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SPECIAL ISSUE

HEMISPATIAL NEGLECT AND VISUAL SEARCH: A LARGE SCALE ANALYSIS

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ABSTRACT

Visual search tasks have standardly been divided into two categories: those in which the target is detected through a serial, attention-driven search and those in which the target is detected rapidly in parallel and, apparently, without attentional processing. Several studies have examined this distinction in patients with hemispatial neglect with the clear prediction that the former, but not the latter, should be impaired. These studies, however, have proved inconclusive. We have addressed this issue in a large sample of patients with unilateral hemispheric infarcts to the left or right hemisphere. In addition to measuring the patients' performance on both types of visual search tasks, we documented the presence and severity of neglect and of visual field defects in these same individuals. Patients with brain-damage with or without accompanying neglect were impaired at searching for the contralateral target on both forms of visual search, relative to normal control subjects, although this deficit was magnified in individuals with neglect and was also exacerbated by the presence of hemianopia. This pattern was also more pronounced in individuals with right- than with left-hemisphere lesions. The findings not only clarify the contradictory neuropsychological data but also provide clear evidence for the involvement of attentional processing in all forms of visual search.

Key words: hemispatial neglect, attentional deficit, visual search

INTRODUCTION

Visual search paradigms, in which individuals search for a pre-defined target in a display containing multiple items, have been used extensively over the last decade or so in an attempt to characterize the neurobehavioral disorder termed "hemispatial neglect" (or "neglect" for short). Neglect is a disorder in which individuals, following an acquired brain lesion, fail to notice or report information on the side of space opposite the lesion, despite intact sensory and motor processes (Bisiach and Vallar, 2000; Bartolomeo and Chokron, 2001). Thus, for example, patients with a right hemisphere lesion fail to copy features on the right of a display while incorporating the corresponding features on the ipsilesional left. The same individual may eat from only the right side of their plate or dress only the right side of their body. The deficit may affect all sensory modalities, including contralateral visual, auditory, somatosensory and olfactory inputs. The presence of neglect may also adversely affect manual and oculomotor behavior in that these patients are often impaired at directing their eyes and/or hand to the contralateral side, even in the absence of visual input (Behrmann et al., 2001; Gore et al., 2001/2002; Hornak, 1992; Mattingley et al., 1998). Finally, neglect can affect the contralateral side of an internal representation in the absence of sensory input, and can be reflected in mental imagery, as so elegantly demonstrated in the seminal work by Bisiach and Luzzatti (1978).

The deficit that gives rise to hemispatial neglect is often attributed to the failure to construct an appropriate representation of space as a consequence of an attentional bias, which favors the processing of ipsilesional stimuli. Interestingly, patients with neglect may orient to highly salient contralesional stimuli but, left to their own devices, do not volitionally direct their attention to that side of space (Làdavas et al., 1994). Given that visual search tasks have been used extensively over the last several decades to examine patterns of visual attention in normal subjects (Bricolo et al., 2002; Neisser, 1964; Treisman and Gelade, 1980; Wolfe, 1998), the use of such measures may be particularly useful in elucidating the nature of the attentional biases in patients with hemispatial neglect. Despite the robustness of this experimental approach in normal subjects, the findings from visual search studies with neglect patients to date remain controversial. We start by describing briefly the paradigms employed in visual search studies with normal subjects, pointing out the central assumptions and major results. We then review the existing data obtained in individuals with hemispatial neglect. Following this, we report the

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SPECIAL NOTE

The authors pay special tribute to Dr Edoardo Bisiach who has been one of the primary researchers in the study of hemispatial neglect and whose seminal contribution is widely recognized. Two of the three authors of this paper (MB and SEB) met Dr Bisiach for the first time in 1986 when he visited the University of Toronto. His visit had a significant impact on us and our future work. In addition, over the years, Dr Bisiach has commented on some of our papers and has been very helpful on several other occasions. His input and collegiality are much appreciated.

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findings we have obtained in a very large group of patients, who have sustained a unilateral hemispheric stroke to either the left or right hemisphere, using a well-established visual search paradigm, and we indicate ways in which these data can shed light on the mechanisms giving rise to the neglect deficit.

Visual Search as an Experimental Paradigm in Normal Subjects

Visual search studies are well-suited as a proxy for real-world attentional requirements, as features of the natural environment such as object clutter are captured while a controlled stimulus environment is maintained. A particularly prolific subset of these studies focuses on the conditions under which the reaction time (RT) and accuracy to locate the target are affected by the number of distractors appearing in the display (Geng and Behrmann, 2002b; Behrmann and Haimson, 1999; Treisman, 1999; Yantis, 2000). Cases in which the time to detect a target is largely unaffected by increasing the number of distractors (e.g., 5 msec/distractor item) are labeled as “feature search” or “disjunctive”, whereas cases in which detection time is significantly slowed by the increasing number of distractors (e.g., 50msec/item) are labeled “conjunctive”. These different search functions have also been referred to as “parallel” vs. “serial” or “simple” vs. “difficult”. The critical distinction is that visual search for targets distinguished by a single feature is scarcely affected by the number of distractors present whereas targets distinguished by feature conjunctions appear to be affected linearly by the number of distractors present. The interpretation of this distinction is that feature search can be executed effortlessly and preattentively (without attention); because search can be conducted in parallel across the entire display and the target “pops out” in this form of search, there is no increase in target detection time with increasing number of items in the display. In contrast, in the conjunctive search task, each item must be sequentially examined to determine whether it is a target. This process requires the allocation of attention, and the serial search results in the monotonic increase in detection time as a function of display size (see, for example, Bricolo et al., 2002). The effect of display size is a critical indicator and is taken to be the primary assay for the involvement of attention (Bundesen, 1990; Duncan and Humphreys, 1989).

Visual Search Tasks in Patients with Neglect

The assumptions derived from the visual search studies with normal subjects lead to a number of critical predictions with regard to neglect. If unilateral neglect does arise from a deficit of attention, then, in the feature search (preattentive) task, performance in individuals with hemispatial neglect should not differ from that of normal individuals and should be unaffected by the size of the display. In addition, feature search should be identical for targets on the contralateral and ipsilateral sides. In contrast, performance should be impaired, relative to normal controls, for conjunction search when the target appears on the contralateral side and this should be exaggerated as the display size increases. Whether search for an ipsilateral target should be normal is not entirely clear, but patients should be differentially impaired for contralateral versus ipsilateral targets in conjunction search. Unfortunately, despite the abundance of studies, there is no clear consensus on the visual search performance of individuals with neglect, as will be apparent from the review of the literature below, and many questions remain unanswered. In addition to this lack of agreement, there are a number of other outstanding and controversial issues which affect the existing findings and we return to these after we have laid out the major studies and their results.

In one of the earliest studies examining visual search with neglect patients, Riddoch and Humphreys (1987) presented a series of cards with displays to three patients with left-sided neglect. The patients were required to search for a target, which was present on half the trials, and accuracy and reaction time (RT) were recorded. In the feature search task, the display contained a red circle among green circle distractors whereas, in the conjunction search task, the display contained an inverted “T” among upright “T” distractors. In the feature search task, RT was unaffected by the number of distractors even when the target appeared on the contralateral side, consistent with parallel search. Note, however, that, even in this condition, there was a high error rate for contralateral targets, suggesting that feature search was not totally intact in these patients. As expected, detection was poor both in accuracy and RT for targets on the contralateral side in the conjunction search task.

A subsequent study by Eglin and colleagues (Eglin et al., 1989), using a red dot among blue and yellow dots (feature search) or a red dot among split blue and intact red dots (conjunction search) and varying array size, distractor number, and location of stimuli, confirmed the impairment in contralateral feature search in six patients with right hemisphere damage (RHD) and in one patient with left hemisphere damage (LHD). In contrast with the control subjects who showed only a linear slope in the conjunctive search task, there was a significant increase in the time taken to detect contralateral targets for neglect patients in both the feature and conjunction search task. Consistent with this is the finding from a related study by the same authors in which patients were required to point to a target (Eglin et al., 1991; 1994). Here, as before, search rates in patients were also slower than those of control participants for feature as well as conjunction search (for other consistent confirmatory evidence, see Rapcsak et al., 1989).

