Neuropsychology
2000, Vol. 14, No. 4, 599–611

DOI: 10.1037//0894-4105.14.4.599

Preattentive and Attentive Visual Search in Individuals With Hemispatial Neglect

Michael Esterman
Veterans Affairs Boston Healthcare System

Regina McGlinchey-Berroth and William Milberg
Veterans Affairs Boston Healthcare System and Harvard University Medical School

Preattentive and attentive visual processing was examined in patients with hemispatial neglect, hemispatial neglect with hemianopia, and control participants. In the preattentive search task, targets possessed a unique feature that was not shared by distractors. In the attentive search task, targets lacked a feature that was present in the distractors. Preattentive search was normal in 3 neglect patients with cortical lesions but not in 2 neglect patients with hemianopia. A 4th neglect patient without hemianopia with a subcortical infarct abnormally used serial search mechanisms in the preattentive task. Neglect patients were characteristically impaired in the contralesional field in the attentive search task. This study demonstrates preserved explicit detection of visual features in cases of hemispatial neglect.

Hemispatial neglect is an acquired disorder in which patients fail to acknowledge, report, or otherwise make explicit use of information falling in the hemispace contralateral to their lesion. Although hemispatial neglect may present after a lesion to the left cerebral hemisphere, it is most often observed after damage to a number of different regions in the right hemisphere, resulting in neglect of left hemispace (Heilman, Watson, & Valenstein, 1993).

Though neglect patients appear to be unaware of information contained within their left visual field, a number of studies have now conclusively demonstrated higher level processing for unattended contralesional visual information in the absence of awareness for that information. To be specific, research has shown that whereas patients with neglect are unable to identify objects in their neglected visual field, the same patients demonstrate deep processing of this consciously inaccessible information on indirect or implicit measures (e.g., Audet, Bub, & Lecours, 1991; Berti & Rizzolatti, 1992; Làdavas, Paladini, & Cubelli, 1993; McGlinchey-Berroth, Kilduff, & Milberg, 1990; McGlinchey-Berroth, Milberg, Verfaellie, Alexander, & Kilduff, 1993). How can one reconcile these paradoxical findings? Recent research investigating the intersection between vision and attention may offer an explanation.

At present, most models of visual information processing distinguish between lower level preattentive visual processing, which occurs in parallel across the visual field, and higher level attentive processing, which occurs serially. Though the precise line at which preattentive processing ends and attentive processing begins is a matter of debate, this distinction may offer an explanation as to why neglect patients are impaired in some tasks but normal in others. That is, it is possible that preattentive visual processing is intact in neglect and can be used to support implicit processing. Furthermore, it may be possible that processing at the attentive level is impaired in neglect and leads to impaired performance on more explicit types of tasks.

The notion that preattentive vision may underlie neglect patients' normal performance in some implicit processing tasks is supported by a growing literature investigating the role of attention in the construction of object-based representations. For example, the feature integration theory (FIT) proposed by Treisman and colleagues (Treisman & Gelade, 1980) posits that attention may be the mechanism by which representations of features are bound together to form whole percepts within a selected region of space. According to this view, preattentive vision extracts simple featural information, such as line orientation, color, depth, and motion, from the visual field in parallel. In a classic demonstration (Treisman & Souther, 1985), a circle with an intersecting line "popped out" of a display containing distractor items of plain circles, as evidenced by a flat reaction time function across increasing numbers of distractors. However, in the reverse search task (plain circle as the target and circles with intersecting lines as distractors), the target did not pop out but rather was located serially, as evidenced by a positively sloping reaction time function. The latter was taken as

Michael Esterman, Geriatric Neuropsychology Laboratory, Geriatric Research Education and Clinical Center (GRECC), Veterans Affairs Boston Healthcare System; Regina McGlinchey-Berroth and William Milberg, GRECC, Veterans Affairs Boston Healthcare System, and Department of Psychiatry, Harvard University Medical School.

This work was supported by National Institute of Neurological Disease and Stroke Grant NS29342. We thank the Harvard Cooperative Program on Aging for referring normal control participants. We also thank Michael Alexander, Julie Higgins, Karen Duncan, Patrick Kilduff, and Chuck Foltz for their valuable contributions to the work presented in this article.

Correspondence concerning this article should be sent to Regina McGlinchey-Berroth, GRECC (182-Boston), Veterans Affairs Boston Healthcare System, 150 South Huntington Avenue, Boston, Massachusetts 02130. Electronic mail may be sent to rmcglin@bu.edu.

evidence that the search required attentional resources. Treisman and Souther (1985) argued that the presence of a unique distinguishing feature (i.e., the vertical line segment) could be detected in parallel with only preattentive visual processing.

Other theories of visual processing suggest that preattentive vision may actually be more extensive than that suggested by FIT. Studies from the visual search literature have indicated that preattentive vision sufficiently processes complex stimulus properties, such as primitive shape description (Donnelly, Humphreys, & Riddoch, 1991), surface representations (He & Nakayama, 1992), and Gestalt groupings (Gilchrist, Humphreys, & Riddoch, 1997; Rensink & Enns, 1995). Furthermore, some visual search studies have shown that access to primitive features is eliminated by preattentive Gestalt and 3-D grouping processes. Thus, visual search cannot access primitive features that were extracted during early visual processing but can only access relatively higher level representations (He & Nakayama, 1992; Rensink & Enns, 1995). Furthermore, using two overlapping objects, Goldsmith (1998) found that conjunction searches (i.e., searches for a target defined by two or more features) were more efficient when the target features were linked to the same object than to different objects in the same location. Goldsmith (1998) suggested that preattentive vision was able to create object representations to which attention could be directed. He summarized these findings by suggesting that "attention might be thought of as navigating through a complex and highly structured preattentive representation, specifying selected portions for higher level processing" (p. 214).

Preattentive processing has also been investigated in patients with neuropsychological disorders. For example, Gilchrist, Humphreys, and Riddoch (1996) found that visual extinction to double simultaneous stimulation was modulated both by edge and brightness-based grouping processes in a patient with Balint's syndrome. Mattingley, Davis, and Driver (1997) also examined preattentive processing in a patient with Balint's syndrome using a visual extinction paradigm. They found that visual extinction was modulated when bilateral stimuli formed a common surface based on perceptual grouping. To be more specific, grouping based on illusory Kanizsa figures and 3-D occluded figures significantly reduced visual extinction, demonstrating that preattentive vision is sensitive to perceptual grouping and 3-D surface properties. Humphreys and Price (1994) examined visual feature discrimination in two patients with simultanagnosia. They reported that these two patients showed preserved parallel search functions for targets that were highly salient when defined by color or size but were impaired when targets were defined by form. An impairment in target detection became apparent for color when saliency was reduced and for size when the exposure duration was limited to only 200 ms. Humphreys and Price suggested that whether or not parallel search was preserved or impaired in patients with simultanagnosia seemed to depend on task difficulty.

The possibility that preattentive processing of visual information is intact in patients with hemispatial neglect has been examined in a number of studies. Aglioti, Smania, Barbieri, and Corbetta (1997) used two texture segmentation tasks similar to that used by Julesz (1981) that critically differed on the visual processes necessary to extract targets from the distracting texture. In the preattentive task, targets differed from the distractors by the additional presence of two vertical line segments and could be perceived effortlessly from the background. In the attentive task, targets differed from distractors in that one of the line segments within an element was moved to a different position within the same element. In this condition, targets could only be detected following careful attentive scrutiny. Compared with normal control participants and other brain-damaged patients, Aglioti et al. (1997) found that neglect patients' performance in the attentive search task was considerably impaired relative to their performance in the preattentive task. However, they noted that it was not clear whether patients actually performed the preattentive search in parallel, because the number of distractors did not vary systematically in the design of this study. It is also noteworthy that although the neglect patients did show a task dissociation, they did not show a visual field dissociation, indicating that accuracy was similar across the two hemifields. The reason why performance in the right visual field was not superior to performance in the left visual field may have been related to factors such as task difficulty and freedom of movement.

