Search Deficits in Neglect Patients Are Dependent on Size of the Visual Scene

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Patients with hemispatial neglect are impaired at moving their attention to a target on the contralesional display side. In the present study, visual display area was varied independently of the number of items displayed within the area. Patients searched for the absence of a simple visual feature in displays that produce serial search performance in normals (R. Klein, 1988; A. Treisman & J. Souther, 1985; J. M. Wolfe & C. W. Pokorny, 1990). The contralesional delay was enhanced for stimulus arrays that were distributed over a larger display area, which suggests that neglect is more severe when attention has to be moved over a larger distance. The directional disengage deficit in neglect (M. I. Posner, J. A. Walker, F. A. Friedrich, & R. D. Rafal, 1984, 1987) therefore depends on the size of information presented within a display, the number of ipsilesional items competing for attention (M. Eglin, L. C. Robertson, & R. T. Knight, 1989), and the distance of the contralesional attention movements.

A distributed neural network supports visuospatial attention (Corbetta, Miezin, Shulman, & Petersen, 1993). A lesion anywhere in this network may produce hemispatial neglect. Even if full-blown neglect does not develop, a contralesional deficit in visual tasks can still be measured after such brain lesions (Eglin, Robertson, & Knight, 1991; Posner, Walker, Friedrich, & Rafal, 1984). Yet little is known about the various properties of a display that might contribute to the contralesional deficit. In the present article, we examine a new display property—namely, display area—that may contribute to the contralesional search deficit seen in patients with neglect (Eglin, Robertson, & Knight, 1989).

Several studies have demonstrated that in neglect, information on the ipsilesional, intact side affects contralesional performance. For instance, Morrow and Ratcliff (1988) demonstrated that patients with neglect to the left caused by right-hemisphere injury could respond rapidly to information on their left side if precued to do so. Yet they were disproportionately slowed by a cue on their right side presented before the target appeared on the left side. The same result had been reported for patients with parietal lesions, independent of whether they showed signs of clinical neglect (Posner et al., 1984). These findings support the idea of a directional deficit in disengaging attention from an ipsilesional cue in the neglect syndrome (Posner et al., 1984; Posner, Walker, Friedrich, & Rafal, 1987).

The observation that neglect becomes worse after presentation of an ipsilesional cue suggests that neglect would be decreased if no stimuli appeared on the intact side. In addition, the magnitude of neglect should depend on the amount of information on the intact side. The more information there is to engage attention ipsilesionally, the more severe neglect should be.

These predictions were verified in a study (Eglin et al., 1989) in which subjects had to locate a target among varying numbers of distractors in serial or parallel search tasks (see Treisman & Gelade, 1980). When a search array was presented in contralesional hemispace with no distractors appearing on the ipsilesional side, patients found the targets as rapidly on the neglected side as on the intact side. When distractors were added to the intact side, the amount of neglect increased proportionately with the number of distractors on the intact side. This indicated that overattention to ipsilesional items enhanced contralesional neglect.

Neglect of items on the contralesional display side may be seen even when the entire display is presented in the intact visual field (Ladavas, Petronio, & Umilta, 1990). This finding indicates that the critical factor for neglect is the relative position of an item within a stimulus array. This conclusion is supported by a visual search study in which the amount of irrelevant information on the contralesional display side was varied in patients with neglect (Grabowecky, Robertson, & Treisman, 1993). Response times to find a target in the center of a stimulus array were slower in a condition where irrelevant "flanks" appeared on the ipsilesional side only than in a condition where irrelevant flanks appeared on both the ipsilesional and the contralesional sides. Although there were more irrelevant items overall in the "bilateral flank"
displays, response times in this condition were similar to a condition with no flanks present at all.

These results demonstrate that a problem in disengaging attention from information on the intact side of a display cannot entirely explain the performance of neglect patients. The ipsilesional information was the same for bilateral and ipsilesional flanks. However, the target's relative position within the stimulus array was different. The effect of adding unilateral ipsilesional flanks was to displace the central area of the displays (which contained the target) toward the contralesional side in relation to the entire array, which resulted in an increase in response times to the targets in that area. In the bilateral flanks condition, the center of the display was the same as when no flanks were present, and similar response times were found in these two conditions.

These results demonstrate that information on the contralesional side of a display contributes to the frame of reference that defines the spatial layout of the display and the target's position within this frame. Somewhat paradoxically, patients must perceive the entire display in order to ignore the contralesional side. It is probable that the reference frame is constructed preattentively (without conscious awareness) and that attentional search begins on the ipsilesional side of this reference frame. To the degree that neglect represents a disengage problem, disengagement must be relative to this frame.

If the target's relative position within a reference frame and the number and distribution of objects within that frame are the critical factors for producing neglect, then does it matter how large the display area is from which the frame is constructed? Or is the magnitude of neglect the same in large and in small frames as long as the number and arrangement of objects within the frame remain constant?

Serial search through an array of distractors presumably reflects movements of attention across internal representations of the distractor objects (Treisman & Gelade, 1980). Therefore, serial search in normals is relatively unaffected by the overall spatial extent of the stimulus arrays (Treisman, 1982) or by short exposure durations that prevent eye movements (Treisman & Gormican, 1988). An effect of display area is expected only if it influences feature discriminability (cf. Treisman, 1982). This suggests that the disengage problem in neglect may depend primarily on the absolute number of items within the frame.

Conversely, there is evidence that attention movements across space require time proportional to the distance of the movement (Egly & Homa, 1991; Shulman, Remington, & McLean, 1979; Tsai, 1983). Because we know that neglect patients attend to the ipsilesional side of a display and only gradually move their attention contralesionally, the overall distance over which attention has to be moved may affect the neglect deficit. The effect of distance has been investigated only in a cuing paradigm. Neglect was more severe with far contralesional than with near contralesional targets, especially on those trials on which attention had first been cued to the ipsilesional side (Stark & Coslett, 1991). Neglect is therefore more severe when attention has to be disengaged to move to a far contralesional as opposed to a near contralesional target in a cuing paradigm.