Finally, in a recent study, Pavlovskaya et al. (2002) compared the performance of four RHD and one LHD patients with neglect, sustained following rather extensive cortical damage, and six healthy control subjects on a task involving search for an oriented line element. In the feature search, the target was an oblique line embedded among vertical lines and in the conjunction search the target was an oblique yellow line embedded among blue lines of a shared orientation and yellow lines of a differing orientation. Consistent with the data reviewed above, all patients were impaired in both the feature and conjunction versions of these tasks and their performance deteriorated as the target appeared further contralaterally.

In direct contrast to the studies described above, however, several other studies have argued for preservation of feature search in neglect patients. For example, three patients with neglect and cortical lesions tested by Esterman and colleagues (Esterman et al., 2000) revealed normal preattentive search. A fourth patient with neglect following a subcortical lesion did not show normal feature search and exhibited an effect of array size on search time. Note, however, that two additional patients with neglect and hemianopia also showed impaired contralateral feature search. All patients were impaired on the conjunctive search task with contralesional targets, leading the authors to conclude that only serial, effortful search is affected in hemispatial neglect but that the ability to extract low-level featural information across the field in parallel is preserved.

Consistent with the Esterman et al. study, Aglioti and his colleagues (Aglioti et al., 1997) examined the search performance of a very large group of individuals, consisting of 75 participants with LHD or RHD. Both groups included individuals with and without neglect. Subjects performed a task using two different visual textures in which, in one case, the target was easily segregated and detected and, in the other case, was difficult to detect. The critical finding was that contralateral errors were disproportionately higher on the latter task as opposed to the former, indicating that neglect only impaired the more effortful search performance. It is of note here that because the number of items was not manipulated in these displays, it is difficult to know whether these tasks map directly onto the preattentive versus attentive distinction made previously.

In a similar vein, Arguin et al. (1993) investigated eight LHD participants both with and without visual attention deficits on feature (orientation or colour as the distinctive feature) and conjunction search tasks (orientation and colour conjoined). The patients with visual attention deficits performed similarly to controls in contralateral hemispace on the feature search task, but had longer reaction times for contralateral targets on the conjunction task. The authors concluded from this finding that feature search performance was preserved in participants with visual attention impairments.

The preservation of feature search performance in neglect patients is also consistent with findings using experimental paradigms that do not necessarily require visual search. For example, several studies have reported that patients with neglect are still able to extract low-level information and derive primitive shape descriptions from information appearing on the contralateral side. For example, when the contralesional item of a display could be grouped with the ipsilesional information on the basis of Gestalt factors such as similarity (Ward et al., 1994), symmetry (Driver et al., 1992), colour and proximity (Driver and Halligan, 1991), or brightness or collinear edges (Gilchrist et al., 1996; Rorden et al., 1997), report of the left-sided stimulus was better than when the left sided information could not be grouped with a simultaneously-presented right sided stimulus. This was also the case when the left-sided information could be grouped with the right-sided information by ‘goodness’ of an object such as a global outline (Farah et al., 1993), illusory contour (Kanizsa-type figure) (Mattingley et al., 1997) or of any well-configured object or whole (Boutsen and Humphreys, 2000). The benefit attributed to the contralesional information under these conditions is thought to arise from the fact that low-level visual information can be extracted preattentively and this enables the grouping of the contralateral and ipsilateral information. It has also been suggested that the extraction of preattentive contralateral information may suffice for deriving detailed information to allow access to lexical and semantic processing (Esterman et al., 2000; Kumada and Humphreys, 2001; Humphreys, 2003; but see Behrmann et al., 1990 for an alternative explanation of how these effects might arise).

Finally, the preservation of feature search is consistent with the findings of a recent study using evoked response potential (ERP) and functional magnetic resonance imaging (fMRI) in patients with neglect and extinction. Note that in visual search tasks, aside from trials with a single item, there are always multiple items in a display, and, as such, this resembles double simultaneous stimulation trials on which extinction is elicited. In this study, Vuilleumier et al. (2000), using combined ERP and event-related fMRI, showed that even stimuli that were not explicitly reported (i.e., suffered extinction) gave rise to activation in right V1 and inferior temporal cortex and elicited a nonsignificantly reduced N1 evoked potential. These findings suggest that visual information may be processed by posterior and early parts of the visual system and that this might correspond to preattentive processing. However, in the absence of coupling with dorsal frontal and parietal areas (perhaps mediating attentional processing), conscious awareness is precluded and this may be consistent with attentive processing (but see Marzi et al., 2000, for a different result).

As is evident from this overview, there are clearly a number of discrepant findings especially with regard to the preservation of contralateral feature search in neglect and the extent to which contralateral information can be processed by these patients. This lack of agreement may arise for several different reasons. One obvious possibility is that the methods adopted in the different studies vary quite substantially, including the number of subjects tested (with very small numbers in some cases), the nature of the search task (colour discrimination, letter detection, pointing or cancellation), and the reliance on a single or on multiple dependent measures (accuracy and/or RT). Of course, the qualitative and quantitative differences between the different subject samples can also contribute to the different outcomes; this heterogeneity in lesion size and site is exacerbated when the subject sample is small and, indeed, there is well-documented variability across patients.

In addition to these obvious reasons, a number of other factors could potentially complicate the results and these confounding factors are not necessarily addressed or controlled in the various studies. Firstly, we do not know whether any apparent deficit that is observed in the neglect patients is a function of a hemispheric lesion *per se* or whether the deficit is solely a consequence of hemispatial neglect. Because many studies compare the performance of the neglect patients to the performance of a group of normal, healthy control subjects and do not include a group of brain-damaged individuals without neglect, it is not possible to know whether the deficit is attributable to neglect *per se* or to brain damage more generally. Secondly, related to this, we do not know whether the apparent deficit is correlated with the severity of neglect, as one might predict if the deficit is truly attentional in nature. Because the number of subjects is small in some studies, or in those studies in which there are a large number of subjects, patients are simply assigned to a presence/absence of neglect dichotomy, it has not been possible to examine the correlation between severity of neglect and visual search behavior in detail. Thirdly, we do not know to what extent the presence of a visual field defect affects performance. This has recently become a rather substantial issue in understanding hemispatial neglect; whereas Doricchi and Angelelli (1999) and Toth and Kirk (2002) have shown that neglect patients with hemianopias make greater ipsilesional bisection errors in line bisection tasks then neglect patients without hemianopias, Ferber and Karnath (1999) have found otherwise. To the extent that the presence of a field defect has been taken into account in studies of visual search, the results have proven contradictory. As mentioned above, Esterman et al. (2000) find that only patients with hemispatial neglect accompanied by a field defect are impaired at feature search whereas Aglioti et al. (1997) report no difference as a function of the presence/absence of field defects in reaction time (RT). Note that Aglioti et al. (1997) do find an increased number of errors but this is so in all individuals with field defects and is not restricted to those patients with neglect.

The final issue concerns differences between individuals with left hemisphere lesions and those with right hemisphere lesions. Neglect is notoriously associated with RHD more often than with LHD, although the extent of this relationship is also somewhat controversial (Ogden, 1987). Studies using transcranial magnetic stimulation and functional magnetic resonance imaging have pointed to differences between the two hemispheres in their relative involvement in attentional processing (Ashbridge et al., 1997; Corbetta et al., 1995, 1998) and suggest greater involvement of the right hemisphere in attentional tasks such as conjunction search. To the extent that this issue has been considered, the data remain contradictory. Gainotti et al. (1986), for example, have argued for no difference between LHD and RHD patients in visual search tasks whereas others (for example, Halligan et al., 1992; Weintraub and Mesulam, 1987) do find differences between these groups. Because the number of subjects in these studies is typically small, and because patients with LHD with neglect tend to have milder forms of neglect than their RHD counterparts, a clear comparison between hemispheric groups with severity of neglect and presence of hemianopia equated, is very difficult. It remains to be determined, therefore, whether there are hemispheric differences in visual search in patients with neglect when these other factors are taken into account.

