

SEARCH PATTERNS AND NEGLECT: A CASE STUDY*

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Abstract—An irregular and unsystematic search pattern may contribute to unilateral neglect. We examined the sequence of cancellations performed by a patient with unilateral neglect and found that she followed a systematic and stereotypic vertical search pattern. To overcome this vertical search pattern, foils were placed in rows. These foils induced slightly more horizontal movements, but did not alter her neglect. In another attempt to overcome her vertical search and tendency to cancel on the right, she was explicitly instructed to cancel targets alternating to and from the right and left sides of the array. This strategy overcame her vertical search, but, instead of modifying the severity of her neglect, this task only changed its spatial distribution. The altered spatial distribution of neglect is difficult to reconcile with current theories of neglect. We suggest that this patient demonstrates a limited capacity to sequentially be aware of or act upon stimuli.

INTRODUCTION

INDIVIDUALS WITH unilateral neglect as a consequence of brain damage fail to orient towards, report, or respond to stimuli contralateral to their lesion. Attentional, intentional and representational theories have been proposed to account for these clinical observations [12]. However, these theories do not explicitly specify what kind of search patterns, if any, patients with unilateral neglect use within attended spatial fields. Nor do they specify whether there is a relationship between search pattern and neglect of targets.

CHEDRU *et al.* [3], used electro-oculographic recordings to investigate visual search in normal controls and brain-damaged individuals. They found that, whereas normal controls had circular search patterns, often starting in the top left quadrant, the search of brain-damaged individuals was “unsystematic and irregular”. In addition, patients with unilateral neglect searched left space for shorter period than right. The irregularity of search patterns in brain-damaged individuals was replicated by BELLAZA *et al.* [1]. If eye movements reflect attentional exploration, these studies suggest that some aspects of neglect might be a result of disorganized and inefficient exploration.

On cancellation tasks patients sequentially cancel targets on a stimulus array. A disorganized search strategy would be manifested by an unsystematic search for targets. We examined how a patient with unilateral neglect moved from target to target on cancellation tasks to assess her search patterns. We wished to learn if her pattern of cancellation was in

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any way organized and if experimental manipulations of search patterns would influence neglect.

PATIENT HISTORY

M.F., a 73-year-old, right-handed woman with a history of atrial fibrillation, suffered a stroke on 19 June, 1990. On that morning, she developed dysarthria and a left hemiparesis over several minutes. Her sister commented upon M.F.'s unconcern and lack of desire to go to the hospital. For several days after admission M.F. remained lethargic. As she recovered, she was left with a dense left hemiplegia. After 3 weeks she was transferred to a rehabilitation hospital. At that time she was alert, oriented and aware of her stroke. Her memory, language comprehension and repetition were normal. Her language production, while being aprosodic, was fluent, grammatic and well articulated. She did not have an agnosia or an apraxia. She demonstrated extinction to double simultaneous visual, auditory and tactile stimulation. She bisected to the right of midline on line bisection tasks, and did not copy elements of a simple drawing on the left. She did not have a deviation of her eyes or head, and she had normal visual fields on bedside confrontation testing. Her left hemiplegia persisted. A computer tomography (CT) scan of her head 1 week after the stroke revealed a large infarct in the right middle cerebral artery distribution, involving the right parietal and frontal lobes (Fig. 1).

METHODS

General procedure

M.F. was tested between 8 and 10 weeks after her stroke, in a quiet and secluded room in an Assisted Living Home. Stimulus arrays were presented in front of her and centered at her mid-sagittal plane with respect to her body. Each cancellation task was considered complete when M.F. indicated she was finished. If she stopped cancellation, but made no indication, after 15 sec she was asked if the task were complete. The next task was initiated only after she said she was finished. Within each trial, conditions were presented randomly. Short breaks were taken every 20 min.

Experiment 1

Stimuli. Stimulus arrays consisted of targets that were identical "O"s distributed over 72.25 sq. in. Arrays had either 16, 32 or 64 targets with 1/4 of the targets randomly distributed within each quadrant. Two different arrays were used for each condition to minimize practice effects in learning target location. The reason for varying the number of targets was to address different theoretical questions for a different set of experiments (to be reported).

Procedure. The sequence that M.F. followed in canceling targets was recorded by one of us (AC) on identical arrays. She performed a total of 20 trials with each condition.

Results. In the 16-target array, M.F. canceled 14.6 (± 2.1), in the 32-target array she canceled 21.2 (± 3.8) and the 64-target array she canceled 27.6 (± 5.2) targets. The sequence that she followed in canceling targets was drawn on master stimulus arrays. Each movement from one target to another was represented by a line drawn between targets. Her sequence of cancellations on all the trials were superimposed on the master arrays (Figs 2a,b,c). As can be seen by this visual display, she had an overwhelming tendency to move in a vertical direction. She almost always began in the top right. From there she tended to move down to the bottom of the array and then back up, gradually inching leftward until she stopped. To quantify these directional movements, each individual movement was classified as being in one of four directions (Fig. 2d): Right (316–45°), Up (46–135°), Left (136–225°) and Down (226–315°). The percentages of movement in each direction are listed in Table 1. How M.F. moved in each direction was not significantly different for the three arrays with different numbers of targets: $\chi^2(6 \text{ d.f.}) = 4.78, P > 0.10$.