Distance effects in covert attention movements may be due to the fact that the neural systems involved in covert attention movements are closely linked to neural systems involved in the programming of eye movements. Rizzolatti, Riggio, Dascolla, and Umiltà (1987) associated attention movements with the same neural mechanisms involved in the programming of saccades. Inferior parietal lesions in monkeys produce deficits in saccadic eye movements and in covert attention movements (Lynch & McLaren, 1989). Patients with progressive supranuclear palsy, with initial slowing of vertical eye movements, show a slowing of vertical, but not horizontal, covert attention movements (Rafal, Posner, Friedman, Inhoff, & Bernstein, 1988). It is well known that visual neglect is associated with oculomotor problems including conjugate eye deviation into ipsilesional hemispace (De Renzi, Colombo, Faglioni, & Gibernoni, 1982), paucity of exploratory eye movements into the neglected hemispace (Chedru, Leblanc, & Lhermitte, 1973; Hornak, 1992; Ishai, Furukawa, & Tsukagoshi, 1987; Johnston, 1988; Johnston & Diller, 1986), and hypometric saccades into the contralesional hemispace (Girotti, Casazza, Musicco, & Avanzini, 1983; Heilman, Watson, & Valenstein, 1980). These oculomotor problems may be associated with the degree of attentional problems in neglect patients. Once attention and the eyes are engaged ipsilesionally, it may be difficult for neglect patients to program eye movements in a contralesional direction, especially for far contralesional targets. This difficulty may be paralleled by an attentional deficit even under conditions where eye movements are not required.

In a search task with large enough displays, overt eye movements may be necessary to overcome acuity limitations in the periphery. Oculomotor deficits in neglect patients may therefore contribute to the delay in finding contralesional targets with large display areas. Peripheral contralesional targets may be hard to detect because the patients are slow to initiate eye movements in that direction. Attention movements to the contralesional periphery may be similarly slowed.

For the experiment described in this article we created an additional search task in which subjects searched for a simple feature in displays that produce parallel search performance in normals (Klein, 1988; Treisman & Souther, 1985; Wolfe & Pokorny, 1990). On the basis of previous results (Eglin et al., 1989), we expected neglect patients to show faster search performance on this second task, although their search performance was not expected to be parallel. We included the second task in the present study to confirm that the abnormal search pattern in neglect patients is due to a serial attention deficit and is less severe in a task that requires less attention.

Method

Subjects

Patients. Seven male and 2 female patients with a neurological or neuropsychological diagnosis of left hemispatial neglect were selected (see Table 1 for patient characteristics). On the day of
Table 1

*Patient Characteristics*

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age (years) and sex</th>
<th>Pathology and duration</th>
<th>Side</th>
<th>Visual fields</th>
<th>Line cancellation(^a)</th>
<th>Lesion</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.L.</td>
<td>53, M</td>
<td>CVA, 4 mo</td>
<td>R</td>
<td>L-hemianopsia</td>
<td>86</td>
<td>CT not available</td>
</tr>
<tr>
<td>R.M.</td>
<td>66, M</td>
<td>CVA, 1 mo</td>
<td>R</td>
<td>L-hemianopsia</td>
<td>98</td>
<td>CT not available</td>
</tr>
<tr>
<td>C.D.</td>
<td>48, F</td>
<td>CVA, 1 wk</td>
<td>R</td>
<td>Full, L visual extinction</td>
<td>98</td>
<td>76</td>
</tr>
<tr>
<td>W.H.</td>
<td>60, M</td>
<td>CVA, 9 mo</td>
<td>R</td>
<td>Full fields</td>
<td>100</td>
<td>98</td>
</tr>
<tr>
<td>B.A.</td>
<td>54, M</td>
<td>CVA, 1 mo</td>
<td>R</td>
<td>L-hemianopsia</td>
<td>96</td>
<td>36</td>
</tr>
<tr>
<td>A.K.</td>
<td>67, M</td>
<td>CVA, 1 wk</td>
<td>R</td>
<td>Full fields</td>
<td>96</td>
<td>32</td>
</tr>
<tr>
<td>U.W.</td>
<td>70, M</td>
<td>CVA, 2 yr</td>
<td>R</td>
<td>L-hemianopsia</td>
<td>66</td>
<td>4</td>
</tr>
<tr>
<td>H.E.</td>
<td>47, F</td>
<td>CVA, 4 wk</td>
<td>R</td>
<td>Questionable L-hemianopsia</td>
<td>100</td>
<td>92</td>
</tr>
<tr>
<td>R.P.</td>
<td>48, M</td>
<td>Pathology unclear, 2 mo</td>
<td>R</td>
<td>L visual extinction</td>
<td>73</td>
<td>57(^b)</td>
</tr>
</tbody>
</table>

*Note.* M = male; F = female; CVA = cerebrovascular accident; R = right; L = left; Ipsi. = ipsilesional; Contra. = contralesional; CT = computed tomography scan.

\(^{a}\)Percentage of lines cancelled on the ipsilesional and contralesional sides of the page on the day of testing (maximum performance on each side is 100%). \(^{b}\)Averaged over two tests.
testing, each patient failed to cancel some lines on the contralateral side of the page in Albert’s (1973) line cancellation task (see Figure 1). All patients were tested within 24 months of onset of neurological symptoms. Five of the patients were tested within 4 weeks of onset and were in an acute state of visual neglect. Two of those (C.D. and A.K.) could only be tested at bedside. The most severe case of neglect was in a patient who was unable to cross out lines past the midline of the page (U.W.). In this patient, neglect was chronic and had persisted for 24 months.