In light of the controversial findings and the many remaining outstanding questions, we have undertaken a study of the visual search performance of a large group of patients, consecutively admitted to a university teaching hospital stroke care unit, who suffered a stroke to either the left or right hemisphere. We have included not only individuals with no neurological deficits to serve as controls but also individuals who have suffered a hemispheric lesion but who do not exhibit neglect to serve as an additional control group. In addition to completing a bedside battery used to diagnose neglect and to document its severity, we had subjects complete a computerized version of feature and conjunction search performance for targets presented to the

TABLE I

Overall Demographic Information for the Stroke and Control Participants

	Stroke participants		Controls participants
Number of participants	104		34
Hemisphere damaged	RHD = 56	LHD = 48	—
Average age	70.1 years	69.7 years	68.6 ± 6.6
Average education	13.03 years	12.72 years	12.9 ± 4.0
Sex	Males = 33 Females = 23	Males = 24 Females = 24	Males = 14 Females = 20
Handedness	All Right Handed		All Right Handed
Neglect	None = 30 (53%) Mild = 14 (25%) Severe = 12 (22)%	None = 39 (82%) Mild = 9 (18%)	

contralateral or ipsilateral side and we measured accuracy and RT. Subjects also underwent clinical visual field testing, and the extent of a visual field defect was documented. Finally, because of the large patient sample, we have been able to compare RHD and LHD with neglect where the severity of the neglect (and presence of hemianopia) is equated in the two groups. With this data set, we will first attempt to replicate the finding of impaired contralateral search in patients with neglect. We will then examine detection of ipsilateral targets in conjunction search. But perhaps most relevant is that we will determine whether feature search is normal in individuals with neglect. Lastly, we will explore whether the visual search performance of the patients is influenced by the presence and/or severity of neglect, the side of the lesion and/or the presence of hemianopia.

MATERIALS AND METHODS

Subjects

Individuals with and without brain damage consented to participate in this study. The non-brain-damaged control group consisted of volunteers, age- and education-matched to the patients, living independently in the community served by Sunnybrook and Women's College Health Sciences Centre. These control subjects were screened for neurological and serious medical illness and were excluded if such diseases were present.

The brain-damaged group was recruited from a consecutive series of patients with stroke admitted to the Sunnybrook and Women's Stroke Care Unit. All brain-damaged participants were right-handed with corrected visual acuity of at least 20/40. All patients met the following criteria: age between 20-85 years, clinical and radiological evidence of a single, unilateral lesion, no other neurological/mental illness (i.e., dementia, epilepsy, previous stroke), no other serious concomitant illness (e.g., cancer), and no history of substance abuse. All stroke patients were tested within three months of stroke onset. They were recruited as soon after the stroke as they were able to sit up and undergo computerized testing. Those who could not understand test directions because of severe aphasia were excluded (n = 4). Although an attempt was made to perform the computerized visual search task and neglect testing on the same day, this was not always possible for logistical reasons. Patients tested within the first 2 weeks post-onset were allowed a maximum of 4 days between different components of the testing since neglect can improve substantially in the first 2 weeks after a stroke. If the patient was unable to be tested in the first two weeks, an interval of 9 days was allowed. If performance on the neglect battery was within normal limits, a longer testing interval was allowed if the patient remained neurologically stable, since it was unlikely that performance would change in that interval.

In total, 48 left hemisphere-damaged (LHD) and 56 right hemisphere-damaged (RHD) individuals consented to participate in this study along with 34 elderly non-neurological control subjects, for a total sample of 138 subjects. The overall demographics and clinical characteristics of the different groups are given in Table I. The etiology of the lesion was similar in RHD and LHD groups, with infarcts of the middle cerebral artery being the most frequent. The control subjects and stroke patients did not differ with respect to age (t = 0.82, p = .41), education (t = – 1.91, p = 0.06), or gender distribution ($\chi^2 = 2.67$, p = 0.10).

Neglect is generally not that easy to diagnose and, depending on the nature of the subtests used in a screening battery, the diagnosis can vary (Halligan and Marshall, 1992). To maximize the reliability of the diagnosis, the presence of hemispatial neglect was assessed using the Sunnybrook Neglect Battery, a comprehensive evaluation of neglect, consisting of four different sub-tests: a shape cancellation task published by Mesulam (1985), spontaneous drawing and copying of a clock and daisy, line bisection, and a line cancellation task. Performance is scored out of 100 (Black et al., 1990; Leibovitch et al., 1998). In this

TABLE II

Breakdown of Subjects by Presence and Severity of Field Defect with and without Neglect after Damage to the Left or Right Hemisphere

Field defect	Left hemisphere damage		Right hemisphere damage		
	N–	N+	N–	N–	N++
None	25	4	19	3	4
Mild	1	2	3	4	3
Moderate	0	1	2	2	0
Severe	6	1	1	2	1
Unknown	7	1	5	3	4
Totals	39	9	30	14	12

battery, performance of control subjects is used to define the upper limits of normal performance, and scores are assigned as performance deviates from this cut-off. Based on the extent of the deviation, performance can be classified as within normal limits (score < 6), or reflecting mild (score 6-39) or severe neglect (score > 40). Of the LHD group, nine patients were classified as having neglect (all mild). Of the right RHD group, 30 had no neglect using the above criteria, 14 had mild neglect and 12 had severe neglect.

Patients were also tested for the presence of a field defect by finger counting or movement to confrontation as part of the Stroke Scale. The outcome of this evaluation could be designated as absent, mild/moderate or severe field defect (i.e., complete homonymous hemianopia). Unfortunately, this test was not conducted on 20 patients (8 left hemisphere, 12 right hemisphere) and so their visual field status remains unknown. Because all our analyses are done with individuals in whom visual field status is known, these subjects are not included in any of the analyses. Table II presents the breakdown of the subjects by side of hemispheric damage, neglect status, and visual field status.

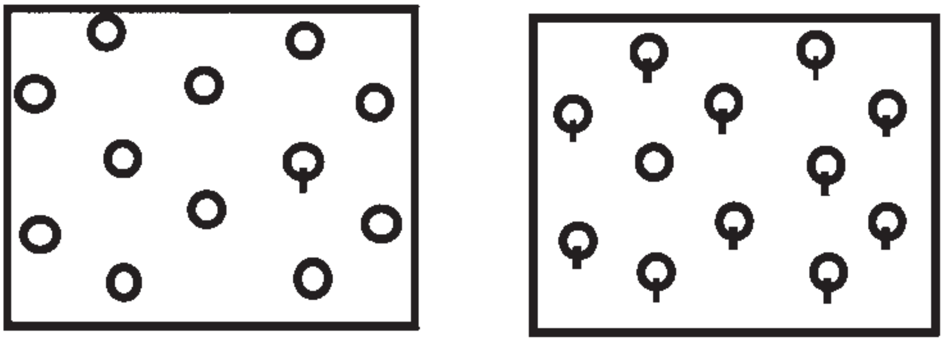
Apparatus and Stimuli

Subjects performed two visual search tasks, based on those used successfully with normal and brain-damaged individuals (Treisman and Souther, 1985; Eglin et al., 1994). In the feature search task, the participant had to identify a "⚲" among "○ s", with the differentiating feature being the stick on the Q. In the conjunction search task, there is no single differentiating feature on the target and the "○" was the target while the "⚲" served as the distractors. Although it is not obvious what features are conjoined in this latter case, it is well known that searching for the absence of a differentiating feature leads to serial, labored search in the same way that conjoining two features does (Treisman and Gelade, 1980), and hence we refer to this task as conjunction search to remain consistent with the literature. In half of the trials, the target was present and, in the other half, it was absent. The array size varied from 1, 6, and 12 items with an equal number of trials for each array size. The position of the target, when present, varied across 12 different points (6 left-sided and 6 right-sided) on the screen with an equal sampling of all these positions. The target was never located directly along the vertical midline of the array. There were a total of 120 trials in each search task.