Discussion. The visual display clearly demonstrates that M.F. followed a systematic search pattern and was not disorganized. An inefficient search pattern cannot account for M.F.'s neglect of targets. We then tested to see whether altering her search pattern would alter her

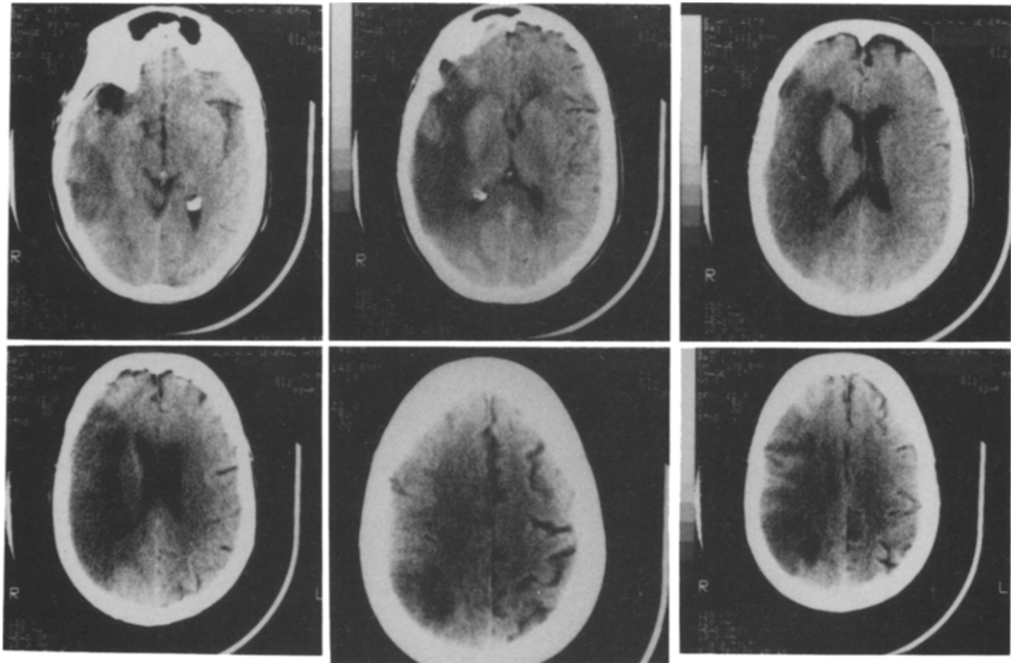


Fig. 1. CT scan done 1 week after the stroke, demonstrating an infarct in the distribution of the right middle cerebral artery.

neglect. To this end we manipulated stimulus arrays by placing foils in different patterns, specifically trying to induce a horizontal search pattern.

Experiment 2

Stimuli. Arrays consisted of 32 "O"s as targets and 32 "X"s as foils such that 1/4 of the targets and 1/4 of the foils were distributed in each quadrant. There were three patterns of how the foils and targets were distributed with respect to each other. In the first condition, targets and foils generally followed a vertical pattern, such that a column of targets was always next to a column of foils. Within this column of targets or foils, care was taken not to have targets or foils lined up directly one on top of the other. The second condition had targets and foils following a horizontal pattern such that a row of targets was always above and/or below a row of foils. Again, care was taken not to have targets directly adjacent to one another. The third condition consisted of targets and foils alternating in both vertical and horizontal directions, such that each target was surrounded by foils (in a diamond pattern) and each foil was similarly surrounded by targets.

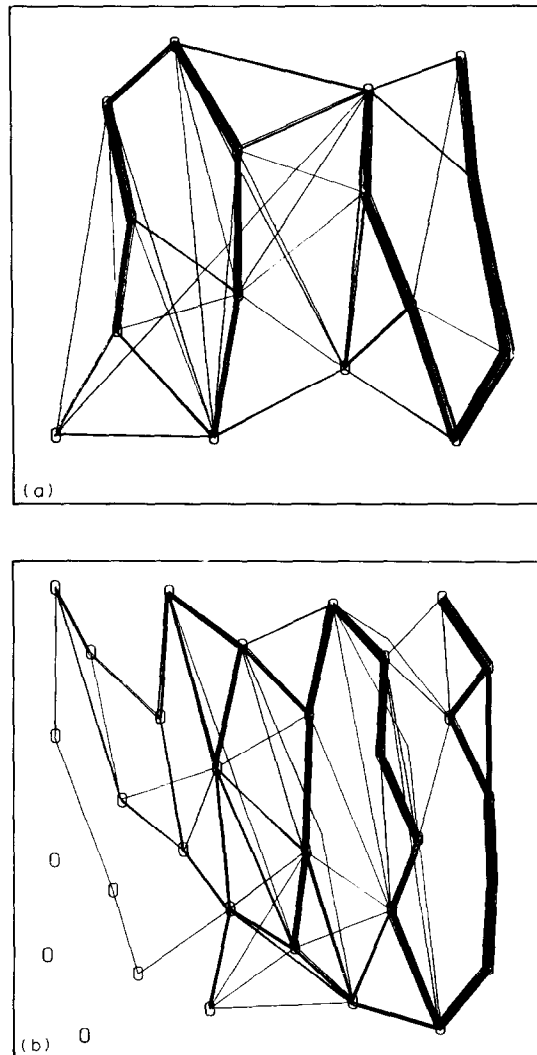


Fig. 2(a), (b).