Eight patients had had cerebrovascular accidents, and for 1 patient pathology was unclear. All patients were right-handed. Their mean age was 57 years (SD = 8.5).

The average lesion volume was 58.47 cc (SD = 22.87). Six patients had posterior lesions involving parietal and temporo-parietal cortex. Four of these patients also had frontal involvement (frontal eye field). One other posterior lesion included damage to the hippocampus, calcarine cortex, and pulvinar. The lesion of 1 patient was restricted to dorsolateral frontal cortex. Two patients had full visual fields as tested upon confrontation; 1 had a left visual extinction. The other 6 patients had left homonymous hemianopsias.

The patients were informed of the experimental, nontherapeutic nature of the tests and consented to participate. They were free to withdraw from the study at any stage.

Normals. Normal control subjects were matched for age, sex, and handedness to the patient group. Seven male and 2 female subjects with a mean age of 57.2 years (SD = 8.9) participated. All were right-handed with normal or corrected-to-normal vision. They were paid $20 for approximately 30 min of participation.

Stimuli and Conditions

Because some of the patients could only be tested at bedside, all of the patients were shown the stimuli on sheets of paper and their reaction times (RTs) were timed with a stopwatch to the closest 10 ms. Normal subjects were too fast to be timed in the same way, so displays identical to the ones used for the patients were presented on a computer, which recorded RTs to the closest millisecond.

The stimuli for patients were created with black Letterpress circles and lines on white paper (see Figure 2). For the feature-absent search task, a large and a small display size were created. The target was a large circle (O) among distractors that were large circles with an intersecting line (Qs; see Panels A and B of Figure 2). In this task, the target was defined by the absence of the intersecting line. In normals, this search task produces serial search performance (Klein, 1988; Treisman & Souther, 1985; Wolfe & Pokorny, 1990). In the feature-present search task, the target was a circle with an intersecting line (Q) among distractor circles (Os; see Panel C of Figure 2). In normals, feature-present search is fast and preattentive (Klein, 1988; Treisman & Souther, 1985; Wolfe & Pokorny, 1990).

The circles for the large displays were 21 mm in diameter with 5 mm line width on white paper 27.9 cm × 21.6 cm. The intersecting lines were 14 mm in length with 5 mm line width. For the feature-absent task with small display area, the large stimulus displays were reduced by photocopying and then glued to white cards 9.1 cm × 5.2 cm. The diameters of the small circles were 5.7 mm and the lengths of the intersecting lines were 4 mm. Line width was 1.4 mm. The overall display area subtended about 29° horizontally by 24° vertically for the large displays and about 10° horizontally by 6° vertically for the small displays at a viewing distance of about 50 cm.

A target was present in every display, and subjects were asked to point to it as soon as they had detected it. Patients with severe neglect are able to successfully search for a target under conditions where they are sure that a target must be present on each trial (Eglin et al., 1989). It has been shown that verbal or visual cues can help neglect patients to attend to the otherwise neglected side of a display (e.g., Riddoch & Humphreys, 1983). In our tasks, the knowledge that a target must be present in each display seems to serve as a cue, even in patients with severe neglect, to initiate search of the neglected side of the display if the target cannot be found on the intact side.

Five conditions with 16 observations each were created, 8 with the target on the right side of the page and 8 with the target on the left. In the four conditions of relevance here, there could be 0 or 15 distractors on the same side as the target (set size 1 and set size 16), combined with 0 or 16 distractors on the opposite side of the page (opposite-side distractors 0 or 16). With the unilateral conditions (0 opposite-side distractors) we wanted to replicate our previous result that absolute hemispatial position of the arrays does not affect neglect. These unilateral conditions allowed an estimate of search efficiency on each side of the display. In the bilateral conditions, the effects of ipsilesional and contralesional distractors on search performance could be evaluated.

A fifth condition was created with a target plus 15 distractors (set size 16) with a single distractor on the opposite side of the page (opposite-side distractor 1). This condition was included to counterbalance the condition with a single target (set size 1) with 16 opposite-side distractors. With the fifth condition added, a single item in any bilateral display was a target on half the trials and a distractor on the other half. The fifth condition was not included in the analysis.

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For the large displays of the feature-absent task, an imaginary rectangle consisting of 8 × 4 3.4-cm-sided squares was centered on the page. To make overall density of the displays similar, these squares were slightly smaller (3.0 cm) for the feature-present task. Each stimulus was randomly placed anywhere within one of these imaginary squares so that the displays gave the impression of randomly scattered stimuli. The smallest distance between adjacent stimuli was about 3 mm. In each condition, the target appeared once in every other of the 16 imaginary squares on one side of the page. The conditions were counterbalanced such that the target appeared at least twice but never more than three times in
The stimulus arrangement in each display was
visual angle, the length of the intersecting line was 0.35°,
line width. The length of the intersecting line was 0.35° of
visual angle, the length of the intersecting line was 0.35°,
and line width was 0.11°. The stimulus arrangement in
each display was structured individually to match the corresponding displays used with patients.

**Procedure**

Eight patients performed all three tasks (large and small feature-absent search and feature-present search) on the same day. For 1 patient (A.K.) the small feature-absent task was completed in one session, and the other two tasks were done on the following day. The tasks were run in a counterbalanced order such that each task was used three times as the first, second, or third task, and each task was followed at least twice (and never more than four times) by any other task. For each task, a new random order of trials was used for the 1st, 3rd, 5th, 7th, and 9th patients. The reverse order of the previous patient was used for the 2nd, 4th, 6th, and 8th patients. Two patients were tested at bedside (C.D. and A.K.), and the others were taken to a testing room. The patients were shown the three practice sheets, and the search task was explained to them. It was emphasized to them that a target was present in each display. They were instructed to point to the target with their right hands on each trial. The stimulus sheets were centered in front of the patients, but they were free to move their eyes and heads. We measured RTs with a stopwatch beginning 10 ms after the time the stimulus sheets were turned right side up in front of the patients and stopping when they touched the targets with their fingers. On 2% of trials, patients verbally indicated that no target was present and only initiated search of the neglected side when told to do so.