In an earlier study using a more standard visual search paradigm, Riddoch and Humphreys (1987) presented three neglect patients with a series of cards on which were printed visual search displays; reaction times were recorded manually. In one task, the display contained a red circle target among a number of green circle distractors (parallel search task), and in a second task the display contained an inverted *T* target among a number of upright *T* distractors (serial search task). In both tasks, targets were present on half of the trials. In the parallel search task, reaction times did not increase linearly with the number of distractors (i.e., set size), indicating "that neglect patients can manifest parallel processing of stimuli on the neglected side of space" (Riddoch & Humphreys, 1987, pp. 166–167). However, patients did show a high error rate for left-sided targets, suggesting that "attention is not reliably captured by contralateral stimuli" (p. 167). Not surprisingly, in the serial search task, neglect patients were found to be impaired in both response latency and accuracy. An important finding was that when patients were cued to the left side of the search displays, the number of errors was greatly reduced in the parallel task. From these data, the authors concluded that there is a breakdown in the mechanism by which preattentive information captures attention in neglect, but that patients can consciously orient their attention in order to detect preattentively specified information.

Eglin, Robertson, and Knight (1989) also examined preattentive visual search in patients with neglect. In their feature search task, a red dot target was presented among yellow and blue dot distractors. In their conjunction search task, displays consisted of a split red dot target presented among split blue and complete red dot distractors. Unlike control participants, neglect patients showed a pattern of attention-based serial search even with the stimuli that elicited parallel search performance in the control participants. In a related study, Eglin, Robertson, Knight, and Brugger (1994) found that search rates in neglect patients were slower in the feature search task than control participants, again indicating an attentional search. Eglin et al. suggested that the "slow search rates could reflect a deficit in preattentive processes in the patients" (p. 461). On the other hand, they also offered the possibility that because the preattentive task required participants to accurately locate the target (i.e., point), they introduced "a significant attentional component even in displays that typically produce search functions consistent with parallel search" (p. 461).

The studies reviewed above present a conflicting account of neglect patients' performance in preattentive search tasks. Aglioti et al. (1997) had evidence indicating preserved preattentive processing in a texture segmentation task. Riddoch and Humphreys (1987) also concluded that preattentive processing was intact, but the evidence was somewhat mixed because of the high error rate in the parallel search task. However, Eglin et al. (1989, 1994) found a pattern of serial search in what was, for normal controls, a parallel search task, which indicates a possible impairment in preattentive processing. Hence, the current study was intended to examine preattentive processing in the context of visual search tasks in individuals with neglect. Using a case study approach (Caramazza & McCloskey, 1988), we examined four neglect patients' preattentive and attentive visual processing in the context of two computer search tasks modeled after Treisman and Souther (1985). The first was a preattentive search task in which participants searched for a target consisting of a circle with an intersecting line among a field of circles. The second was an attentive search task in which participants searched for a circle among a field of circles with intersecting lines. If preattentive processing is intact in neglect, as suggested by the findings of Aglioti et al. (1997) and Riddoch and Humphreys (1987), neglect patients' search performance in the preattentive task would not differ from that of normal control participants in either the left or right visual field. That is, response time and error rate should not differ as a function of set size. In the attentive search task, we anticipated that neglect patients would be impaired with regard to both response time and error rate when the target appeared in their contralesional visual field but normal when it appeared in the ipsilesional field. In addition, two control patients with left homonymous hemianopia in addition to neglect were included and were expected to be impaired when targets appeared in the contralesional field in both search tasks.

Method

Participants

Four individuals diagnosed with left hemispatial neglect were recruited from the Braintree Rehabilitation Hospital in Massachusetts. As shown in Figure 1, 2 patients (M.C. and J.M.) suffered a single right hemisphere stroke involving the territory of the middle cerebral artery (MCA). A third patient (K.G.) presented at the hospital with an acute stroke; however, magnetic resonance imaging revealed extensive right hemisphere cortical atrophy with no evidence of a discrete lesion. The fourth patient (D.B.) suffered from a right thalamic hemorrhage. All patients were administered the Standard Comprehensive Assessment of Neglect (McGlinchey-Berroth et al., 1996), which includes several copying, reading, cancellation, line bisection, and extinction tasks. Each patient showed neglect of left space on at least two of these tasks (see Table 1). In addition, the neglect patients performed a picture discrimination extinction measure on the computer (McGlinchey-Berroth et al., 1993) and were impaired for left visual field stimuli but intact for right visual field stimuli.

Two additional patients (M.M. and D.M.), also recruited from the Braintree Rehabilitation Hospital, had a left homonymous hemianopia as well as varying degrees of neglect (see Table 1). M.M. suffered a right posterior parietal embolic stroke following a myocardial infarction and a subsequent angioplasty procedure. Computerized tomography (CT) indicated that the lesion was restricted to the posterior parietal lobe and included occipital radiations and cortex. D.M. had a right MCA aneurysm and subsequently underwent a right craniotomy and clipping of the aneurysm. As shown in Figure 1, CT revealed a right temporal and frontal hemorrhage producing marked midline shift (affecting the occipital radiations) and a large right MCA infarct. Similar to M.M., D.M. also failed to detect single left stimuli during extinction testing. A neurologist also confirmed primary visual field deficits in both cases. These two patients were used as control participants for the neglect patients in the preattentive search task. They were not tested in the attentive search task.

Last, four healthy adult participants served as controls for the neglect patients. They were recruited from the community and were matched with regard to age ($M = 54.33$ years) to the neglect patients ($M = 51.25$ years). All control participants had no history of neurological disorders, substance abuse, or psychiatric illness.

Apparatus

Visual search tasks were administered using a Macintosh Powerbook 3400c and a 14-inch monitor. The software package, Psychlab (Gum, 1992), was used to present picture files on the screen and record responses with millisecond accuracy. Responses were made by button press on a Carnegie-Mellon University Button Box. An ophthalmologic chin rest was adjusted to place the participant's eye level at midline and maintain a 12-inch distance from the computer screen.

Stimuli

The stimuli for the current study consisted of circles and circles with an intersecting vertical line. Each circle subtended a visual angle of 2.98 degrees. The search window in which targets and distractors appeared was a white rectangle (14.60 degrees to the left and right of midline, 10.62 degrees above and below midline). Target and distractor stimuli were defined by the specific search task, as described below.