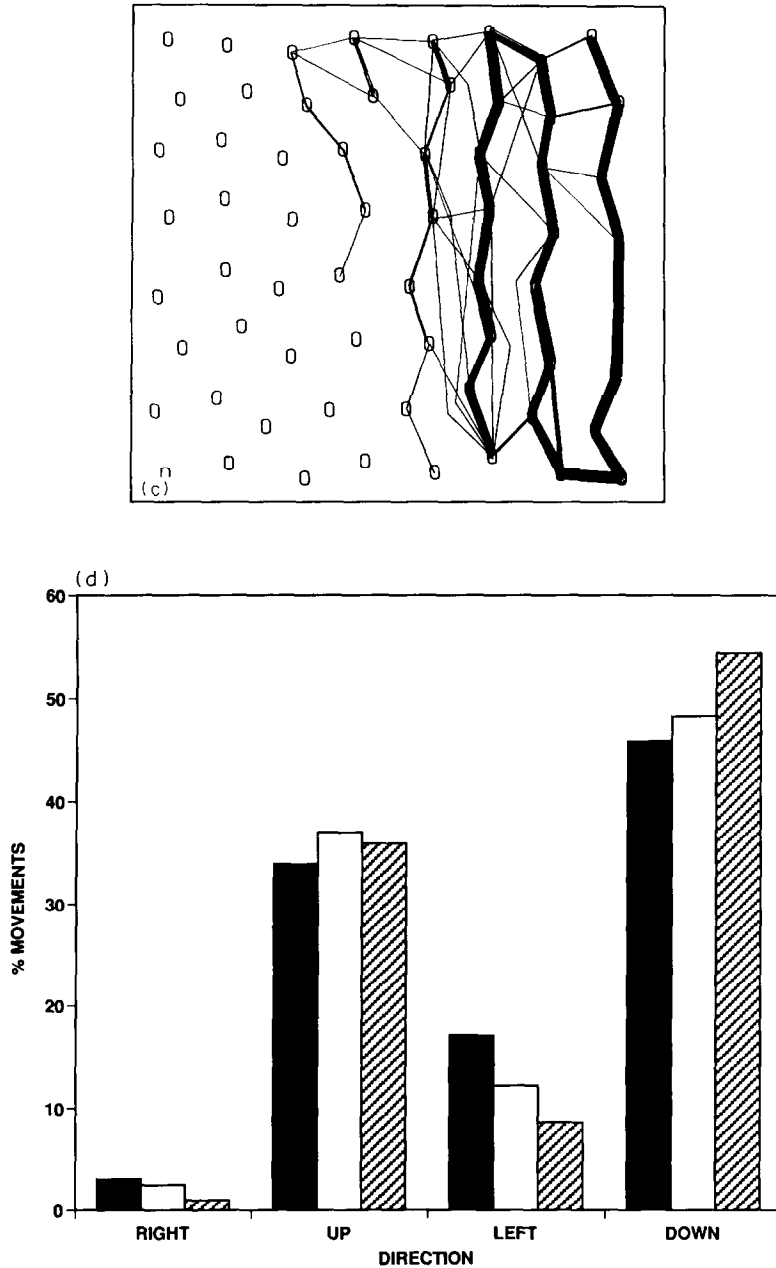


Fig. 2. Pattern of cancellation on arrays with (a) 16 targets, (b) 32 targets, (c) 64 targets and (d) percent of movement in each direction. ■ = 16 targets, □ = 32 targets, ▨ = 64 targets.

If the presence of foils in the stimulus arrays affected M.F.'s search, with targets and foils in columns, we would expect her vertical search to be emphasized and, with targets and foils in rows, perhaps a horizontal search would be induced. In the third condition she might adopt yet another search pattern, such as moving diagonally, or she might not have any consistent pattern. If her search pattern was altered, the number of targets canceled would be an indication of whether neglect was reduced or increased by alternate search strategies.

Table 1. Percent of movement in each direction

	Right	Up	Left	Down
Experiment 1				
16 targets	3.1	33.9	17.1	45.9
32 targets	2.5	37.0	12.2	48.3
64 targets	1.0	35.9	8.7	54.4
Experiment 2				
Vertical foils	0	35.7	7.7	56.7
Diagonal foils	1.6	35.3	15.2	47.9
Horizontal foils	1.4	35.4	24.2	39.0

Procedure. The sequence of her cancellations was recorded and displayed as in Experiment 1. She performed 20 trials for each condition.