For the normal subjects, three orientation displays were used to explain the task. Subjects rested the index fingers of their right hands on a key. They were instructed to keep the key pressed when a display was flashed until they had located the target visually. They were then to release the key and point to the target. RTs were measured from stimulus onset to the release of the response key. Immediately after the pointing response, subjects put their fingers back on the response key and the next display sequence was shown 2,525 ms after the previous one had been turned off. No display was presented unless the key was pressed down. The display sequence included a warning dot for 300 ms in the center of the screen, followed by the stimulus display. Two different randomization sequences were alternated between subjects. The task sequences used were the same as those used for the patients.

To allow time for the pointing response, we provided a 1,000-ms interval during which the display remained on the screen after the release of the response key. A display timed out if no response occurred within 2,525 ms of display onset, and RT was recorded as 2,525 ms (0.28% of trials in the small and the large feature-absent tasks). Trials on which the response key was released prematurely and the pointing response was not immediately recorded by the experimenter and excluded from analysis (0.42% in the feature-present task, 1.94% in the large feature-absent task, and 1.39% in the small feature-absent task).

For practical reasons the RT measurement was different for normal controls (from stimulus onset to release of response key) and for patients (from stimulus onset to touching of the target). Therefore, RTs included movement time for the patients. However, as is evident from the Results section, movement time into ipsi- and contralesional hemispace did not contribute to RTs in the patients. In addition, we have replicated the contralesional search deficits found in neglect patients in a paper version of the task (Eglin et al., 1989) with a different group of patients in a computerized version of the same task with a key-release response (Eglin et al., 1991). Therefore, we are confident that the different re-

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**Figure 2.** Example of stimulus displays. (Not drawn to scale; the difference in size between large and small displays was larger in the actual experiment.) Panel A: Large feature-absent task with a target on the right side; set size is 16, with 16 opposite-side distractors. Panel B: Small feature-absent task with a target on the left side; set size is 16, with 16 opposite-side distractors. Panel C: Feature-present task with target on the left; set size is 1, with 16 opposite-side distractors.
response procedures used in the present study for patients and normals do not jeopardize the results.

Results

The means of the median RTs averaged across subjects for the four relevant conditions in the feature-absent search task with large display area (circles), the feature-absent search task with small display area (triangles), and the feature-present search task (squares) are shown in Figure 3 for the patients and in Figure 4 for normals. Note that the patients’ RTs in Figure 3 are given in seconds. On the abscissa are the number of items present on the side of the page where the target appeared (set-size target side). Because all patients had right-sided lesions, the right display side was the intact side and the left display side was the neglected side for all patients. Set size was 1 when a single target was presented. Set size was 16 when a target appeared among 15 distractor items. The parameter is the number of items on the side of the page opposite to the target (opposite-side distractors). In unilateral displays, there were no items opposite to the target (solid lines). In bilateral displays, there were 16 distractors on the side opposite to the target (dashed lines).

Effects of Display Area in the Feature-Absent Task: Large Versus Small Display Area

Two important results are evident from Figures 3 and 4. First, opposite-side distractors have symmetrical effects across target sides in normal subjects (circles and triangles with dashed lines). In contrast, there is a prominent asymmetry evident in the patient data. Latencies to locate an ipsilesional target were completely unaffected by 16 opposite-side distractors on the contralesional side, whereas there was a large delay for contralesional targets when 16 opposite-side distractors were present on the ipsilesional side. Second, the asymmetry found on bilateral trials in the patients was more pronounced for the large (circles) than for the small (triangles) displays.

We used planned comparisons to evaluate the predicted effects. Because the patient data were collected with a stopwatch, whereas normal data were recorded by a computer, the raw data of each individual subject were transformed to z scores. By using z scores, we could minimize differences in overall distribution and variance in the patient and normal data and emphasize the overall pattern of the data. Individual means of the normalized data in each condition for each subject were entered into statistical analyses.

In the bilateral display conditions with 16 opposite-side distractors (dashed lines), search latencies were symmetrical in normals, but not in the patients, and the planned Group (normals or patients) × Target Side (left or right) × Opposite-Side Distractors (0 or 16) comparison was highly significant, \( F(1, 16) = 37.08, p < .001 \). This contralesional delay in the patient group was more pronounced for the large than for the small display areas, and the Group (normals or patients) × Display Area (large or small) × Target Side (left or right) × Opposite-Side Distractors (0 or 16) comparison was also significant, \( F(1, 16) = 8.23, p < .02 \). The asymmetry was entirely due to the bilateral displays with 16 opposite-side distractors (dashed lines), \( F(1, 16) = 8.01, p < .02 \), whereas unilateral displays (solid lines) did not contribute to the Group (normals or patients) × Display Area (large or small) × Target Side (left or right) interaction, \( F < 1 \). These results show that in the patients, there is a pronounced delay in detecting contralesional targets when ipsilesional distractors are present. This delay is enhanced when the search stimuli are distributed over a larger display area.

Effects of Hemispace With Unilateral Displays

The unilateral stimulus arrays (triangles and circles with solid lines in Figures 3 and 4) were presented either on the right or on the left side of the page. Because patients were...
asked to point to the targets with their right hands, slower hand movements into left hemispace could have resulted in overall slower RTs to targets on the left than to targets on the right. This was not the case, and the Group (normals or patients) × Target Side (left or right) and Group (normals or patients) × Target Side (left or right) × Display Area (large or small) interactions did not approach significance (both F < 1).