Procedure

Each task consisted of 288 randomized display trials, and a single target was present in the display on half of these trials. For purposes of counterbalancing across the two visual fields, the display area was divided into six columns, three on each side of midline. Displays were symmetrical across the vertical midline;

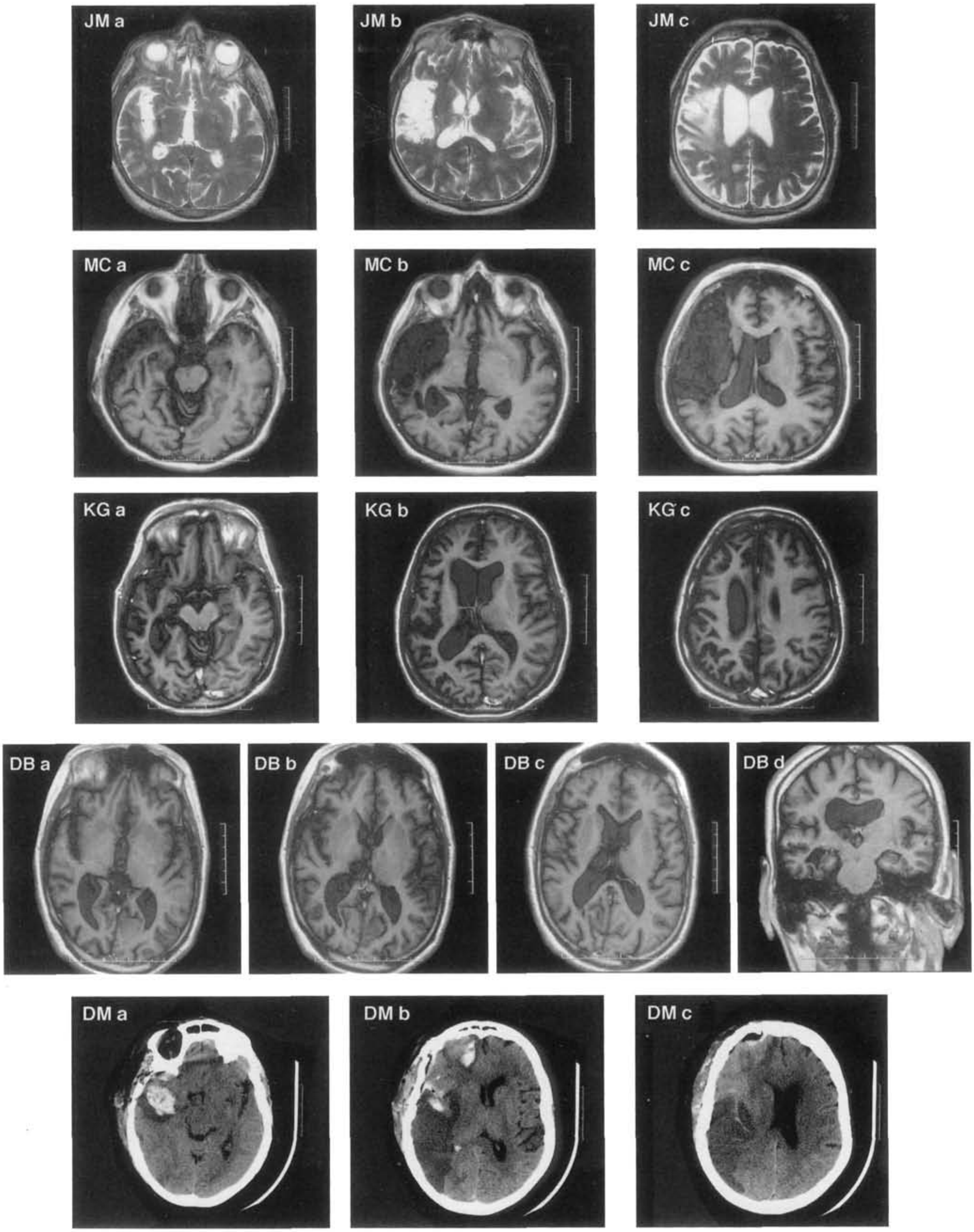

Figure 1. Brain imaging (magnetic resonance imaging) for neglect Patients J.M., M.C., K.G., and D.B. and computerized tomography for hemianopic Patient D.M.

Table 1
Clinical Characteristics of Patients

Patient	Age (years)	Clinical manifestations
J.M.	59	Recall copy Line, letter, and symbol cancellation tasks Visual extinction Picture discrimination task
M.C.	51	Visual extinction Symbol cancellation Picture discrimination task
K.G.	51	Cross copy, hidden copy, recall copy, scene copy Line, letter, and symbol cancellation tasks Visual extinction Picture discrimination task
D.B.	44	Line bisection Visual extinction Picture discrimination task Neglect dyslexia
M.M.	67	Line, letter, and symbol cancellation task Figure copy Line bisection Left homonymous hemianopia
D.M.	61	Cross copy, scene copy Line bisection Line, letter, and symbol cancellation tasks Left homonymous hemianopia

thus, left and right field trials were mirror images of each other across the vertical midline. The number of objects present in one display (set size) was either 2, 4, 8, or 16. The same display maps were used for both search tasks, such that target and distractor positions were constant across tasks.

In the preattentive search task, the target was a circle with an intersecting vertical line, and distractors were circles with no intersecting line. Thus, the target contained a simple feature (vertical line) that differentiated it from the distractors (see Panel A of Figure 2).

In the attentive search task, targets and distractors were reversed, such that the target was a circle and the distractors were circles with an intersecting vertical line. Thus, the target lacked a distinct feature that the distractors possessed (see Panel B of Figure 2).

Each patient was tested individually in either the hospital or his or her home. The tasks were administered on separate days, and the task order was counterbalanced across participants.

Participants were instructed to press the button labeled "yes" if the target was present in the display and to press the button labeled "no" if the target was absent from the display. Responses were made with the participants' right hand, which was their dominant hand.

Each trial was initiated by the examiner by means of a key press. After a 1,500-ms delay, the search display was presented on the computer screen and remained on the screen until participants made their response. All participants were encouraged to respond as quickly but as accurately as possible. Before each search task, participants were administered a task-appropriate practice set consisting of 16 trials. If additional practice was necessary, the practice set was repeated.

Results

Primary dependent variables consisted of the decision latency for correct target-present trials and the percentage errors on target-present trials. Because we only considered the errors that were derived from target-present trials, the data presented here consist of only detection errors (misses) and not false positive responses (which occurred on no more than three target-absent trials per individual). The percentage of errors and decision latency for target-absent trials were not central to the purpose of this experiment and thus are not discussed.

Trials were eliminated from analyses for two reasons. Some trials were lost when it became clear to the experimenter that the participant overtly strayed from the task (looked away from the screen, asked a question, and so forth). This situation occurred on an average of 7.25 critical trials for neglect patients, 6.00 critical trials for hemianopic patients, and 0.88 critical trials for control participants. In addition, correct trials that were greater than or less than 2 *SD*s from a participant's mean were removed from the data set. This procedure was repeated for a total of two iterations and resulted in the elimination of an average of 8.63 critical trials for neglect patients, 5.00 critical trials for hemianopic patients (parallel search task only), and 8.75 critical trials for control participants.

Below, each patient is presented as a single case study. We performed regression analyses for each individual using set size as the predictor variable and response latency (per trial) as the dependent variable for the left and right visual fields for both the preattentive and attentive search tasks. In addition, each patient's percentage errors are presented as a function of set size and visual field for each of the two tasks. Next, the mean percentage errors for the preattentive search task are presented as a function of set size for the two hemianopic patients. Note that their left visual field performance did not permit a calculation of the regression curve

