performance when the distractor strip was shifted leftwards. Despite this shift, both patients always commenced their search on the extreme right and then inspected the distractor zone. Thus, both appear to have an intrinsic bias to direct search towards the ipsilesional side, regardless of the location of distracting elements. Kinsbourne [33] first suggested that there may be a bias following right hemispheric injury to direct attention towards the lesion, because attentional mechanisms in the left hemisphere are unopposed. A number of investigators have subsequently remarked upon the 'magnetic attraction' of the right side of space in left-sided neglect [12, 17]. Furthermore, individuals with left-sided neglect have been shown to direct their gaze to the right in the dark when there are no visual stimuli present to capture attention [31].

We suggest that both the patients reported here have a bias to direct a focused aperture of attention to the right. The difference between them lies in the effect of stimulus attributes on visual search. For AJ, reductions in distractor load allow him to shift the focus of search to the extreme left, whereas for IP changes in distractors have little or no effect. It is possible that AJ's visual field on static perimetry (Fig. 2) reflects this bias to direct a focused (constricted) field of vision to the right. A similar relative field defect has been demonstrated in monkeys with frontal lesion [36].

The role of the frontal lobe in directing attention

A number of disorders of attention have been reported following injury to the frontal lobes. Unilateral visual neglect [26], disorders of visual search and control of gaze [47, 59, 61], difficulty in maintaining attention [55, 63], and vulnerability to distracting stimuli [47, 65] have all been described. The results reported in this study suggest there is a specific relationship between neglect of contralateral space and distractability in ipsilesional space. Whereas other authors have suggested that distractability following frontal injury "is the opposite of neglect" ([16], p. 128), our conclusion is that it plays an important role in the frontal neglect syndrome: AJ fails to look to the left when distracting stimuli are present on the right.

It has been suggested that normally visual objects compete for attentional resources, and a major function of attentional mechanisms is to select objects of interest (targets) and suppress from competition those which are non-targets (distractors). The hypothesis has been advanced that the posterior parietal cortex serves to detect novel events in the periphery and automatically direct attention towards them [25, 49]. The view of frontal neglect advanced here suggests that normally the right inferior frontal lobe plays an important role in selecting

targets and suppressing responses to distractors. When this function fails, objects which lie ipsilateral to the lesion act to distract attention and prevent it shifting towards contralateral space. Hence the difficulty patients with frontal neglect experience with cluttered cancellation tasks and the relative ease with which they perform line bisection [4, 24, 37].

The results of electrophysiological studies conducted in both man and monkey support the proposal that the frontal cortex plays an important role in selection of sensory stimuli. In a dichotic listening task, the amplitude of an attention-related negativity elicited by a target is reduced if it is preceded by a distracting stimulus in patients with right dorsolateral frontal lesions. Control subjects and patients with lesions in the homologous region of the left hemisphere did not show such a distractor-related effect [65]. In monkey, it has been shown that the presence of distractors within the receptive fields of frontal eye field visuomovement cells suppresses their activity. In contrast, if targets of forthcoming saccades fall within these receptive fields, activity is enhanced [56, 57]. However, it is not yet established whether this selection-related activity arises within the frontal eye field or is transmitted to it from other regions. Recent investigations in man have demonstrated that the critical region injured in neglect associated with lesions of the lateral frontal lobe lies in the right inferior frontal gyrus [4, 24, 27]. This area is located ventral to the frontal eye field [46] and is part of the homologue of Broca's area (for a review of frontal neglect, see [26]).

In summary, we have presented evidence that changes in stimulus attributes, in particular changes in distractor load, have a significant effect in modulating the extent of visual neglect in a patient with a lesion confined largely to the right frontal lobe. We have proposed that a major component of left spatial neglect in this case is attributable to distractability towards objects in right hemisphere. This may reflect a special role of the right frontal lobe in selecting visual targets and discarding distracting objects from visual search.

Acknowledgements—This work is supported by a grant from the Wellcome Trust to M.H. We thank Jon Driver, Stephen Jackson and Jason Mattingley for a number of stimulating discussions on frontal neglect. We are grateful to two anonymous reviewers for their helpful comments on the manuscript.

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