We also examined whether in the patients, search efficiency itself was affected by placing the unilateral search arrays completely within ipsi- and contralesional hemispace. Decreased search efficiency within contralesional hemispace would be reflected in a greater difference between set sizes 1 and 16 for contralesional than for ipsilesional displays. Again, this was not the case and the Group (normals or patients) × Target Side (left or right) × Set Size (1 or 16) interaction did not approach significance (F < 1). Therefore, when unilateral displays are placed entirely within ipsi- or contralesional hemispace, there is no difference in overall latency or in search efficiency even in patients with rather severe neglect.

**Search Rate per Item**

To assess overall search speed in the different tasks, we calculated a search rate per item from the search latencies. We used three different set sizes, ignoring the right and left manipulation in the design: set size 1 (single targets), set size 16 (unilateral displays), and set size 32 (bilateral displays; see Figure 5). We performed regression analyses on the median RTs for each set size for each subject in order to obtain a slope and intercept for the regression function. Because on average, only half of the distractor items have to be searched until the target is detected, the search rate per item equals twice the slope of the regression functions. This measure of search rate per item is independent of the motor response and reflects the increase in RT when searching displays with 16 or 32 items as opposed to a display with a single target.

In normals, the mean search rate was 30.9 ms per item in the search task with the large displays and 20.3 ms per item with the small displays. Linearity accounted for 99% of the variance due to set size. In the patients, the search rates were much slower and amounted to 233 ms per item with large displays and 197 ms per item with small displays. Linearity accounted for 95% of the variance due to display size with large display areas and for 92% of the variance with small display areas. The regression analyses suggest that search performance in the feature-absent tasks reflects serial search with focused attention for both patients and normals.

A planned comparison on slopes calculated from the normalized data confirmed that search rates were slower with large than with small displays both for the patients and for normals. There was a significant effect of display area (large or small), F(1, 16) = 9.02, p < .01, but there was no Group (normals or patients) × Display Area (large or small) interaction, F(1, 16) = 1.53, p > .10.

Treisman did not find an effect of display area on search rate with displays that varied from about 6° to about 15° of visual angle (Treisman, 1982). Display areas larger than 15° have never been tested. The slowed search rates in the large display areas used in the present task, extending to almost 30° of visual angle, may therefore reflect the involvement of eye movements.

**Target Quarter-Sections**

In order to examine more closely the effect of the relative position of the target within the stimulus array, we collapsed RTs over the different conditions and divided the displays into vertical quarter-sections from far right (S1) to far left (S4). In this way, the effects of distractors ipsilesional to the target could be assessed across the entire stimulus page. In Figure 6 (patients) and Figure 7 (normals) median RTs are plotted as a function of the target’s relative position on the page. There are a total of 16 data points for each quarter-section. In each quarter-section ipsilesional to the target, there appeared an average of 4 distractor items. So for the far contralesional targets (S4), there were an average of 12 distractor items ipsilesional to the target across displays.

As is evident from Figures 6 and 7, normal subjects located targets in the center of the display faster than in the right or left outer quarter-sections with both large and small display areas. In contrast, patients detected the most ipsilesional targets the fastest and the most contralesional ones the slowest so that the search latencies show a progressive increase from far ipsilesional to far contralesional targets.

The three-way Group (normals or patients) × Target Side (left or right) × Subfield (near or far) interaction was highly significant, F(1, 16) = 65.53, p < .001, but this effect did not interact with display size (large or small), F(1, 16) = 2.19, p > .10. RTs for targets on the contralesional side were slower, however, in the large than in the small displays for patients, and the three-way Group (normals or patients) × Target Side (left or right) × Display Size (large or small) interaction was significant, F(1, 16) = 7.68, p < .02.

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*Figure 5.* Means of the median reaction times (in milliseconds) pooled across target side for displays of set size 1 (single targets), set size 16, and set size 32 for patients (empty symbols) and normal control subjects (filled symbols) in all three search tasks. Circles = large feature-absent task; triangles = small feature-absent task; squares = large feature-present task.
These results indicate that in the patients, large display areas resulted in a disproportionately steep RT increase across the midline of the displays (see Figure 6). Such a midline effect was found in an earlier search task (Eglin et al., 1989) and may reflect a problem in disengaging attention from the ipsilesional half of the display in order to move it to the contralesional half (Robertson & Eglin, 1993).

Independent of the relative position of the target within the stimulus array, RTs might increase the further into absolute contralesional hemispace attention has to be moved. We performed an additional planned comparison to compare the effects of a target's absolute spatial position versus its relative position within the array. Targets in the far peripheral quarter-sections of small bilateral displays (S1 and S4) appeared at the same mean distance from center in absolute spatial coordinates as targets in the near quarter-sections of large bilateral displays (S2 and S3; see Figure 6). If relative position within the stimulus array contributes to the response latencies, then RTs to targets in quarter-section S1 of the small bilateral displays should be faster than RTs to targets in quarter-section S2 of the large bilateral displays, because the S1 targets in the small displays are at the ipsilesional edge of the stimulus array, whereas the S2 targets in the large displays are toward the center of the stimulus arrays. Conversely, RTs to targets in quarter-section S4 of small bilateral displays should be slower than those to targets in quarter-section S3 of large bilateral displays, because the S4 targets in the small bilateral displays appear at the contralesional edge of the stimulus arrays, whereas the S3 targets in the large bilateral displays appear near the center of the arrays. The relative positions within a stimulus array differ for target quarter-sections in the above comparisons, whereas their absolute spatial positions (P1 and P2) are equal (see Figure 8). The planned Group (normals or patients) \( \times \) Target Side (left or right) \( \times \) Relative Position Within the Display (outer or inner quartiles) comparison was significant, \( F(1, 16) = 11.21, p < .01 \). This interaction was entirely due to the patient data, for which the Target Side (left or right) \( \times \) Relative Position (outer or inner quarter-section) interaction was highly significant, \( F(1, 8) = 30.76, p < .001 \), whereas it did not approach significance for normals (\( F < 1 \)). In the patients, relative position affected search latencies on both display sides, and the main effect for relative target position was significant for contralesional targets (RTs to S3 targets in large displays were faster than RTs to S4 targets in small displays), \( F(1, 8) = 16.14, p < .01 \), as well as for ipsilesional targets (RTs to S2 targets in large displays were slower than RTs to S1 targets in small displays), \( F(1, 8) = 7.99, p < .03 \). These results indicate that RTs to S2 and S3 targets in the large displays differed from RTs to S1 and S4 targets in small displays, although these targets appeared in the same absolute spatial positions. Thus, it is the relative position of a target within a stimulus array, rather than absolute spatial coordinates, which determines the amount of neglect in the patients.