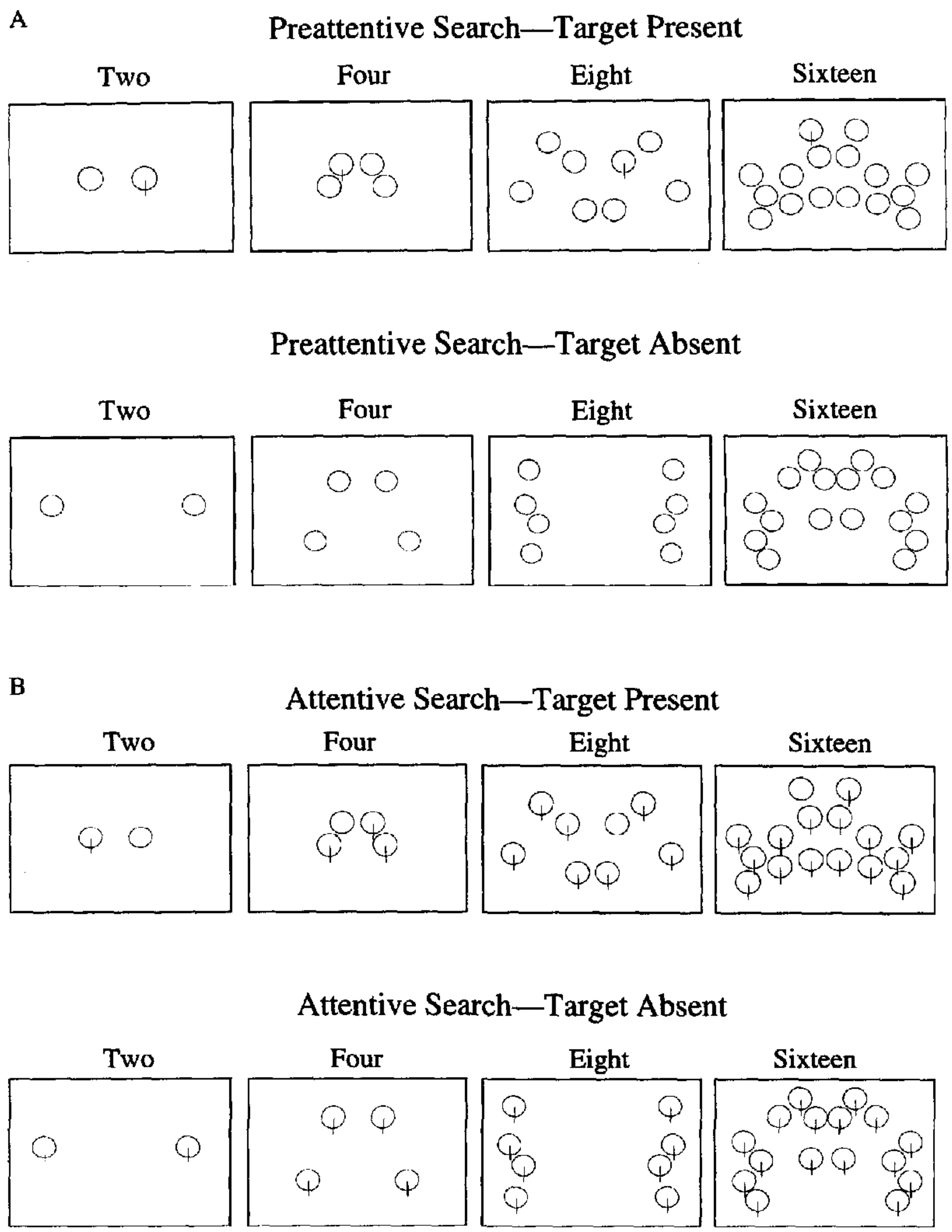

Figure 2. Panel A shows sample displays from the preattentive search task, and Panel B shows sample displays from the attentive search task. In both panels, the top four displays are examples of trials in which the target was present, and the bottom four displays are examples of trials in which the target was absent. The numbers above each display indicate the total number of items in the display (set size).

because of the high error rate in detecting targets in the left visual field. In addition, the response latencies and percentage errors for the control participants are presented as a group analysis first for comparative purposes only. Thus, the regression equations were derived from each individual's mean latency as a function of set size, visual field, and task. The data derived from the control participants are presented first so as to establish the pattern of normal performance in our preattentive and attentive search tasks.

Control Participants

Figure 3 presents the mean response latencies for control participants for the preattentive and attentive search tasks. In the preattentive search task, regression analyses revealed that the slope of the search function was 3.0 ms per item in the left visual field (SE = 0.50) and 6.48 ms per item in the right visual field (SE = 1.81). The magnitude of these slopes suggests that these searches were conducted primarily with parallel mechanisms. In contrast, in the attentive search task, regression analyses indicated a slope of 49.56 ms per item in the left visual field (SE = 5.66) and 60.20 ms per item in the right visual field (SE = 14.56). The magnitude of the slopes in the attentive search task suggests that these searches required serial search mechanisms.

Mean percentage errors for control participants are presented in Table 2. As can be seen, there was a slight set size

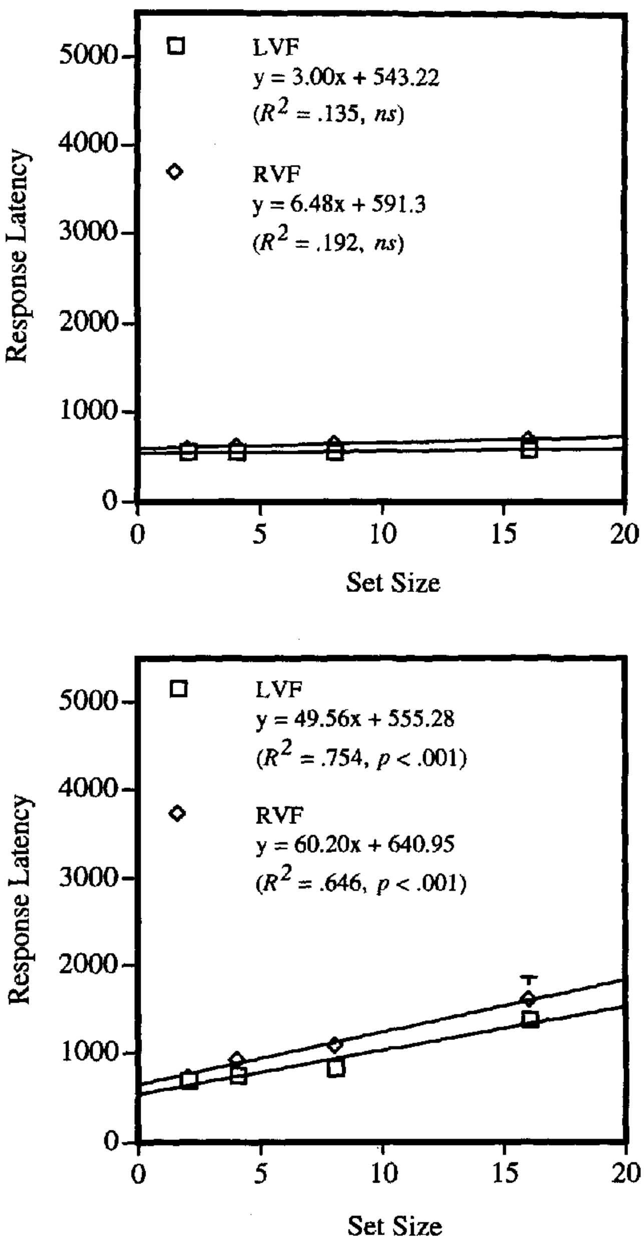

Figure 3. The top panel displays control participants' response latencies in the preattentive search task; flat regression slopes in both visual fields are indicative of a parallel search. The bottom panel displays control participants' response latencies in the attentive search task; the positive regression slopes indicate a serial search. LVF = left visual field; RVF = right visual field.

Table 2
Mean Percentage Errors for Control Participants in the Preattentive and Attentive Search Tasks as a Function of Visual Field and Set Size

Search task and set size	Left visual field	Right visual field
Preattentive task		
Two	0.00	0.00
Four	1.67	2.78
Eight	2.78	5.64
Sixteen	0.00	0.00
Attentive task		
Two	2.78	0.00
Four	1.39	2.78
Eight	2.78	2.78
Sixteen	8.66	9.73

effect in the attentive search task. This effect was confirmed in an analysis of variance (ANOVA) that examined the effects of task, visual field, and set size in which a significant interaction was observed between task and set size, $F(3, 9) = 6.45$, $p < .05$. No other main effects or interactions were significant in this ANOVA.[1]

Neglect Patient J.M.