Results. As demonstrated in the visual display (Figs 3a,b,c), the sequence of her cancellations continued to assume a vertical pattern. When the targets and foils were distributed in rows, there was some inducement of horizontal movements, however, the overall search continued to be vertical. For arrays with targets and foils distributed vertically, she canceled 18.0 (± 4.2); for targets and foils distributed horizontally, she canceled 19.7 (± 3.8); for targets and foils distributed surrounding each other, she canceled 18.5 (± 5.4). Performance, as measured by number of cancellations, was not statistically different using a Kruskal-Wallis One Way Analysis of Variance ($P=0.58$).

As in Experiment 1 M.F.'s directional movements were recorded as being in one of four directions (Fig. 3d). Although the overall pattern of search remained vertical, the placement of foils did change the proportions of movement in each direction (Table 1): χ^2 (6 d.f.) = 13.5, $P < 0.05$.

Discussion. M.F.'s pattern of search, starting at the top right and working her way vertically, was minimally altered by variation in the stimulus arrays, and there were no differences in how many targets she canceled. From this experiment it remained unclear whether the lack of change in her neglect was because altering search patterns did not influence neglect or whether the alteration in her search pattern, although statistically significant, was insufficient to influence her neglect. Experiment 3 was designed to explicitly change her search pattern.

Although patients with neglect tend not to attend to left-sided stimuli, they may be able to do so when specifically directed to the left. For example, if cues are placed on the left side of lines, patients are capable of noticing these cues [19]. Experiment 3 was designed to exploit this ability of patients to orient to the left when explicitly instructed. If M.F. were able to consciously orient to the left, we could set up task instructions to ensure an altered search, and examine its effects on neglect.

Experiment 3

Stimuli. M.F. was asked to cancel all target on stimulus arrays that consisted of either 32 or 64 identical "O" targets distributed over either 72.25 or 36.13 sq. in., such that 1/4 of the targets were randomly placed in each quadrant. The reason for varying the area of the arrays again had to do with a different set of experiments (to be reported). The order of the conditions was randomized within each trial, and M.F. performed 10 tasks in each of the four conditions.

Procedure a (traditional cancellations.) M.F. was asked to cancel all the targets on the arrays as she had before. The sequence of her cancellations was not recorded. She performed 10 trials in each cancellation condition for a total of 40 trials.

Procedure b (alternating cancellations). After completion of the previous set of trials, M.F. was presented with the same stimuli and instructed that, after she had canceled a target on the right (where she always began), she had to

move over and cancel a target on the left before she could cancel another target on the right. She was to proceed in this alternating pattern until she indicated that she had canceled all the targets. Again, the order of the stimulus arrays were randomized in each trial, and she performed 10 trials for a total of 40 cancellation tasks.

Results. M.F. canceled an average of 27.0 (± 4.7) targets of a possible 32 targets. There were no performance differences whether she canceled in the traditional manner, alternated right to left, or whether the targets were distributed over 72.25 or 36.13 sq. in. [Kruskal-Wallis statistic (3 d.f.) 1.99, $P=0.57$]. Similarly, of 64 possible targets she canceled an average of 38.5 (± 11.3) targets, with no performance differences between types of cancellation procedure or array sizes [Kruskal-Wallis statistic (3 d.f.) 0.74, $P=0.86$].

As shown in Table 2, for each condition the number of targets canceled were different across the columns using Kruskal-Wallis One Way ANOVA ($P < 0.001$). For the traditional

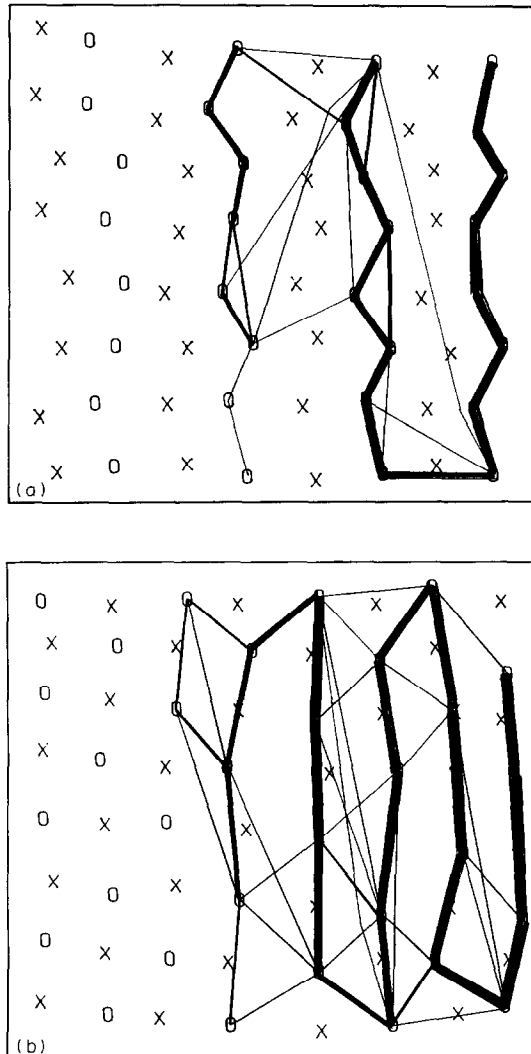


Fig. 3(a), (b).