**Effects of Task Type With Display Area Kept Constant: Feature-Absent Versus Feature-Present Search**

Two important results are evident from Figures 3 and 4. First, the contralesional delay in the bilateral display conditions (circles and squares with dashed lines) was more pronounced in the feature-absent search task (searching for Os in Qs) than in the faster feature-present search task (searching for Qs in Os). A planned Group (normals or patients) \( \times \) Task (feature absent or present) \( \times \) Target Side (left or right) \( \times \) Opposite-Side Distractors (0 or 16) comparison was highly significant, \( F(1, 16) = 34.72, p < .001 \). This interaction was entirely due to the bilateral display conditions: \( F(1, 16) = 28.77, p < .001 \) for the Group (normals or patients) \( \times \) Task (feature absent or present) \( \times \) Target Side (left or right) interaction. The unilateral displays did not contribute to this asymmetry between target sides: \( F(1, 16) = 1.12, p > .10 \) for the unilateral displays.

Second, in the unilateral baseline conditions (solid lines), the baseline search functions for the patients again did not
targets in the periphery. To some extent, this should affect formation. Eye movements may be necessary to localize displays (relative target positions are peripheral) and displays (relative target positions are central) and small search targets in bilateral displays in absolute spatial positions PI (near Figure 8.

Means of the median reaction times (in seconds) for targets in bilateral displays in absolute spatial positions P1 (near ipsilesional side) and P2 (near contralesional side) for large search displays (relative target positions are central) and small search displays (relative target positions are peripheral) for patients and normal subjects.

differ between ipsilesional and contralesional displays, and the Group (normals or patients) × Target Side (left or right) × Set Size (1 or 16) and Target Side (left or right) × Set Size (1 or 16) comparisons did not approach significance (both Fs < 1.14).

Search rates were calculated by regression analyses on the median RTs in displays of set size 1, set size 16 (unilateral displays), and set size 32 (bilateral displays). In normals, the search rate was 3.7 ms per item in the feature-present task, compared with 30.9 ms in the feature-absent task. A search rate of 3.7 ms per item suggests fast, preattentive search, as has been reported in the literature (Klein, 1988; Treisman & Souther, 1985; Wolfe & Pokorny, 1990). In the patients, search rates were again slower than in normals. They were 51 ms per item in the feature-present task compared with 233 ms per item in the feature-absent task. Although faster than in the feature-absent task, the search rate in the feature-present task was not fast enough to suggest parallel, preattentive search.

Planned comparisons confirmed that search rates were faster in the feature-present than in the feature-absent search task both for normals and for patients, both Fs(1, 8) > 58.34, p < .001. The difference in search rates between tasks (feature-absent vs. feature-present), however, was larger for normals than for patients, and the Group (normals or patients) × Task (feature absent or present) interaction was significant, F(1, 16) = 8.82, p < .01. Compared with normals, patients were especially slowed in the feature-present task. This result may point to a deficit in preattentive visual search mechanisms in the patients (see Eglit et al., 1989; Robertson & Eglin, 1993).

Search in the Visual Periphery

When displays become very large, visual acuity at the periphery of the displays decreases. Acuity limitations decrease feature discriminability and reduce localization information. Eye movements may be necessary to localize targets in the periphery. To some extent, this should affect both the feature-absent and the feature-present search tasks. However, visual search in the periphery might be especially difficult when the task requires attention.

Normals searched the stimulus arrays from the center outward (see Figure 6). Acuity limitations should therefore affect targets in the outer sections of the displays more than in the central sections, where normals seem to look and attend first. Therefore, we divided the bilateral displays into a central display section with 16 items (quarter-sections S2 and S3 collapsed) and a peripheral display section with 16 items (quarter-sections S1 and S4 collapsed). The mean of the median RTs to the central and to the peripheral display sections are given in Figure 9.

For the large and small feature-absent tasks in normals, the planned Section (central or peripheral) × Display Area (large or small) comparison was significant, F(1, 8) = 6.03, p < .04. For the peripheral sections there was a main effect of display area (large or small), F(1, 8) = 6.99, p < .03, whereas display area had no effect on targets in the central sections, F < 1. The central sections extended about 4.5° of visual angle for small displays and 16° for large displays. The absence of a display area effect in the central sections is consistent with the findings in the literature in which similar display areas were tested (Treisman, 1982). The RT slowing found with large displays was entirely due to the peripheral display sections, which extended out to 9° of visual angle in small displays and to almost 30° in large displays.