The mean response latencies for the preattentive and attentive search tasks for Patient J.M. are presented in Figure 4. As can be seen, regression analyses for the preattentive search task revealed a slope of 8.21 ms per item in the left visual field and a slope of 4.35 ms per item in the right visual field. In the attentive search task, regression analyses revealed a slope of 202.61 ms per item in the left visual field and a slope of 82.56 ms per item in the right visual field. The magnitude of the slopes for the left and right visual field in the preattentive search task was similar to those found in the control participants, suggesting that J.M.'s preattentive search was normal. By contrast, the slope of approximately 202 ms per item in the left visual field in the attentive task suggests that J.M. was impaired relative to control participants and to his own search performance in the intact right visual field.

J.M.'s percentage errors differed as a function of task and visual field. As shown in Table 3, J.M. made very few errors in either the left or the right visual field when performing the preattentive search task but made a considerable amount of errors in the left visual field when performing the attentive search task. This pattern of errors is consistent with the response latency data.

Neglect Patient M.C.

Figure 5 presents the response latencies for the preattentive and attentive search tasks for Patient M.C. Regression

[1] The lack of significance in this ANOVA should be regarded cautiously, as the number of control participants, and thus power, was limited.

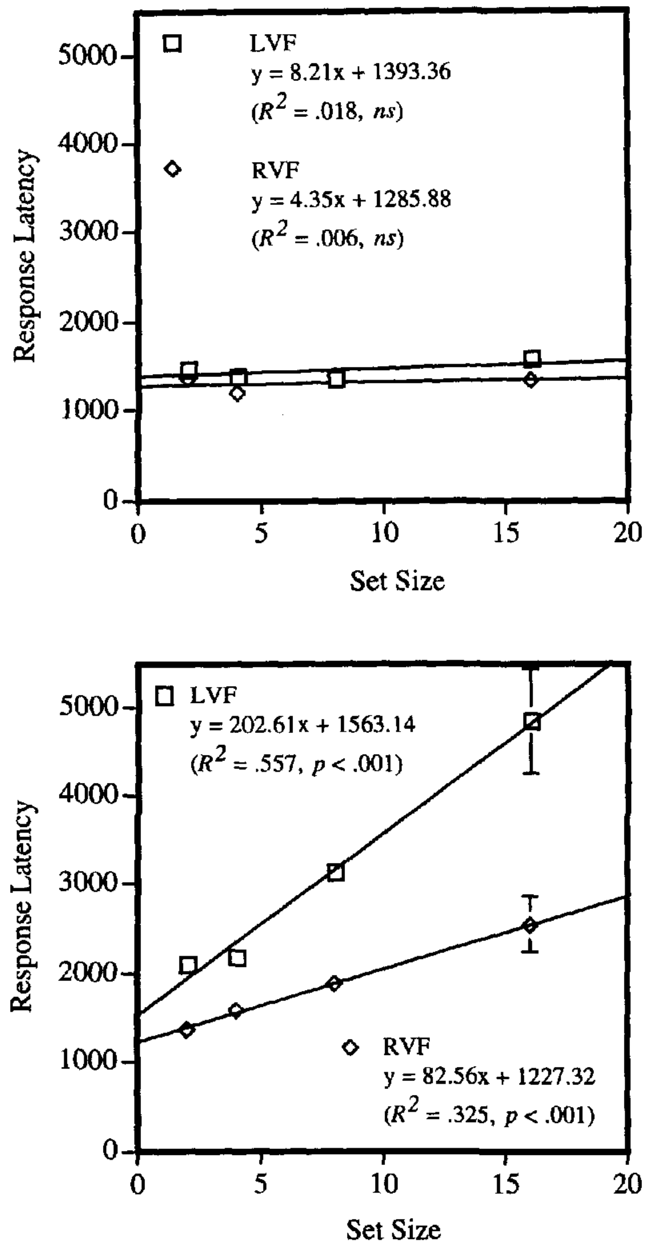

Figure 4. The top panel displays J.M.'s response latency in the preattentive search task; the flat regression slopes in both visual fields are indicative of a parallel search. The bottom panel displays J.M.'s response latency in the attentive search task; positive regression slopes are apparent in both visual fields, with performance in the left visual field (LVF) markedly less efficient than in the right visual field (RVF).

analyses for the preattentive search task revealed that the slope of the search function was 5.94 ms per item in the left visual field and –7.45 ms per item in the right visual field. In the attentive search task, regression analyses revealed a slope of 54.23 ms per item in the left visual field and 28.29 ms per item in the right visual field. Like J.M., M.C.'s response latencies in the preattentive search task were similar to control participants, suggesting the use of primarily parallel search mechanisms. M.C.'s performance on the attentive search task was somewhat more difficult to interpret. The slope of approximately 54 ms per item in the left visual field was similar to that found in the normal controls and was steeper than the slope of 29 ms per item in the right visual field. Thus, M.C.'s pattern of performance was similar to that found in patient J.M. in which the left visual field performance was less efficient than the right visual field

Table 3
Percentage Errors for Neglect Patients in the Preattentive and Attentive Search Tasks as a Function of Visual Field and Set Size

Search task and set size	Left visual field	Right visual field
Patient J.M.		
Preattentive task		
Two	0.00	0.00
Four	0.00	0.00
Eight	0.00	0.00
Sixteen	5.56	0.00
Attentive task		
Two	22.22	0.00
Four	44.44	0.00
Eight	27.78	11.11
Sixteen	33.33	5.88
Patient M.C.		
Preattentive task		
Two	5.88	0.00
Four	0.00	0.00
Eight	13.33	5.56
Sixteen	17.65	0.00
Attentive task		
Two	58.82	12.50
Four	66.67	5.88
Eight	58.82	13.33
Sixteen	47.06	25.00
Patient K.G.		
Preattentive task		
Two	5.56	0.00
Four	5.88	0.00
Eight	0.00	0.00
Sixteen	11.11	0.00
Attentive task		
Two	11.11	0.00
Four	43.75	0.00
Eight	41.18	11.11
Sixteen	66.67	5.56
Patient D.B.		
Preattentive task		
Two	0.00	0.00
Four	0.00	5.88
Eight	5.88	0.00
Sixteen	0.00	0.00
Attentive task		
Two	0.00	0.00
Four	0.00	0.00
Eight	31.25	0.00
Sixteen	33.33	0.00