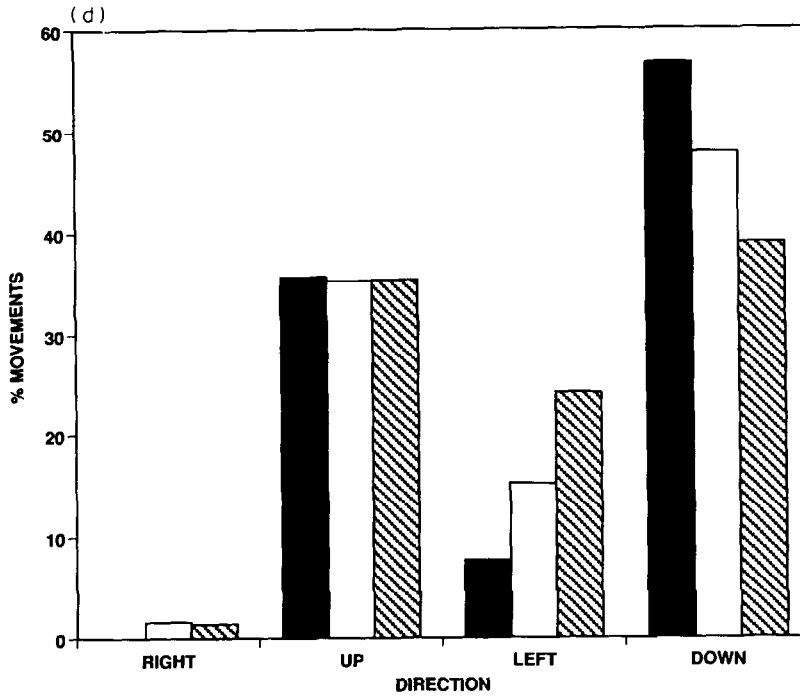
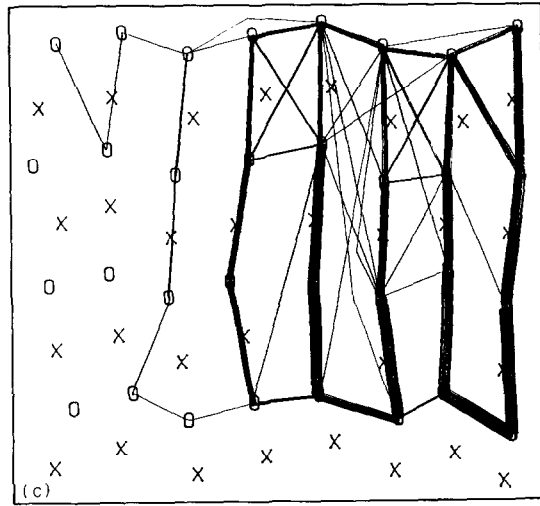


Fig. 3. Pattern of cancellations on arrays with (a) vertical foils, (b) diagonal foils, (c) horizontal foils and (d) percentage of movements in each direction, ■ = vertical foils, □ = diagonal foils, ▨ = horizontal foils.

cancellation tasks, M.F. clearly demonstrated left-sided neglect. When asked to move back and forth between the right and left parts of the stimulus array, neglect was not abolished. Instead, she demonstrated a different spatial pattern of neglect. To analyse this change of

Table 2. Mean scores of targets (SD) canceled by column in Experiments 3

	Far left	Middle left	Middle right	Far right
32 Targets				
Traditional	5.1 (1.9)	7.7 (0.7)	8.0 (0.2)	8.0 (0.0)
Alternating	5.5 (2.8)	6.2 (2.0)	6.0 (2.3)	7.8 (0.5)
64 Targets				
Traditional	2.3 (2.8)	8.2 (4.3)	13.8 (2.9)	15.5 (0.9)
Alternating	7.3 (4.6)	9.2 (4.5)	6.7 (4.4)	13.6 (3.4)

spatial distribution of neglect, the following procedure was used. Each stimulus array was divided into four columns (far left, middle left, middle right, far right) containing an equal number of targets. To assess relative distributions of canceled targets within each trial, the total number of targets was divided by four, and a deviation from this mean was recorded for each column. For example, if on an array a total of 16 targets were canceled, the mean for each column (1/4 area) would be four. If on the array the patient canceled eight in the far right, four in the middle right, three in the middle left and one in the far left (total = 16), the relative distribution of neglect would be recorded as +4 in the far right, 0 in the middle right, -1 in the middle left, and -3 in the far left. Such a conversion allows comparison of the spatial distribution of neglect across trials despite variability from trial to trial.

To statistically test for homogeneity of distribution of neglect across both methods of cancellation, the frequency of negative values from the above procedure within each spatial column was compared. The distribution of neglect was different depending on which procedure was used for arrays with 32 targets, χ^2 (3 d.f.) = 15.01, $P < 0.005$, as well as 64 targets, χ^2 (3 d.f.) = 14.31, $P < 0.005$.