The tasks were administered using a Mac Plus computer and PsychLab Software (Bub and Gum, 1991). Subjects responded using a button box, placed along the midsagittal plane. To avoid the complications of stimulus-response compatibility, subjects used the top and bottom buttons, with the upper button indicating target present and the lower indicating target absent. Stroke patients used their ipsilesional hand to perform the task. To account for the fact that half the patients used their left hand and the other half used their right, handedness was manipulated in the control group so that half of the controls responded with their right hand and the other half responded with their left hand. Each trial was preceded by a fixation point (a large dot), which was presented in the center of the screen 150 msec before each trial. Immediately thereafter, the array appeared and remained on the screen until the subject responded. Before each test session, there was a 9 trial practice session, which could be repeated once, if necessary. If a subject was unable to perform the task after 2 practice blocks, s/he was excluded from the study.

Data Analysis

Two dependent variables were used in the analyses: accuracy and median reaction time (RT). The number of correctly identified targets provided the measure of accuracy. Because we analysed the data separately for left and right targets, each of which have half the number of trials compared with the target absent condition, we use percentage accuracy as the dependent measure to equalize the data. Participants with less than 50% accuracy in any trial condition (i.e., < 5 correct responses) were excluded from the statistical analyses based on RT. In the RT analysis, the median was calculated per subject for each array size for target present, separately for left and right targets, and target absent trials. In addition, the slope of RT across array size was used as an index, where



I. *Pop-out* Task.
Target defined by a distinctive feature:
specifically, an intersecting line.

II. Serial Task.
Target defined by the lack
of a distinctive feature.

Fig. 1 – *The pop-out and serial visual search tasks. The search tasks are similar to those published by Treisman and Souther (1985). In the pop-out task, the target is defined by the presence of a vertical line on the circle. In the serial search task, the target lacked the vertical line present on the distractors.*

necessary, to provide a measure of search efficiency and to summarize the RT data for a single subject. This index is well-established as a summary statistic and the slope sizes for various search paradigms have been well documented (Treisman and Gormican, 1988). A further measure which has been shown to be useful in characterizing performance is the ratio between the slope for targets present and target absent with a 2:1 ratio, indicating self-terminating search since, on average, it takes half the time to find the target as it would to determine that no target is present (Treisman and Gelade, 1980; Treisman and Souther, 1985).

We conduct analyses of variance (ANOVA) to compare the patient groups against each other as well as against the non-neurological control subjects. Before doing so, however, we wanted to ensure that there was no difference within the healthy controls when responses were made with the left versus the right hand. To do this, we performed an ANOVA on the control data with response hand (left/right) as a between-subject variable and array size (1, 6, 12), search task (feature, conjunction) and target location (left/right) as within-subject variables. There was no significant effect of response hand for the normal control subjects, nor an interaction between response hand and any of the other factors, (all $F < 1$). Hence, the control data are collapsed across the variable of response hand for all future analyses.

For all the remaining analyses, we plot data for left and right targets separately and compare these to the data from target absent trials. Initially, we compare the performance of normal control subjects separately with left brain-damaged patients and then with right brain-damaged patients with and without neglect. Then, we directly compare the performance of brain-damaged patients with neglect following left versus right hemisphere damage when the severity of neglect is equated. All the initial analyses are done using data obtained only from those patients who do not have field defects. Thereafter, we examine whether the presence of a field defect makes any additional contribution to search performance over and above that of neglect. In all cases, *post hoc* comparisons are conducted with $p < .01$ (a rather more conservative value given the number of pairwise comparisons). Only the major results and significant findings are reported.

RESULTS

To address the questions of concern, we start by analysing the data from the LHD and RHD groups separately, using the control data as the benchmark for comparison.

Left Hemisphere Damage

To examine whether there is a deficit in visual search in patients with LHD and whether this differs depending on the presence of neglect, we separated the brain-damaged patients without field defects into those with neglect (LHD N+; N = 4) and those without neglect (LHD N–; N = 25). In addition to this between-subjects variable, we included three within-subjects variables: search type (feature, conjunction), side of target (left, right, target absent) and display size (1, 6, 12). In the RT analysis, all main effects and interactions were significant. Many of these effects are also present in the analyses of accuracy. Because detection time is the metric used most often for visual search (and indeed, in our paradigm, accuracy is a rather limited dependent measure given the relatively restricted number of trials per cell and the unlimited exposure duration of a trial), we focus more specifically on RT and only make some brief statements about accuracy of performance.

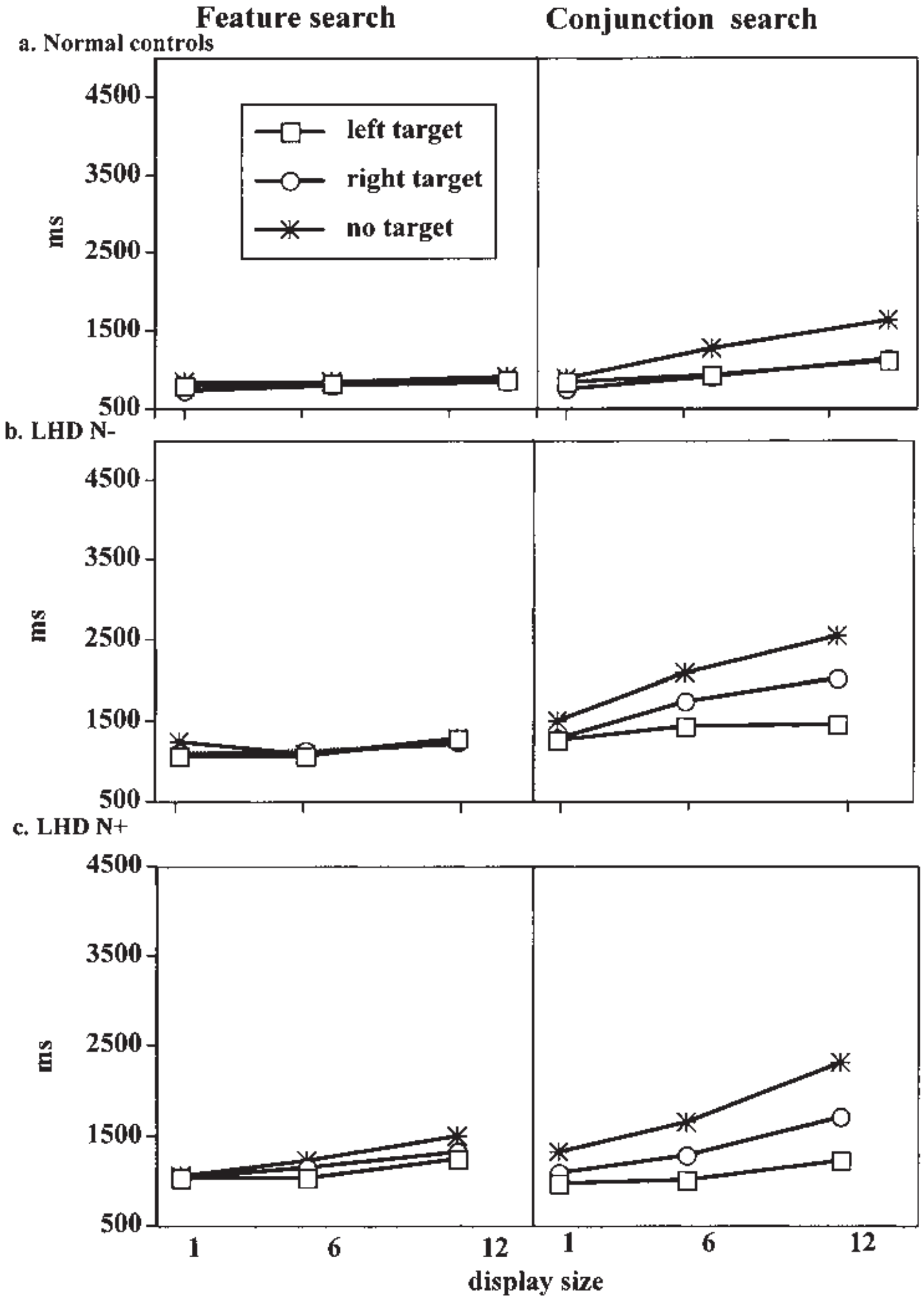


Fig. 2 – *Mean of median reaction time for (A) non-neurological control subjects, (B) patients with LHD but no neglect and (C) patients with LHD and accompanying neglect on feature and conjunction search as a function of display size and presence (left/right) or absence of target.*