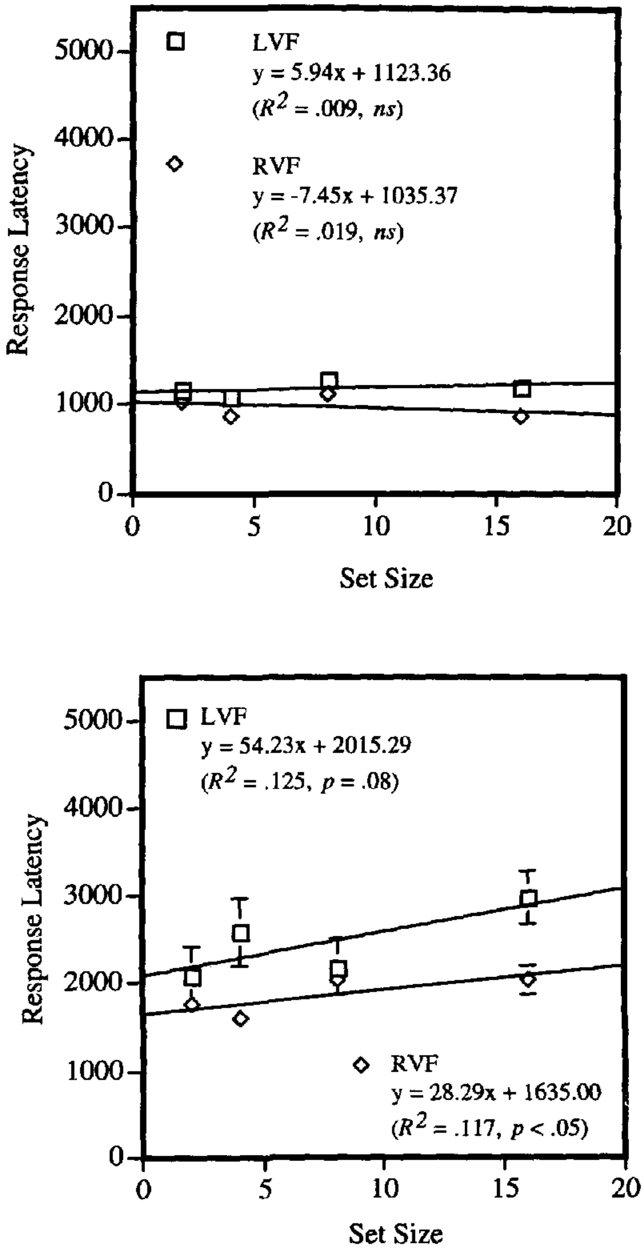

Figure 5. The top panel displays M.C.'s response latency in the preattentive search task, with the flat regression slopes in both visual fields indicating a parallel search. The bottom panel shows M.C.'s response latency in the attentive search task and reveals positive regression slopes in both visual fields, with performance in the left visual field (LVF) markedly less efficient than in the right visual field (RVF).

performance. This pattern suggests an impaired serial search mechanism in the left visual field. Caution in this interpretation is warranted, however, because the slope of 29 ms per item in the right visual field is shallow compared with the normal participants' slope of 60 ms per item, and her slope of 54 ms per item in the left visual field is similar to control participants' slope of approximately 50 ms per item. Precisely why this slope was so shallow in the right visual field compared with the left visual field may reflect a strategy whereby M.C. began searching for targets in the right visual field first before searching the left visual field.

M.C.'s percentage errors differed as a function of task and visual field. As shown in Table 3, M.C. produced more errors in the attentive search task compared with the preattentive search task and more errors in the left visual field compared with the right visual field. However, the difference in percentage errors between the two types of search tasks was most striking in the left visual field, where she produced an average of 9% errors in the preattentive task (6 out of 64 trials) and 58% errors in the attentive search task (36 out of 64 trials). This distribution of errors is consistent with the response latency data in which the attentive search was strikingly less efficient in the left visual field compared with the right visual field and was also less efficient than the preattentive search in both visual fields.

Neglect Patient K.G.

The mean response latencies for the preattentive and attentive search tasks for Patient K.G. are presented in Figure 6. Regression analyses for the preattentive search task revealed slopes of 6.03 ms per item in the left visual field and −3.51 ms per item in the right visual field. In the attentive search task, regression analyses revealed slopes of 116.28 ms per item in the left visual field and 72.76 ms per item in the right visual field. K.G.'s search slopes in both the left and right visual field in the preattentive search task were similar to those found in the control participants, suggesting that K.G.'s preattentive search was normal. By contrast, the slope of approximately 116 ms per item in the left visual field in the attentive task suggests that K.G. was impaired relative to control participants and to her own search performance in the intact right visual field.

As shown in Table 3, K.G.'s error rates varied as a function of task and visual field. K.G. made only 6% errors in the left visual field (4 out of 70 trials) and no errors in the right visual field when performing the preattentive search task, whereas she made 41% errors in the left visual field (28 out of 69 trials) and only 4% errors in the right visual field (3 out of 69) when performing the attentive search task. This pattern of errors is consistent with the response latency data in which search performance in the left visual field seems to be impaired only during the attentive search task and not the preattentive search task.

Neglect Patient D.B.

The mean response latencies for the preattentive and attentive search tasks for Patient D.B. are presented in Figure 7. In contrast to the other three neglect patients, D.B.'s performance in the preattentive search task suggested a greater influence of serial search processes that was not evident in the other patients. In fact, regression analyses for the preattentive search task revealed significant slopes of 50.06 ms per item in the left visual field and 26.66 ms per item in the right visual field. In the attentive search task,

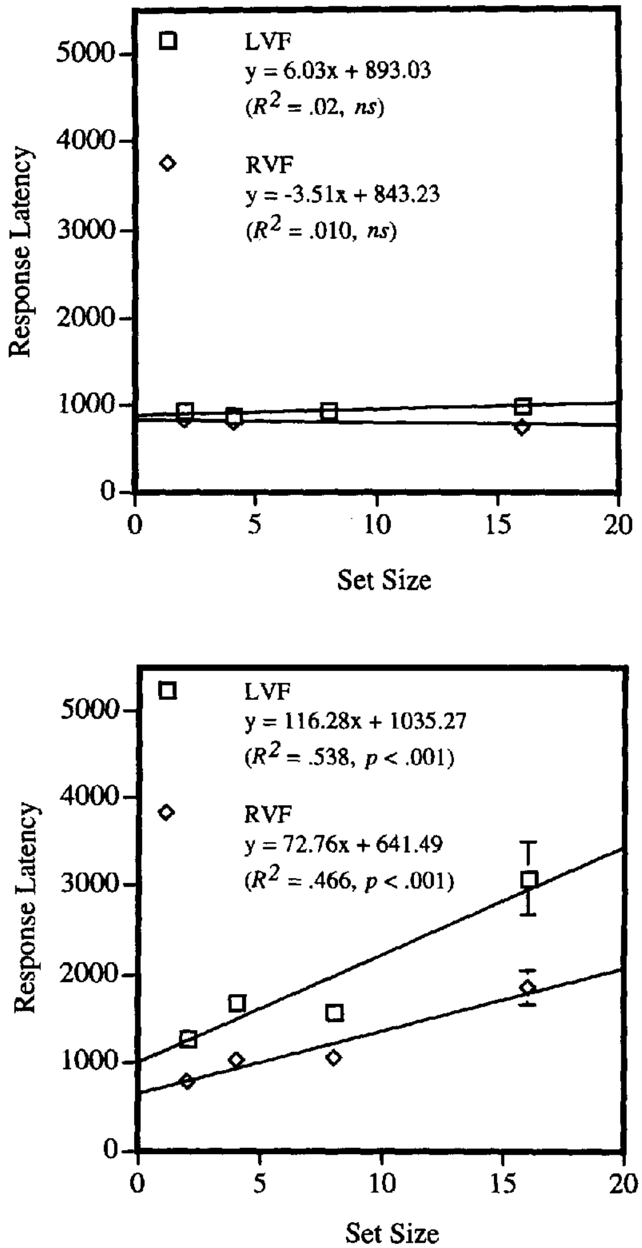

Figure 6. The top panel shows K.G.'s response latency in the preattentive search task; the flat regression slopes in both visual fields are indicative of a parallel search. The bottom panel displays K.G.'s response latency in the attentive search task and shows positive regression slopes in both visual fields, with performance in the left visual field (LVF) markedly less efficient than in the right visual field (RVF).

regression analyses revealed slopes of 148.26 ms per item in the left visual field and 50.32 ms per item in the right visual field. These data suggest that D.B. relied on serial search processes in both the preattentive and attentive search task but did so to a much greater extent in the left visual field than in the right visual field. It is important to point out, however, that D.B.'s performance in the attentive search task was similar to the other three neglect patients; it was his performance in the preattentive task that set him apart from the other patients.