As can be seen in the Fig. 4, on traditional cancellations for 32 targets, the column to the far left consistently had the least number of canceled targets. For 64 targets again the expected distribution is seen: the far right having the greatest number of targets canceled followed in general by the middle right, the middle left and the far left consistently having the least number of targets canceled. With the alternating condition the pattern is very different. In a number of trials early in the block she canceled more targets in the far right and far left than either middle column. An example of such dramatic neglect of central targets when alternating as compared to the usual neglect of left-sided targets is shown in Fig. 5(b). Sometimes when moving to the left she would not go all the way to the left and canceled targets in the middle left rather than the far left. On these trials she canceled more targets in the middle left than either the far left or the middle right. This pattern is more evident in the later trials as demonstrated in Fig. 5(c).

General observations. Although M.F.'s sequence of cancellations was not explicitly recorded as in Experiments 1 and 2, observationally she followed the same stereotypic pattern as in Experiment 1. In the alternating condition, M.F. seemed to use a motor strategy. After canceling on the right, she would move her hand across the stimulus array towards the left and appeared to be following her hand with her head and eyes. She moved slower to the left than she did on returning to the right. She tended to move across

horizontally, such that if she canceled on the top right she would then move to the top left. Initially she had a tendency to go to the border of the left side, moving towards the center from both the left and the right as she proceeded. As the trials continued, there was more variability in how far she reached into the left side of the array. There were three instances over the 40 alternating trials when she canceled two targets on the right sequentially. When this was pointed out to her, she immediately continued in the instructed manner. Towards the end of the alternating trials she appeared more tired and volunteered that she found this task more difficult than the previous one.

Discussion. M.F. was able to perform the alternating condition of procedure b. However, having her consciously attend to the left did not improve performance as measured by the number of targets canceled. These findings suggest that overcoming her tendency to search vertically on the right did not alter the extent of her neglect. Instead, what was altered was the spatial distribution of her neglect.

GENERAL DISCUSSION

M.F.'s clinical presentation, lesion location and behaviour were typical of most individuals with unilateral spatial neglect. The size of her lesion (involving both the frontal and parietal lobes) makes it difficult to make precise clinical and pathological correlations. As a single case, the generalizability of our observations to other patients with neglect remains an empiric question. However, she demonstrates a number of findings that are illustrative and raise questions about mechanisms that have been invoked to explain the neglect syndrome.

In the first two experiments, M.F. demonstrates a sequence of cancellations that is stereotypic, with an overall tendency to move in a vertical fashion. It would be difficult to describe this search as disorganized or inefficient. The specific vertical pattern of her search is consistent with current attentional and intentional theories of neglect. Her pattern may be a reflection of an unwillingness to move attention in a leftward direction, making it easier for her to move vertically rather than horizontally after she starts on the right. Alternatively, she may be displaying a directional hypokinesia, and she is less likely to move towards the left than she is up or down. Her overall pattern remained vertical, despite the slight alteration of her search patterns as a result of the placement of foils. Although not specifically discussed by CHEDRU *et al.* [3], in their report (Fig. 2f, p. 98) the graphic eye movement recordings of the subject with left-sided neglect seems to have an overall vertical pattern not seen in the recordings of normals or those with left-hemisphere lesions. It is clear that M.F.'s search was systematic and organized and dispels the notion that inefficient exploration could account for her neglect.

The influence of an altered search on patterns of neglect is examined in Experiment 3. When her search pattern was explicitly altered, it was the *distribution* of her neglect that changed, rather than the *extent* of her neglect. These results are difficult to reconcile with current explanations of neglect.

KINSBOURNE has proposed that each hemisphere normally drives attention contralaterally [14]. Each hemisphere also inhibits the contralateral hemisphere. He argues that in normal individuals there is a mild attentional bias to the right, as the left hemisphere's drive is greater than that of the right. In a patient with right-hemisphere lesion, the unfettered left hemisphere generates a powerful contralateral bias [15]. HEILMAN *et al.* [11], as well as MESULAM [16] have proposed that the right hemisphere alone can direct attention to both