The RT data are plotted separately for feature (left hand panels) and conjunction (right hand panels) search and for each of the three subgroups in Figure 2. Note that we maintain the same y-axis for all subgroups in this figure and we use the same axis in subsequent figures for ease of comparison. The normal control subjects detect targets significantly faster than either the LHD N– or LHD N+ group by about 400-500 ms, F (2, 60) = 17.8, p < .001, whereas the latter two subgroups do not differ from one another in overall RT. Feature search is 319 ms faster than conjunction search, F (1, 60) = 185.4, p < .001, although this difference varies across the three subgroups, F (2, 60) = 12.2, p < .0001 (222 for controls, 382 for LHD N–, 581 for LHD N+). RT increases as a function of display size, F (2, 120) = 35.9, p < .0001, and this too varies across subgroups, F (4, 120) = 8.2, p < .0001, with slopes of 22.6, 35.8 and 42.4 for the controls, LHD N– and LHD N+ subgroups, respectively. The increase in RT with display size is greater for conjunction

TABLE III

Slope of Search (ms) Across Display Size for the Three Subgroups for Left, Right and Absent Targets, Collapsed Across Search Type

	Target left	Target right	Target absent
Normals	17.4	26.8	25.6
LHD N–	23.3	47.8	71.5
LHD N+	13.1	56	53

than feature search, as expected, F (2, 120) = 46, p < .0001. This too is qualified by an interaction with subgroup, F (4, 120) = 4.2, p < .0001; the slopes for feature search were 6.9 ms, 8.1 ms and 12.4 ms for the controls, LHD N– and LHD N+ subgroups whereas those for conjunction search were 38.2 ms, 71.8 ms and 64.3 ms respectively.

Of particular interest, however, is whether search differs as a function of the side of the target: search for left targets is 76 ms faster than for right targets and target absent trials are slowest, with an increment of 283 ms over right trials, F (2, 120) = 81.4, p < .0001. There is an interaction of side of target with search type, F (2, 120) = 103.1, p < .0001, and with display size, F (4, 240) = 17.5, p < .0001, and a three-way interaction of search type × display size × side, F (4, 240) = 27.8, p < .0001. When we examine how these factors affect the different subgroups, we observe a two-way interaction of side of target × subgroup, F (4, 120) = 6.3, p < .0001, but this is qualified in a three-way interaction with search type, F (4, 120) = 6.5, p < .001. The three-way interaction reflects the finding that there is an asymmetry in search for left versus right targets (slower on right) in the patients but not the control subjects, which is exaggerated in conjunction over feature search. This asymmetry is a little more evident in the LHD N+ than LHD N– subgroup, who do not show an asymmetry in the feature search task.

There is also a three-way interaction of display size × side of target × subgroup, F (8, 240) = 2.8, p < .01. This three-way interaction can be interpreted using the data from Table III, which presents the slopes (in ms) across the display sizes, reflecting the increment in RT per item for targets on the left and right and for target absent trials. The essential finding is that, relative to the control subjects, both brain-damaged groups show steeper slopes in visual search for contralateral targets. Although there is no statistically significant difference between the two patient groups on this measure, the LHD N+ patients show numerically faster search for ipsilateral targets than do the LHD N–, who do not differ from the control subjects on this measure. This relative facilitation for ipsilateral targets, primarily evident in the conjunction search, and the slowing for contralateral targets is well-documented in the neglect literature (see below for further illustration of this pattern) (Behrmann et al., 1998; Cate and Behrmann, 2002; Làdavas et al., 1990) and is often attributed to competitive effects between more ipsilateral versus contralateral stimuli. Importantly and crucially, the four-way interaction of all the variables is not significant, F (8, 240) = 1.6, p > .05, suggesting that the impairment for search is equivalent across feature and conjunction search. These findings support the idea that the patients, particularly those with neglect, perform more poorly than the control subjects in conjunction search, as expected, but also in feature search for contralateral targets.

The accuracy data are largely compatible with the RT data. As in the RT, there is no significant four-way interaction but there is a three-way interaction of search type × display size × subgroup, F (4, 120) = 5.4, p < .001, reflecting the increase in error rate in both subgroups, again slightly greater in LHD N+ than LHD N–, in conjunction over feature search with increasing display size. There is no additional effect of side of target and so the asymmetry revealed in RT is not observed here. Because accuracy is reasonably high given the nature of the paradigm, this dependent measure is not as revealing as RT and we do not dwell on it further.

In conclusion, the critical finding is that both left hemisphere brain-damaged groups are impaired compared with the normal control subjects in the detection of contralateral right versus ipsilateral left targets (and absent targets) and this is so to a greater extent as display size increases. This disadvantage for right over left trials especially with increasing display size occurs in both types of search tasks although it is magnified in conjunction over feature search. The two brain-damaged groups show roughly similar patterns across all factors, although the asymmetry of side seen in RT and exaggerated in conjunction search, is a bit more prominent in the LHD N+ than in the LHD N– subgroup. The more severe neglect group also shows a trend towards a complementary facilitation in detecting ipsilateral targets.

Right Hemisphere Damage

The same ANOVAs reported above are run with the RHD patients without field defects and the normal non-neurological controls. However, because there are gradations of severity of neglect, we divide the RHD patients into three subgroups, those without neglect (RHD N–; N = 19), those with mild neglect (RHD N+; N = 3) and those with moderate to severe neglect (RHD N++; N = 4). Note that the number of subjects in some groups is very small but the groups are homogeneous with respect to lesion site, presence of field defect and severity of neglect. We now turn to the RT analysis. There is a significant four-way interaction in the RT analysis, F (12, 304) = 4.8, p < .0001. All main effects and other interactions are also significant, at p < .0005 at least. The data are plotted in Figure 3 for the three RHD subgroups