As shown in Table 3, D.B. made very few errors overall. In the preattentive task, D.B. made only one error in both the left and right visual field. In the attentive task, D.B.'s percentage errors were 16% (11 out of 67) in the left visual field and 0% in the right visual field. Thus, similar to the

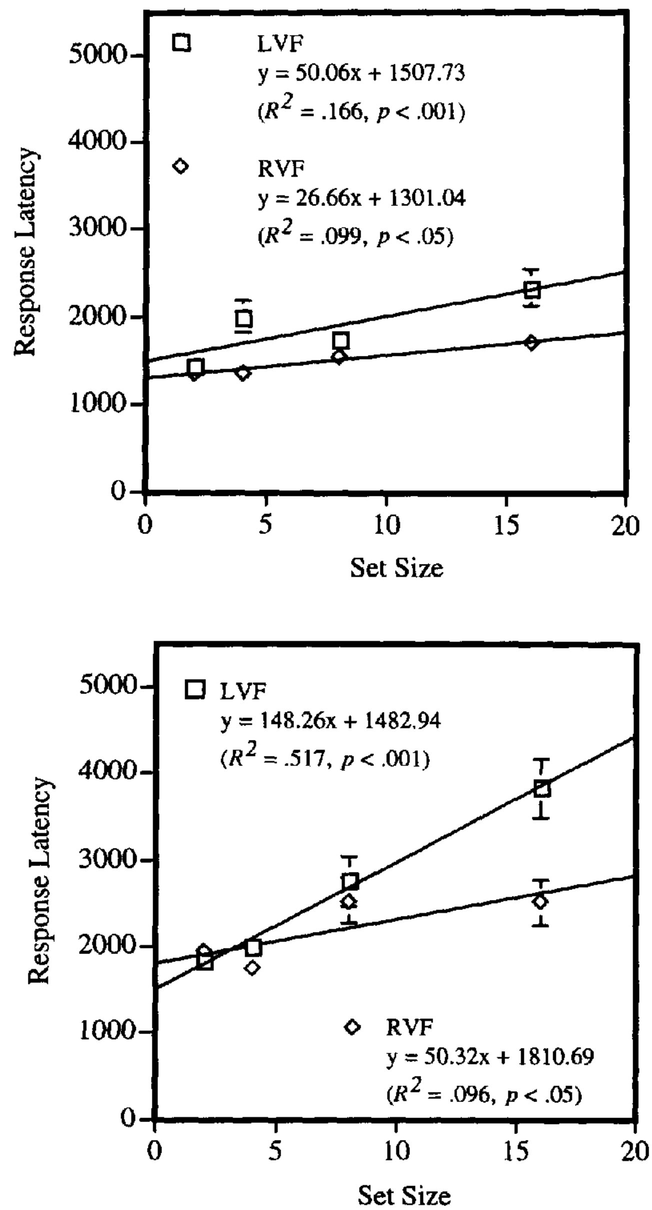

Figure 7. The top panel displays D.B.'s response latency in the preattentive search task and shows abnormal significant serial regression slopes in both visual fields. The bottom panel displays D.B.'s response latency in the attentive search task and reveals positive regression slopes in both visual fields, with performance in the left visual field (LVF) markedly less efficient than in the right visual field (RVF).

other neglect patients, D.B. made consistent errors only in the left visual field during the attentive search task. Note that while D.B. was the only neglect patient to show evidence of serial search strategies in the preattentive search task, he did not make any appreciable errors. Thus, although his use of serial search was not typical of the other patients, it was effective for him in accurately detecting targets in the context of the preattentive task. Precisely why serial search was not as effective in the attentive task may simply be due to the degree to which serial search processes are used in the latter task. That is, in the attentive task, serial search processes are needed to a greater degree than in the preattentive task, as evidenced by the differences in the magnitudes of the regression slopes across these two tasks.

Hemianopic Neglect Patients M.M. and D.M.

Table 4 displays the percentage errors during the preattentive search task for Patients M.M. and D.M., who had a left homonymous hemianopia in addition to left visual neglect. Unlike the neglect patients without primary visual deficits, these patients did not reliably detect targets in the left visual field. Patient D.M. made more errors in the right visual field than Patient M.M. and the majority of the neglect patients; however, examination of where these errors occurred revealed that they were in the left-most portion of the right half of the display (i.e., midline).

Discussion

Preattentive Search

With regard to decision latency in the preattentive search task, three of the patients (J.M., M.C., and K.G.) showed a pattern of performance that was similar to the control participants in both their left and right visual fields. As shown in the top panels of Figures 3 through 6, targets appeared to be detected without a substantial set size effect, evidenced by nonsignificant shallow regression slopes (under 11 ms/item) for both patients and control participants. In fact, the slope for these three neglect patients averaged only 6.73 in the left visual field and −2.2 in the right visual field. These slopes are similar to the control participants' slopes of 3.00 in the left visual field and 6.48 in the right visual field. We suggest that for these three patients, the preattentive search was conducted in parallel and appeared normal in both the left and the right visual field.

This conclusion is supported by these patients' accuracy in detecting targets in the preattentive search task. On average, J.M., M.C., and K.G. made only 5% errors (3 errors) in the left visual field and 0.5% errors in the right visual field. Even in the worst case, Patient M.C. committed only 6 errors out of 64 trials in the left visual field—an error rate of less than 10%—whereas J.M. and K.G. committed less than 4 errors in the left visual field. These figures are comparable to the control participants, who made between 0 and 3 errors in the preattentive task. Thus, although patients did have a slightly higher error rate in the left visual field compared with the right visual field, the number of errors was negligible and likely not suggestive of impaired performance. Within the framework of the FIT (Treisman & Gelade, 1980), for these three patients, targets containing a single defining feature popped out of the array of distracting items.

Neglect Patient D.B., on the other hand, did not show a normal pattern of decision latency in the preattentive search task. His regression slopes in both the left (50 ms per item) and right (27 ms per item) visual field were significant and suggested that serial search mechanisms may have contributed to his performance (similar to Eglin et al., 1989; Eglin et al., 1994). There are at least two explanations for D.B.'s abnormal use of serial search mechanisms in the preattentive search task. First, it is possible that D.B.'s preattentive search is bilaterally impaired and consequently forces him to rely on attentive serial search strategies to a greater extent than normal. Given that attentive search is impaired in the left visual field of patients with neglect, the differential slopes found in Patient D.B. in the left and right visual field would be expected (i.e., greater slope in the left than in the right visual field). As an alternative, it is possible that preattentive processing is disrupted to different degrees in the left and right visual field, with the left being more disrupted than the right. With the current information, it is not possible to discern which of these explanations is correct. An interesting finding, however, was that his abnormal performance in the preattentive search task did not translate into an increase in error rate. In fact, Patient D.B. committed only one error in each visual field in the preattentive task. Thus, although D.B. may have relied on serial search mechanisms to a greater extent than did the other neglect patients and control participants, it did not decrease his accuracy as might be expected. An explanation for this finding may be found by examining the accuracy data from the attentive search task in which D.B. also did not commit any left-sided errors when there were only 2 or 4 distracting items in the display. Only when the attentive task became more difficult (i.e., 8 and 16 distractors) did his use of serial mechanisms begin to degrade his accuracy performance.

The fact that D.B. did not show evidence of pop out in his neglected visual field has several implications. First, preattentive processing is not necessarily preserved in all cases of

Table 4
Percentage Errors for Patients M.M. and D.M. in the Preattentive Search Task as a Function of Visual Field and Set Size

Patient and set size	Left visual field	Right visual field
M.M.		
Two	70.59	0.00
Four	61.11	0.00
Eight	88.89	0.00
Sixteen	100.00	5.56
D.M.		
Two	75.00	0.00
Four	100.00	14.29
Eight	92.31	33.33
Sixteen	100.00	15.38

hemispatial neglect. It is noteworthy that D.B.'s lesion was caused by a subcortical thalamic hemorrhage as opposed to the cortical MCA lesions of the other three neglect patients. Second, it is curious that D.B. did not show pop out in his right visual field, suggesting abnormal use of serial search mechanisms bilaterally. The question is why. One possibility is that D.B.'s preattentive processing impairment is simply bilateral, perhaps because of his hemorrhagic lesion. A second possibility is that once the use of serial search mechanisms is required in one visual field, it may be obligatorily applied to the other visual field; pop out and serial search mechanism cannot dissociate across the visual fields.