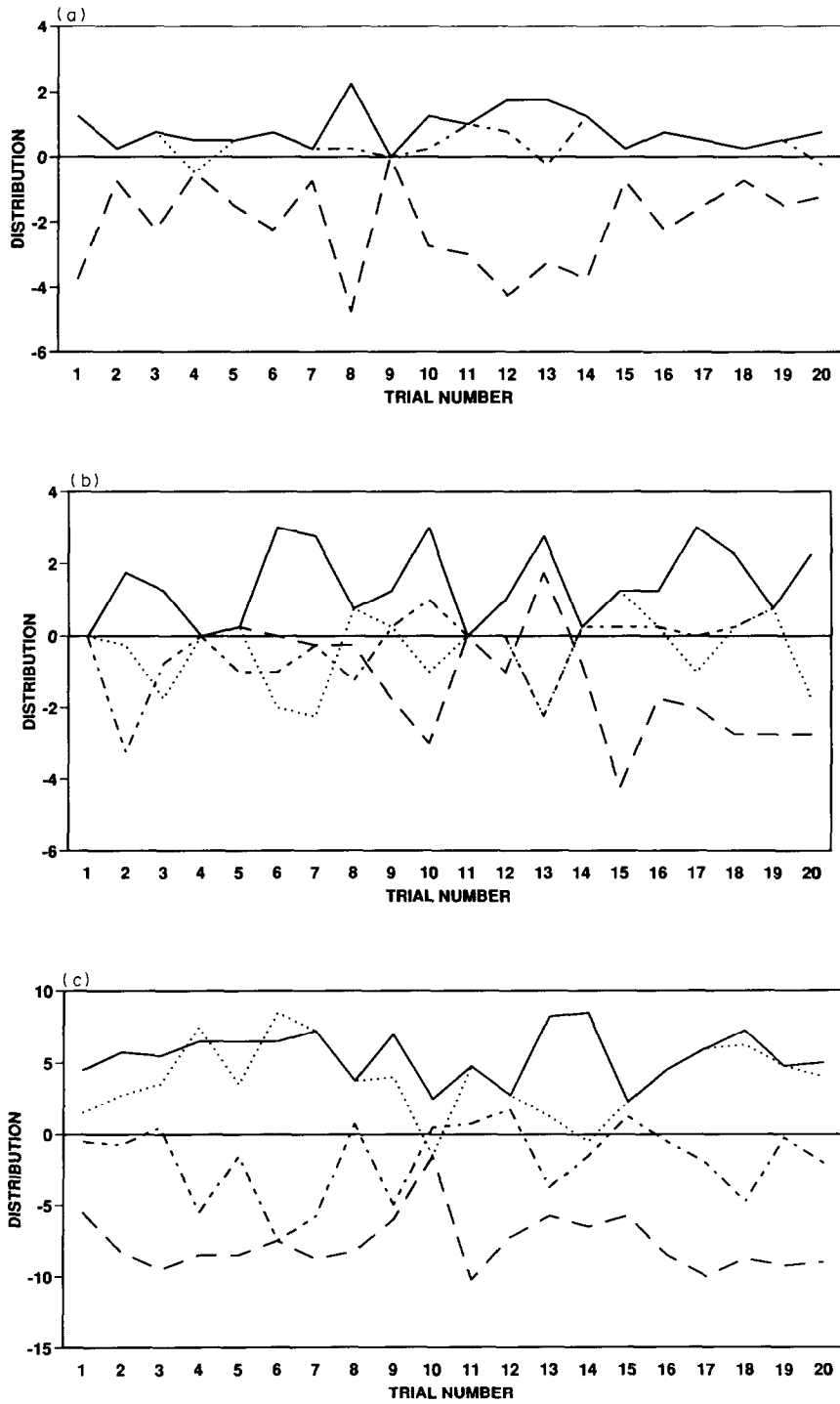


Fig. 4(a), (b), (c).

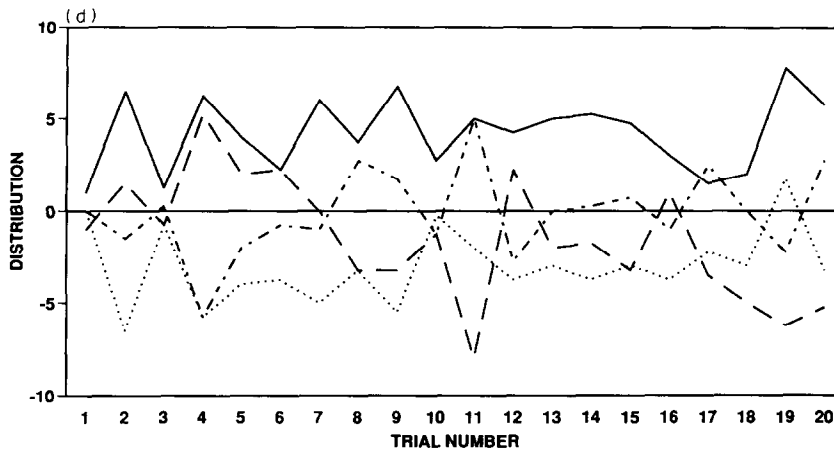


Fig. 4. Relative distribution of neglect on (a) 32 targets, traditional cancellation, (b) 32 targets, alternating cancellation, (c) 64 targets, traditional cancellation and (d) 64 targets, alternating cancellation, — far right, middle right, - · - · middle left, - - - far left.

hemifields and in both directions and is dominant for attention and arousal. The left hemisphere can only direct attention contralaterally. Therefore, right brain-damaged individuals are inattentive to left-sided stimuli. Posner has suggested that patients with neglect have greater difficulty covertly disengaging from ipsilesional stimuli [17]. All of these theories would predict that if a patient is able to shift attention to the left and disengage from ipsilesional stimuli, neglect should be ameliorated or abolished. The lack of change in the extent of neglect and the change in distribution of neglect when M.F. explicitly oriented to the left is not easily explained by these attentional theories.

The existence of a motor-intentional disturbance, with or without a concomitant attentional deficit in some patients with unilateral neglect was suggested by VALENSTEIN and HEILMAN [22]. Intention is thought to be mediated by systems that control physiologic readiness and preparation to respond to contralateral stimuli. Disruption of these systems might result in a disinclination to act in or towards contralateral space. This disinclination would also manifest itself behaviorally as neglect. Since M.F. is capable of intending in and towards neglected space when specifically instructed to do so, this theory cannot account for why she continues to neglect targets or why there is a change in the spatial distribution of her neglect.