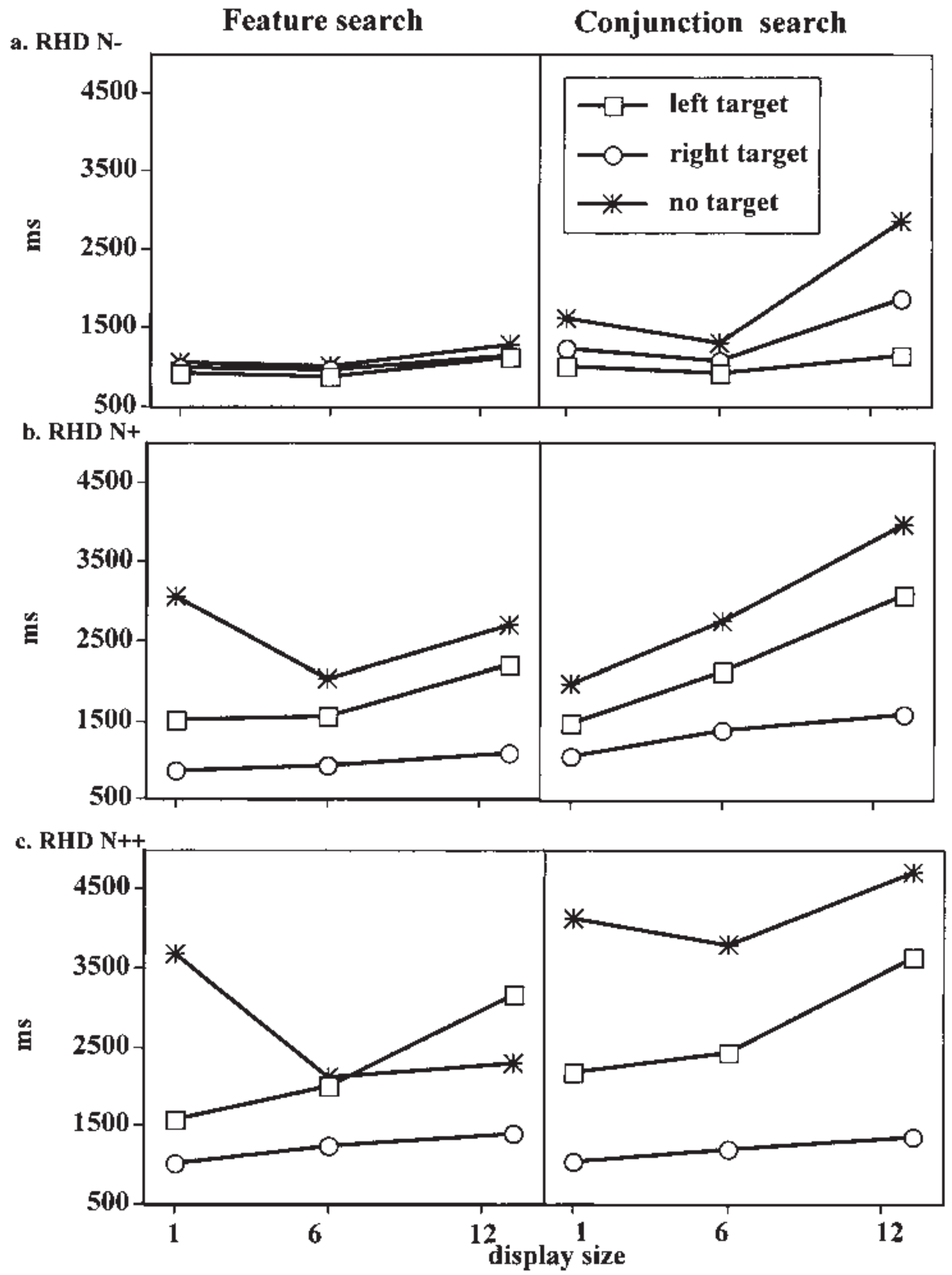


Fig. 3 – *Mean of median reaction time for (A) patients with RHD and no neglect (B) patients with RHD and mild neglect and (C) patients with RHD and more severe neglect on feature and conjunction search as a function of display size and presence (left/right) or absence of target.*

(RHD N–, RHD N+, and RHD N++) and the reader is referred to Figure 2 (top panel) for the corresponding control data.

The overall RT for each group follows the expected ordering of detection time with greater slowing as neglect severity increases, F (3, 54) = 23.9, p < .0001 (normal controls 937 ms, RHD N- 1249 ms, RHD N+ 2091 ms, RHD N++ 3011 ms). There is also a significant main effect of search type, F (1, 54) = 87.5, p < .0001, with a 309 ms advantage for feature over conjunction search. Also, as expected, there is a main effect of display size, with RTs incrementing as display size increases, F (2, 108) = 89.5, p < .0001, and this is exaggerated for conjunction over feature search, F (2, 108) = 53.4, p < .0001, with an 12.8 ms/item slope for the feature search and a slope of 38.8 ms/item for the conjunction search. There is also a significant effect of side, F (2, 108) = 88.7, p < .0001, with an RT advantage of 142 ms for left over right targets, both of which are faster than target absent trials, and an additional 261 ms disadvantage for absent over target right trials. This side difference interacts with search type, F (2, 108) = 92.4, p < .0001, such that the advantage for left over right trials is 30 ms and 255 ms for

TABLE IV

Slope of RT (in ms) for Feature and Conjunction Tasks for Four Subgroups of Participants

Group	Feature search			Conjunction search		
	Target left	Target right	No target	Target left	Target right	No target
Normals	5.3	8.9	17.3	22.9	30.4	34
RHD N–	18.6	13.7	210.3	59.3	33.5	118.2
RHD N+	64.2	23.7	31.8	146	46.3	181
RHD N++	135.9	34.2	– 120.3	155	29.6	56.2

feature and conjunction search, respectively, and 123 ms and 684 ms for left trials over absent trials in feature and conjunction search, respectively. There is also an interaction of display size × side of target, F (4, 216) = 17.9, p < .0001, but this is qualified in the three-way interaction of search type × display size × side of target, F (4, 216) = 9.4, p < .0001; whereas the slope was 16.8 ms, 7.8 ms and 13.7 ms for left, right and absent targets in feature search, the corresponding values for conjunction search were 16.1 ms, 35.8 ms, and 65.3 ms.

But the most pertinent analyses involve the factor of subgroup. There are two-way interactions between search × subgroup, F (1, 54) = 6.6, p < .001, display size × subgroup, F (6, 108) = 17.1, p < .0001, and side × subgroup, F (6, 108) = 15.7, p < .0001. The three-way interaction of search type × display size × subgroup, F (6, 152) = 8.8, p < .0001, is significant, as is search type × side × subgroup, F (6, 108) = 12.5, p < .0001, and display size × side of target × subgroup, F (12, 216) = 11.9, p < .0001. To facilitate comparisons across the subgroups, Table IV contains the slope of the RT function in ms, calculated over display size, for the two types of search task for each of the four subgroups separately for left, right and absent target trials. We should note at the outset that there is one strange data point in the feature search, display size 1, target absent trials in both the RHD N+ and RHD N++ subgroups (see Figure 3 middle and bottom left panels; also to some extent in RHD N++ conjunction search). Target absent on search size 1 is notoriously complicated (Treisman and Gormican, 1988). Also, given that we have rather few subjects in these cells, the variability on this point is high. Aside from this oddity, the remaining data follow a relatively clear pattern.

Relative to the non-neurological control subjects, all three RHD subgroups show steeper slopes in the feature search task and the slope increments over presence and severity of neglect. Moreover, this increase in slope is greater for contralateral left over ipsilateral right targets, as seen in Table IV. A similar pattern is observed in the conjunction search task in which, relative to the non-neurological controls, all brain-damaged subgroups are impaired, including the RHD N– patients, in detecting targets on the left. However, the patients with neglect all search more slowly on the left than those without neglect but there is no difference between RHD N+ and RHD N++. With regard to ipsilateral right targets, there is a trend towards a reverse effect in that the most severe group, RHD N++, shows somewhat faster search and shallower slopes across display size (29.6 ms), relative to the other groups, and no difference between ipsilateral targets in feature and conjunction search. Also, in the most severe neglect group, the slopes for the target absent trials do not necessarily reflect the self-terminating 2:1 ratio, suggesting that search may be terminated early, or that, when a target is present on the contralateral side, the patients may continue to search for a long time until they acquire it, reducing the difference between target present and target absent search times. Support for this latter claim comes from the finding that patients with right parietal lesions and neglect show abnormally long RTs to the absence of a target (Mijovic-Prelec et al., 1998); because of their lowered confidence, they spend an inordinately long time verifying the absence of the target.

The same analysis using accuracy as a dependent measure yields almost identical results. The four-way interaction is significant, F (12, 224) = 2.3, p < .01. All main effects are significant and there are a number of significant two-way and three-way interactions. The pattern yielded by the interaction is roughly the same as that of the RT data. Some small differences do emerge, likely because accuracy is not as telling a dependent measure as RT in this paradigm, but, for the most part, the findings support those obtained from RT.

Taken together, the results are fairly clear. All patients, including those with RHD but no neglect are impaired relative to the control subjects for targets on the left to a greater degree than targets on the right, and this asymmetry is exaggerated in the conjunction search in comparison with the feature search task. Patients with neglect, however, show steeper slopes than those without neglect. Importantly, this increase in slope for contralateral targets is evident in both forms of search and to a greater degree on the left than right. There is also a scaling of the deficit such that the increased contralateral slope is less evident in subjects with no neglect (RHD N–) compared with those with neglect (RHD N+ and N++). The two neglect groups differ from each other in two ways: on contralateral targets, the RHD N++ group is more severely affected by display size than the RHD N+ group but mostly this is true in feature search, and, for ipsilateral targets, the RHD N++ group is

TABLE V

Slope of RT (in ms) for Feature and Conjunction Tasks for LHD and RHD Patients Classified According to Severity of Neglect

Group	Feature search			Conjunction search		
	Contra	Ipsi	No target	Contra	Ipsi	No target
LHD N–	27	21	41	68.4	26.1	102
LHD N+	19.1	3.9	12.1	65.9	16.2	94.9
RHD N–	18.6	13.7	20.3	59.3	33.5	118.2
RHD N+	64.2	23.7	31.8	146	46.3	181

faster than the RHD N+ group (and RHD N–) in conjunction search. The apparent improvement in search for right targets in the most severe neglect group in the conjunction task is consistent with the observation that there is a ‘magnetic appeal’ for targets on the right and this may, in a competitive fashion, give rise to the facilitation of right-sided target detection even over that of normal subjects (Cate and Behrmann, 2002; Làdavas et al., 1990; Behrmannn et al., 1997). A similar result was noted above for the left brain-damaged group with neglect.