Accuracy performance in the preattentive search task for the two neglect patients with hemianopia (whose left visual field error rates were 80% for Patient M.M. and 92% for Patient D.M.) suggests that preattentive visual search may not be preserved in cases of hemispatial neglect in which a primary visual field deficit is present. This finding has important methodological and theoretical significance, because many studies of neglect include patients with co-occurring visual field deficits as well as those with only neglect. In doing so, investigators make the assumption that the two patient groups can garner information equally in the contralesional visual field. The current study, however, demonstrates a dissociation between those individuals for whom preattentive featural information is processed and those individuals who may behaviorally present very similarly but for whom preattentive featural information is likely not processed. A similar dissociation was observed by McGlinchey-Berroth et al. (1993), who found that, unlike patients with only hemispatial neglect, a hemianopic patient did not show implicit picture priming. It is clear that these two groups are differentially sensitive to visual information and should not be combined in group studies.

Attentive Search

In the attentive search task, each of the four neglect patients showed the characteristic dissociation of performance in the left visual field compared with the right visual field and compared with control participants. To be specific, their regression slopes were markedly steeper in the left visual field (averaging 130 ms per item) than they were in the right visual field (averaging 58 ms per item), indicating a less efficient search in the left compared with the right. An important finding was that neglect patients' right visual field regression slopes were similar to the control participants' left (averaging 50 ms per item) and right (averaging 60 ms per item) visual field. In addition, neglect patients committed greater numbers of errors in the left (averaging 37%) compared with the right (averaging 6%) visual field. Taken together, the decision latency data and accuracy data suggest that neglect patients' attentive search in the left visual field was markedly impaired.

General Discussion

Given that some patients have preserved preattentive processes, one must now ask whether neglect patients can use their intact preattentive information to guide a serial search in the contralesional visual field. One prominent model of guided search was proposed by Wolfe and colleagues (Wolfe, Cave, & Franzel, 1989). According to this model, preattentive features identified in parallel can actually guide the serial attentional search. For example, when one is searching for a red horizontal line, preattentive information could inform the serial search mechanism to avoid items that are vertical or green. Although this guidance is not perfect, it does reduce the number of items that need to be searched by eliminating items without target features, thus making the serial search more efficient and not completely random. An important next step in investigating early visual processing in hemispatial neglect, then, is to determine if patients' intact preattentive processing, which allows them to identify the presence of a target-defining feature, can be subsequently used to guide an attention-demanding search.

The intact preattentive processing of simple features demonstrated in this study is only the first step in the examination of preattentive visual processing in the neglected visual field. There are still a great deal of preattentive processes, such as grouping and object formation, that need to be evaluated in order to fully understand what visual processes are intact and what processes are impaired in hemispatial neglect.

References

Aglioti, S., Smania, N., Barbieri, C., & Corbetta, M. (1997). Influence of stimulus salience and attentional demands on visual search patterns in hemispatial neglect. *Brain and Cognition, 34*, 388–403.

Audet, T., Bub, D., & Lecours, A. R. (1991). Visual neglect and left-sided context effects. *Brain and Cognition, 16*, 11–28.

Berti, A., & Rizzolatti, G. (1992). Visual processing without awareness: Evidence from unilateral neglect. *Journal of Cognitive Neuroscience, 4*, 345–351.

Caramazza, A., & McCloskey, M. (1988). The case for single-patient studies. *Cognitive Neuropsychology, 5*, 517–527.

Donnelly, N., Humphreys, G. W., & Riddoch, M. J. (1991). Parallel computation of primitive shape description. *Journal of Experimental Psychology: Human Perception and Performance, 17*, 561–570.

Eglin, M., Robertson, L. C., & Knight, R. T. (1989). Visual search performance in the neglect syndrome. *Journal of Cognitive Neuroscience, 1*, 372–385.

Eglin, M., Robertson, L. C., Knight, R. T., & Brugger, P. (1994). Search deficits in neglect patients are dependent on size of the visual scene. *Neuropsychology, 8*, 451–463.

Gilchrist, I. D., Humphreys, G. W., & Riddoch, M. J. (1996). Grouping and extinction: Evidence for low-level modulation of visual selection. *Cognitive Neuropsychology, 13*, 1223–1249.

Gilchrist, I. D., Humphreys, G. W., & Riddoch, M. J. (1997). Luminance and edge information in grouping: A study using visual search. *Journal of Experimental Psychology: Human Perception and Performance, 23*, 464–480.

Goldsmith, M. (1998). What's in a location? Comparing object-based and space-based models of feature integration in visual search. *Journal of Experimental Psychology: General, 127*, 189–219.

Gum, T. (1992). Psychlab (Version 1. 0776) [Computer software]. Montreal, Canada.

He, Z. J., & Nakayama, K. (1992, September). Surfaces versus features in visual search. *Nature, 359*, 231–233.

Heilman, K. M., Watson, R. T., & Valenstein, E. (1993). Neglect and related disorders. In K. M. Heilman & E. Valenstein (Eds.), *Clinical neuropsychology* (3rd ed., pp. 279–336). New York: Oxford University Press.

Humphreys, G. W., & Price, C. J. (1994). Visual feature discrimination in simultanagnosia: A study of two cases. *Cognitive Neuropsychology, 11*, 393–434.

Julesz, B. (1981, March). Textons, the elements of texture perception and their interaction. *Nature, 290*, 91–97.

Làdavas, E., Paladini, R., & Cubelli, R. (1993). Implicit associative priming in a patient with left visual neglect. *Neuropsychologia, 31*, 1307–1320.

Mattingley, J. B., Davis, G., & Driver, J. (1997, January). Preattentive filling-in of visual surfaces in parietal extinction. *Science, 275*, 671–674.

McGlinchey-Berroth, R., Bullis, D. P., Milberg, W. P., Verfaellie, M., Alexander, M., & D'Esposito, M. (1996). Assessment of neglect reveals dissociable behavioral but not neuroanatomical subtypes. *Journal of the International Neuropsychological Society, 2*, 441–451.

McGlinchey-Berroth, R., Kilduff, P., & Milberg, W. (1990, February). *Semantic processing in the neglected visual field: Evidence from a lexical decision task.* Paper presented at the International Neuropsychological Society, Orlando, FL.

McGlinchey-Berroth, R., Milberg, W. P., Verfaellie, M., Alexander, M., & Kilduff, P. T. (1993). Semantic processing in the neglected visual field: Evidence from a lexical decision task. *Cognitive Neuropsychology, 10*, 79–108.

Rensink, R. A., & Enns, J. T. (1995). Preemption effects in visual search: Evidence for low-level grouping. *Psychological Review, 102*, 101–130.

Riddoch, M. J., & Humphreys, G. W. (1987). Perceptual and action systems in unilateral visual neglect. In M. Jeannerod (Ed.), *Neurophysiological and neuropsychological aspects of spatial neglect* (pp. 151–181). New York: Elsevier.

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*, 97–136.

Treisman, A., & Souther, J. (1985). Search asymmetry: A diagnostic for preattentive processing of separable features. *Journal of Experimental Psychology: General, 114*, 285–309.

Wolfe, J. M., Cave, K. R., & Franzel, S. L. (1989). Guided search: An alternative to the feature integration model for visual search. *Journal of Experimental Psychology: Human Perception and Performance, 15*, 419–433.

Received July 16, 1999
Revision received May 30, 2000
Accepted May 31, 2000 ■