To examine the effect of periphery on attentional search, we compared the large feature-present task (parallel search) with the large feature-absent task (serial search). The Section (central or peripheral) × Task Type (feature absent or present) comparison was highly significant, F(1, 8) = 56.10, p < .001, with the main effect of task type (feature absent or present) being highly significant for both the peripheral and the central sections, both Fs(1, 8) > 110.73, p < .001. This indicates that the slowing of RTs because of serial attention movements was evident in all display sec-

Figure 8. Means of the median reaction times (in seconds) for targets in bilateral displays in absolute spatial positions P1 (near ipsilesional side) and P2 (near contralesional side) for large search displays (relative target positions are central) and small search displays (relative target positions are peripheral) for patients and normal subjects.

Figure 9. Means of the median reaction times (in milliseconds) for targets in the central display section (quarter-sections S2 and S3) and the peripheral (PERIPH) display section (quarter-sections S1 and S4) of bilateral displays in all three search tasks for normal subjects. Circles = large feature-absent task; triangles = small feature-absent task; squares = large feature-present task.
tions but affected the peripheral display sections more than the central ones. Thus, search was slower in the peripheral display sections with the larger display size and with the more demanding task type. This indicates that reduced feature discriminability in the periphery increases the attentional requirements of the task or increases the need for eye movements to peripheral display sections, especially in large displays and in serial search tasks.

In contrast to normals, neglect patients searched the displays from the far ipsilesional side to the far contralesional side (see Figure 5). So the contralesional display side (quarter-sections S3 and S4) was farthest away from the initial fixation and served as the peripheral display section. Quarter-sections S1 and S2 represent the part of the display where patients fixated first and are used as the central display section. The Section (central or peripheral) × Display Area (large or small) interaction was significant for the comparison of the large and small feature-absent tasks, \( F(1, 8) = 7.80, p < .03 \). The Section (central or peripheral) × Task Type (feature absent or present) interaction was also highly significant for the comparison of the parallel and serial task types with large display areas, \( F(1, 8) = 28.15, p < .001 \). These results support the normal data showing that RTs are slowed in display sections far away from initial fixation when the displays are very large and when the task requires more attention.

**Discussion**

**Contralesional Delay and Ipsilesional Hyperattention**

In the feature-absent task, normal subjects showed a delay in finding targets in bilateral displays compared with unilateral displays, which reflects the increased number of distractor items that have to be searched in the bilateral displays. This increase in search latency for targets in bilateral displays was equal for targets on the right side and targets on the left side of the displays. In contrast, as in a previous study (Eglin et al., 1989), there was a pronounced asymmetry in the patients. The patients were slower than normals in locating targets on the contralesional side of the displays when ipsilesional distractors were present, whereas search latencies for ipsilesional targets were fast and hardly affected by contralesional distractor items. This pattern of results is consistent with the suggestion that these patients have a bias to allocate attention to the most ipsilesional items of a display (e.g., De Renzi, Gentilini, Faglioni, & Barbieri, 1989; Kinsbourne, 1987; Ladavas, 1990). This bias results in overattention or hyperattention to the ipsilesional display side. The delay in locating contralesional targets is the sum of the time required to search the ipsilesional items plus an additional delay that may reflect a directional deficit in disengaging attention from ipsilesional items.

This conclusion is supported by the fact that in unilateral displays, the patient data showed no difference between the two displays sides, which indicates that the absolute position of the search arrays within ipsi- or contralesional hemispace is not critical for the contralesional deficit. The result may seem at odds with studies that showed less of a directional bias when the stimuli were shown completely within ipsilesional space and did not extend across the midline into contralesional hemispace with respect to body-centered coordinates (e.g., Bayles, Holtzman, & Volpe, 1986; Heilman & Valenstein, 1979; Karnath, Schenkel, & Fischer, 1991). In some of these tasks, hemispatial hypokinesia may have contributed to the relative better performance in ipsi- than in contralesional hemispace (e.g., Heilman & Valenstein, 1979; Karnath et al., 1991; see also Coslett, Bowers, Fitzpatrick, Haws, & Heilman, 1990). In contrast, the search deficits in the present tasks reflect attentional effects that are due to increased numbers of distractor items independent of the motor response. The attention movements required in the present tasks may show a directional disengage impairment even for stimuli completely within ipsilesional space. Consistent with these data is that a directional impairment independent of absolute hemispace has been shown in patients with neglect and in patients with parietal damage in cuing tasks (Morrow & Ratcliff, 1988; Posner et al., 1987).

**Effects of Overall Display Area: Relative Versus Absolute Positions**

Three important results were found with manipulation of the display area. First, the delay in finding contralesional targets in the feature-absent tasks was more pronounced for the large than for the small displays. Thus, the larger sized displays resulted in more severe neglect. There is growing evidence that neglect patients construct a reference frame in spatial coordinates based on various features of a stimulus array and then allocate their attention to the most ipsilesional parts within that reference frame (Driver, Baylis, & Rafal, 1992; Driver & Halligan, 1991; Grabowecky et al., 1993; Robertson & Eglin, 1993). The more items there are within that reference frame to attract attention ipsilesionally to the target, the more severe the neglect deficit will be. We show in the present study that the absolute size of a display from which the reference frame is constructed contributes to neglect even when the number and distribution of items in the display are held constant.

Second, the different display sizes allowed us to examine search latencies to targets in the same absolute spatial positions (near the midline) but in different relative positions within the displays (central positions in large displays, peripheral positions in small displays). We found that the relative position within the display affected the severity of neglect independent of absolute spatial position. Neglect was more severe the more a target appeared in a contralesional location with respect to other items in the array. Thus, two properties of a display contribute to neglect: the relative position of a target object within a display as well as the overall display area.