Comparisons of Left and Right Hemisphere Damage

Having shown that each of the brain-damaged groups is impaired relative to normal control subjects, we now compare directly the performance of the patients with left versus right hemisphere lesions. As above, these analyses are performed using the data only from those patients without a field defect. The analysis is conducted with side of lesion (left, right) and presence/absence of neglect as between-subjects factors and search type, display size and target (left, right, none) as within-subject factors. We excluded the RHD N++ group so as to equate neglect severity across the two sides of hemispheric lesion groups with the result that only 4 subgroups were included (LHD N–, LHD N+, RHD N–, RHD N+).

The most critical finding is of a five-way interaction between all the factors. Despite the fact that this is a high-order interaction, the pattern is rather simple and can be inferred from Table V. This table incorporates the relevant data from Tables III and IV but “left” and “right” have been replaced with contralateral and ipsilateral to facilitate comparison across the two hemisphere groups. Because our interest here is on side of lesion and presence/absence of neglect, we focus only on these aspects of the analysis.

RHD patients are 58 ms slower in RT than LHD patients, F (1, 46) = 14.2, p < .0005, but this differs depending on the presence of neglect, F (1, 46) = 22.6, p < .0001; although LHD N– patients are 97 ms slower than RHD N–, LHD N+ patients are 1570 ms slower than RHD N– patients. But these hemispheric × neglect differences are exaggerated in RHD N+ patients for contralateral over ipsilateral targets especially for conjunction search and as display size increases. Whereas there is no difference between LHD N– and RHD N– in either form of search, LHD N+ and RHD N+ differ on both search tasks. On both tasks, RHD N+ shows a much steeper slope for both contralateral and ipsilateral targets than LHD N+.

In sum, there are several central results from this analysis: although, patients with RHD detect conjunction targets more slowly overall than LHD patients especially as display size increases and this is particularly so for contralateral targets, this is qualified by the presence of neglect. The difference between RHD patients with and without neglect is greater than the difference between LHD patients with and without neglect. It is also the case that LHD and RHD patients without neglect do not differ from each other and it is primarily the presence of neglect that differentiates between these two hemispheric lesioned groups. We note, however, that, over and above this, the presence of neglect in the RHD N+ group affects both forms of search to a greater degree than the LHD N+ group.

Comparisons of Patients with and without Field Defects

As alluded to previously, there is an ongoing controversy regarding the influence of a hemianopia on neglect performance. Given our large sample, we were able to evaluate this claim by comparing search times for patients with and without field defects (although by the time we classify patients by hemisphere, presence/absence of neglect and presence/absence of hemianopia, the cells are not that large any more). Table II reflects the co-occurrence of field defects (and severity of field defect) with hemispheric damage with and without neglect. As is apparent from these numbers, there is no obvious correlation between field defect and neglect; strikingly, six individuals with severe field defects fall in the LHD N– subgroup whereas four individuals from RHD N++ do not show a field defect.

To examine the effect of a field defect on search performance more systematically, we analysed the RT of the subjects, categorized by presence/absence of field defect, on the two search tasks using a three-factor between-subject ANOVA (side of hemispheric damage, presence/absence of neglect, status of field defect) and the three within-subject variables of search type, side of target and

TABLE VI

Slopes (in ms) of RT Over Display Size for Patients with Left and Right Hemisphere Lesions and with/without Neglect and Field Defects

	Without field defect				With field defect			
	Feature		Conjunction		Feature		Conjunction	
	Left	Right	Left	Right	Left	Right	Feature	Conjunct
Normal subjects	5.3	22.9	8.9	30.4	–	–	–	–
	Contra	Ipsi	Contra	Ipsi	Contra	Ipsi	Contra	Ipsi
LHD N–	27	21	68.4	26.1	43.8	11.1	99.8	43.4
LHD N+	19.1	3.9	65.9	16.2	68.4	13.2	108.6	72
RHD N–	18.6	13.7	59.3	33.5	31.5	19	112	80.6
RHD N+	64.2	23.7	146	46.3	72.6	20.9	160.2	48.4

display size. Note that patients are classified in a binary fashion for presence/absence of field defect rather than by severity in order to be able to cross this factor with side of damage and presence of neglect, and to maintain enough subjects in each cell for the ANOVA. We do not include subjects for whom we do not have definitive information about the status of their visual fields.

The most important finding is that there is a marginally significant five-way interaction of field defect, side of lesion and presence of neglect (coded as a single factor) and the three search variables, F (12, 472) = 1.7, p = .06. Patients with field defects are, on average, 599 ms slower than those without field defects, F (1, 118) = 5.9, p < .02, especially as display size increases, F (2, 236) = 14.2, p < .0001 (absence of field defect 37.4 ms, presence of field defect 72.8 ms). This pattern, however, is magnified in the conjunction over feature search but is also disproportionately affected by the side of lesion (right worse than left) and presence of neglect (presence of neglect worse than absence), F (6, 236) = 2.2, p < .05. Table VI summarizes the slopes for the normal control subjects and patients with and without field defects on the two types of search for left versus right targets, reflecting the data making up the five-way interaction.

What is apparent from the table is that patients without field defects have shallower slopes than their counterparts with field defects, especially in conjunction search. It is the case, however, that the presence of a field defect appears to influence the performance of LHD N–, LHD N+ and RHD N– to a greater degree than RHD N+, possibly because this last group is already so slow that the presence of a field defect does not have much additional impact. We also note that the patients with a field defect show increased slopes for both ipsilateral and contralateral targets although this is so to a slightly greater degree for contralateral targets.

Discussion

The aim of this study was to examine in a systematic fashion, using visual search paradigms, the nature of the attentional deficit in a large group of individuals who had sustained unilateral hemispheric lesions following cerebral infarction. After confirming the decrement in performance for contralateral over ipsilateral targets in conjunction search, we were interested in measuring the detection time for ipsilateral targets in patients relative to control subjects. But perhaps, of more relevance is the status of the feature search performance of the patients compared with the control subjects. These analyses took into account the hemisphere affected (left or right), the presence of neglect and its severity and the presence of hemianopia.

To address these issues, we obtained data from 48 left-hemisphere damaged patients, 56 right-hemisphere damaged patients and a group of non-neurological control subjects on a standard neglect battery. We also documented the presence of a visual field defect in the patients on confrontation testing. Finally, all subjects completed a computerized experiment consisting of a well-established visual search task with two components; the first component involved search for a target which is typically acquired rapidly and independently of the number of distractors by normal subjects (feature search) and the second component involved search for a target which is acquired more slowly and is significantly affected by the number of distractors in the array (conjunction search). Although studies of this type have been conducted in the past, the findings remain controversial.

The first major result is that following a lesion to either hemisphere, individuals without neglect are impaired relative to intact normal subjects. However, individuals with a lesion and with concurrent neglect are even more impaired than their non-neglect counterparts. Interestingly, both patient groups, with and without neglect, show incrementally slower search in both feature and conjunction searches as display size increases and this is so to a greater extent for contralateral than ipsilateral targets. Because of the graded severity of neglect among the RHD group, we could also evaluate whether this pattern was affected by the extent of the neglect. There was no significant difference as a function of severity of neglect and RHD N+ and RHD N++ show roughly similar magnitudes of deficit on contralateral search. Interestingly, the more severe group showed a shallower slope for ipsilateral targets in the conjunction task, reflecting the competition between items on the left and right and the advantage for the ipsilateral items. A hint of this competitive advantage for ipsilateral targets was also seen after LHD in individuals with neglect.

A comparison of the patients' performance as a function of side of hemispheric lesion shows that, even when we equated for the presence and extent of neglect in the two groups, RHD patients are more impaired at contralateral conjunction search as display size increases than their LHD counterparts. This difference is magnified by the presence of neglect so that the greater impairment for RHD N– than LHD N– is magnified when comparing RHD N+ and their LHD N+ counterparts.

The presence of a field defect also contributes to the impairment in search performance although, once the difference between presence/absence of neglect is taken into account, the additional contribution of a field defect is not that large. Also, to the extent that it exists, the presence of hemianopia does not appear to be specific and seems to slow search down for both ipsilateral and contralateral targets.

These findings have provided some clear answers. Our results are consistent with the other studies that find a deficit in contralateral feature search (Riddoch and Humphreys, 1983; Eglin et al., 1989; Pavlovskaya et al., 2002). Interestingly, the magnitude of the deficit we have observed is also comparable to that obtained in these other studies. In light of this, our data challenge those studies, which claim that feature search is preserved in hemispatial neglect. As laid out above, a number of possible factors can account for the discrepant findings across the different studies. In our case, given the large patient sample and the heterogeneity of our subjects, we have been able to control a range of variables, which might have influenced the previous results.

In addition to addressing the controversial findings and to exploring the factors that might have confounded these previous studies, our data have also highlighted some other interesting effects that have not received much discussion to date. Patients with severe neglect, counterintuitively, show a speed up on ipsilateral conjunction search. In contrast, patients with no or mild neglect are slow on conjunction search for ipsilateral and contralateral search. These observations are compatible with a view in which there is competition for attention. If the attentional bias is strong ipsilesionally, targets will be quickly detected but this might have adverse consequences for contralateral detection. If, however, the ipsilesional bias is less strong, search might be slow for both ipsilesional targets and for contralesional targets. Some studies have also reported poorer ipsilesional performance for patients compared with controls (Eglin et al., 1989; 1996; Geng and Behrmann, 2002a) and others have found that the search patterns of neglect patients are equally poor in the contralesional and ipsilesional visual field (Chatterjee et al., 1992; Halligan et al., 1992). The claim that there are no hemifield differences also finds support in studies that do not use visual search; for example, using partial and whole report procedures, Duncan and colleagues document the presence of poor visual processing in both hemifields in neglect patients (Duncan et al., 1999). One possible explanation for the range of results concerns the severity of neglect. We only see an ipsilesional advantage for the severe neglect patients whereas for those with less severe neglect (and even for those with no neglect), we find decrements in performance in both hemifields but somewhat greater in the contralateral than ipsilateral space.

Before going on to examine the theoretical implications of these findings, we need to rule out an alternative interpretation of our results. One possible reason that we find poorer feature search in the neglect patients, relative to the controls, might be that the patients have additional brain damage to earlier visual areas and it is this damage, rather than the neglect *per se*, that might contribute to impaired parallel search and preattentive processing. In a detailed analysis of the lesion sites of all patients, done by identification of the lesion location/s on the CT scans in reference to the 24 best fitting slices from the Talairach and Tournox stereotactical anatomical reference system (Talairach and Tournox, 1998), only 8 of the RHD patients (14%) and only 8 of the LHD patients (17%) have damage to occipital cortex (Ebert, 1998). There are several obvious reasons from the data to indicate that the impaired feature search is not solely attributable to this additional damage to early visual areas. Firstly, only a small proportion of the groups have patients with damage to this area and this sample size is not large enough to carry the statistical effects of the whole group. Secondly, because some of these patients have field defects, and make many contralateral errors, their data are not included in the RTs and so, the slopes are calculated without their data. Finally, we note that when we examine the performance of individuals with versus those without field defects, we still observe an impairment in feature search in those subjects who do not have field defects. Taken together, these findings suggest that the increased slope in RTs for feature search as a function of array size is not simply attributable to the additional presence of occipital lobe damage.

In addition to clarifying the neuropsychological data on hemispatial neglect, our findings have implications for claims about the fundamental nature of attentional processing. Although the distinction between preattentive (feature) search and attentive (conjunction) search is well engrained in cognitive psychology, its validity has been challenged from numerous perspectives. Our data also challenge this dichotomy in that the supposed preattentive task does not survive hemispatial neglect. Consistent with our result, it has been suggested that even preattentive search requires some amount of attention; when a concurrent task is performed, interference is seen even though this should not be the case, according to a view of a capacity-free parallel preattentive search mechanism (Joseph et al., 1997). Indeed, even in the original empirical visual search studies in normal subjects, feature search did not have a completely flat slope, which would truly indicate attention-free processing, and, instead, a serial search pattern was defined as one in which the slope is greater than 10-20 milliseconds per item (Treisman and Gelade, 1980). Our findings are concordant with the notion that all forms of visual search engage some form of attentional processing.

It seems clear then that the binary distinction between preattentive/featural and attentive/conjunction processing does not obviously hold and, indeed, there have been recent attempts to articulate a theoretical perspective that does not rely on this dichotomy. On these more integrated accounts, there is no obvious distinction between preattentive and attentive processing. Instead these views rely on the principles of competition and cooperation between features and objects to resolve the constraints of visual attention and to determine the efficiency of attentional selection. Feature search is hypothesized to be fast and accurate because competition between targets and distractors is resolved quickly. In contrast, conjunctive search is slower and more prone to error because target-distractor similarity or distractor-distractor heterogeneity produces greater competition between items and therefore takes longer to resolve (Duncan and Humphreys, 1989).

One theoretical perspective that eschews this dichotomy and that has gained considerable popularity lately is the Biased Competition and the Integrated Competition accounts (Desimone and Duncan, 1995; Duncan and Humphreys, 1989; Duncan et al., 1997). This view suggests that attention is an emergent property of competition between representations of stimuli within the nervous system and that processing is qualitatively similar regardless of whether a target stimulus in visual search is distinguished from distractors by a single feature or by a conjunction of features. The obvious prediction from this type of account is that in patients with neglect, search will be affected for both featural and conjunction targets but that the latter will be more impaired than the former. This view also makes allowance for competition between ipsilateral and contralateral items, and we observe such competition in individuals with more severe neglect who search ipsilesionally a little better. Our data fit well with this competitive view and support an interactive account of attention and selection.

The conceptual divide between feature and conjunction search, like the divide between “primary” and “high level” deficits (Halligan and Marshall, 2002), is also not obviously supported by recent functional imaging studies. The relevant finding from a large number of recent studies is that activation in early visual areas can be affected by activation in parietal and frontal cortices and these top-down influences can modulate activation in striate and extrastriate areas (for example, Noesselt et al., 2002; Somers et al., 1999) and in the lateral geniculate nucleus (O’Connor et al., 2002), even in the absence of visual stimulation (Kastner et al., 1999). Given the bi-directional reciprocal interactions between earlier and later visual areas, there is no clear dichotomy or separation onto which feature and conjunction search might be mapped. Instead, the dynamic feedforward and feedback interactions are more compatible with a single, integrated account of visual search, as outlined above.

In conclusion, we have clearly demonstrated that patients with neglect are impaired at feature and, as expected, on conjunction search on the contralateral side. This result has implications for models of attentional selection and challenges the idea that feature search can be done in parallel in the absence of attention. It is the case, however, that not all forms of contralateral search are impaired to the same extent in individuals with neglect. In a recent series of studies, Humphreys and Riddoch (2001; 2001/2002) had a patient with left neglect search for a target (cup) defined by an action “find an object you can drink from” or by a name “find the cup”. Interestingly, search was more efficient in the former than latter case and this benefit was enhanced as display size increased. The advantage for action-defined search is attributed to the existence of action-defined templates, which are activated by affordances of objects. These results are provocative and suggest that not all forms of search are created equal and not all forms of search suffer equally following brain-damage. Understanding the distinctions and boundaries between these different forms of search remains a future challenge.

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