Third, our analyses of the central display sections confirm that within certain limitations (up to about 15° of visual...
angle), visual search rates in normals are independent of the overall area of the stimulus arrays (Treisman, 1982). This is consistent with the idea that search rates reflect attention operating on internal representations of objects that may be free of absolute spatial distance effects (Treisman & Gelade, 1980). With larger displays, feature discrimination (distinguishing Qs from Os) and localization of the target become more difficult in the periphery of the displays. Our results show that both an increase in display area as well as an increase in attentional requirements (feature-absent search task) slowed responses primarily to peripheral target locations. Low feature discriminability in the periphery of the large displays may slow the attentional search rates. It has been shown in normals that search rates increase when targets and distractors become more similar, which makes the discrimination more difficult (Duncan & Humphreys, 1989). In addition, more eye movements to peripheral targets may become necessary for the more attention-demanding search task.

The neural systems involved in saccade programming and in covert attention movements are closely associated (e.g., Lynch & McLaren, 1989; Rafal et al., 1988; Rizzolatti et al., 1987). Thus, the oculomotor deficits in neglect patients, which include conjugate eye deviation into ipsilesional hemispace (De Renzi et al., 1982), paucity of exploratory eye movements (Chedru et al., 1973; Hornak, 1992; Ishiai et al., 1987; Johnston, 1988; Johnston & Diller, 1986), and hypometric saccades into contralesional hemispace (Girotti et al., 1983; Heilman et al., 1980), may be associated with deficits in covert attention movements. Eye movement problems may enhance the patients' deficit on the contralesional display side when the displays are large and when the search task requires more attention.

Serial and Parallel Search Tasks

Search in the feature-absent task required more attention than search in the feature-present task in normals and in neglect patients. The target in the feature-absent task (O) shares all of its features with the distractors (Qs). There is no simple feature present in targets that would distinguish them from distractors and that could be detected by preattentive mechanisms. The current results, supported by reports in the literature (Klein, 1988; Treisman & Souther, 1985; Wolfe & Pokorny, 1990) that used similar search tasks, indicate that both normals and patients with neglect used an attentional mechanism to sequentially search the distractor items in the feature-absent tasks.

In the feature-present task, search rates were consistent with fast, preattentive processing in normals. Search rates in the patients suggested a slower, attentional search mechanism. This slowing of search rates in patients compared with normals was also found in a previous study (Eglin et al., 1989).

These slow search rates could reflect a deficit in preattentive processes in the patients. If preattentive processes fail to guide attention to likely target locations, search becomes inefficient. Because search was also slowed in the feature-absent task used in the present study, to which preattentive processes contribute little, deficits in preattentive mechanisms may not be the only factor producing slowed search rates in the patients. Serial attentional mechanisms may also be slowed in the patients. Because our tasks require subjects to accurately locate the target, there may be a significant attentional component even in displays that typically produce search functions consistent with parallel search. Attention has to be summoned to the position of the preattentively detected target feature. This may be fast and automatic in normals but may be slow in the patients even with salient targets.

Theories of Neglect

The theory that neglect represents part a directional disengage deficit (Morrow & Ratcliff, 1988; Posner et al., 1984, 1987) is consistent with the current data. However, neglect is not fully explained by a simple disengage hypothesis. The disengage deficit is relative to other items in the display. It is enhanced by increased numbers of ipsilesional items in the display (Eglin et al., 1989) and by a relative contralesional target location within the array (Grabowecky et al., 1993). In addition, the present study shows that the disengage deficit is more severe if attention is disengaged to be moved far contralesionally rather than near contralesionally. Thus, the directional disengage deficit depends on at least three additional components: the relative position of the disengage location, the number of ipsilesional items competing for attention, and the distance of the imminent attention movement.

The data are in part consistent with Kinsbourne's (1987) theory of neglect, which suggests an orienting bias toward the ipsilesional side because of release of inhibition from the damaged hemisphere. An orienting bias can explain why neglect patients start visual search at the ipsilesional edge of a display. An orienting bias is not sufficient, however, to explain why these patients get stuck on the ipsilesional items in the display. An orienting bias alone is also not sufficient to explain the effects of display size and why it takes longer to move attention contralesionally in large displays. Thus, the results in our search tasks point to additional factors, such as number of objects in a display and display area, that influence neglect.

Similarly, our data are consistent with recent data from a positron emission tomography study in normals which suggested that two distinct regions in right superior parietal lobe separately direct attention to left and right hemisphere, whereas the left superior parietal lobe directs attention primarily to right hemisphere (Corbetta et al., 1993). These findings may explain why neglect is more frequent after right than after left parietal injury. Our results show that this bias to direct attention to the left is influenced by different properties of a visual scene such as its overall size and the distribution of objects within the scene.
Summary

The present results replicate a previous study showing that visual search is inefficient in patients with neglect. Search was slow in both search tasks in the present study, including the feature-absent search task, to which early preattentive processes contribute little, because all distractor items (Qs) contain the target (O). Slowed visual search rates in neglect patients therefore seem to result from an impairment in both preattentive as well as focal attention mechanisms. The patients' disengage deficit when moving attention contralesionally (Posner et al., 1984, 1987) may also contribute.

As in previous studies, a contralesional search deficit was found to be dependent on abnormal attention allocation to ipsilesional stimuli. The use of unilateral displays presented entirely within ipsilesional or contralesional space showed that the absolute spatial positions of visual objects within ipsi- or contralesional hemispace are not critical for the contralesional deficit. The critical factors that predict the contralesional deficit are the target's relative position within a stimulus array (see also Grabowecky et al., 1993), the number of items attracting attention ipsilesionally to the target (Eglin et al., 1989), and the overall spatial extent of the stimulus array. Our results are consistent with, but not fully explained by, theories of neglect that claim an orienting bias toward the ipsilesional side (Kinsbourne, 1987) or a directional disengage deficit (Posner et al., 1984, 1987). The present study indicates an important new component of neglect: the distance of the attention movement following disengagement of attention. Thus, increasing the size of a visual scene will enhance neglect of its contralesional regions.

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