A disturbance of an internal representation of space has been proposed by BISIACH *et al.* [2]. After demonstrating that patients with unilateral neglect will predominantly recall items on one side of a visually evoked memory (imagery), he has suggested that part of the mental representation itself is mutilated. Patients with neglect are unable to form left-sided mental representations. M.F. was capable of forming left-sided representations when so instructed, and this did not abolish her neglect. An inability to form left-sided representations cannot account for the results of Experiment 3.

We suggest that M.F.'s neglect is insufficiently explained by previous theories that invoke a deficit in exploration, a directional bias in attention or intention, an inability to disengage from stimuli, or an inability to form a left-sided mental representation. We propose that a

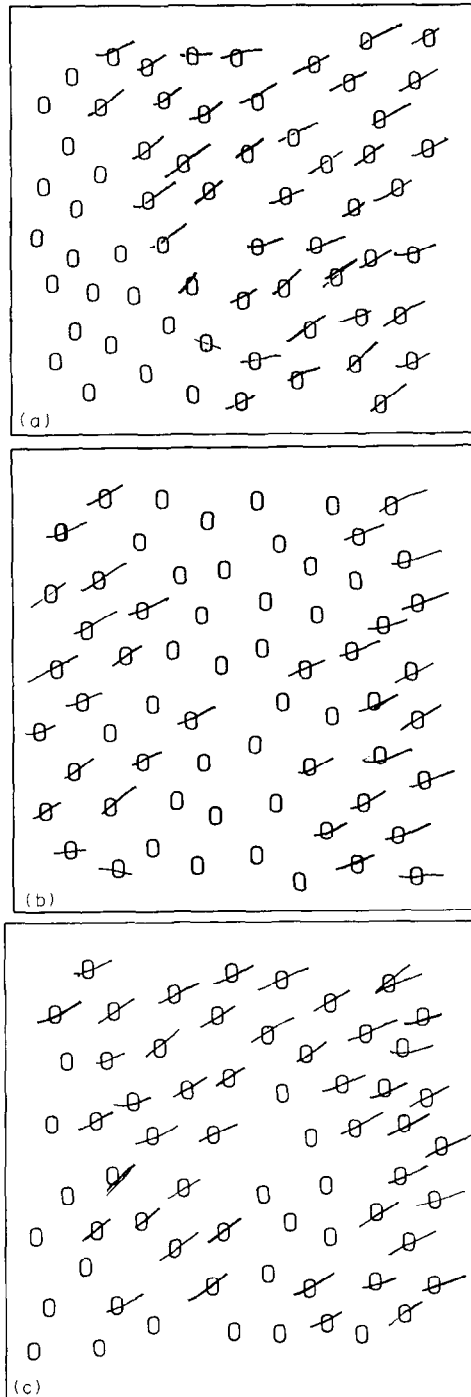


Fig. 5. Examples of performance on arrays with (a) 64 targets, traditional cancellation, (b) 64 targets, alternating condition (early trial) and (c) 64 targets, alternating condition (late trial).

limited capacity to either be aware of, or to consecutively act upon stimuli explains the change in spatial distribution of her neglect. This limited capacity to attend to or act upon stimuli, although usually observed on the right, is not confined to this spatial location.

Other investigators have used paradigms with explicit cuing to the left in patients with neglect. In line bisection, neglect is ameliorated in some patients with left-sided cuing [10, 19]. This "improvement" would seem to be inconsistent with our findings. However, under the conditions of being cued to the left, it is possible that part of the rightward extent of the line is actually being neglected, and performance would appear to be improved. ROBERTSON reported findings that suggest such spatial shifts of neglected fields may occur [20]. Patients with unilateral neglect were shown stimuli on one or both sides of a video monitor. They were asked to report what they saw and where. Under noncued conditions, patients with neglect made more errors of omission on the left side, as would be expected. However, when explicitly cued to the left, some patients made more errors of omission on the right. He also suggests that a limited attentional capacity may be operating in these patients.

Further investigations will be required to characterize the limited capacity demonstrated by M.F. This observed capacity limitation is qualitatively different from those of other reports. Patients with unilateral neglect have been shown to have worse performances than other brain-damaged patients and normal controls on tasks requiring simultaneous sensory attention or simultaneous motor actions. They frequently demonstrate extinction to simultaneously presented stimuli [5, 8]. This finding has been interpreted as demonstrating a limited capacity to direct attention to both stimuli at the same time. Similarly, when patients with neglect are asked to carry out two motor tasks simultaneously, they do so with a greater reduction of efficiency or accuracy than brain-damaged controls [4]. These experimental paradigms, as well as Robertson's, demonstrate a limited capacity that is locked *in time*. There is a limited capacity to distribute attention or intention at any given instance. Our patient's decreased capacity to search and cancel targets represents a limitation in performance *over time*. The demands placed upon her attentional and intentional systems are relatively stable within each instance that she cancels a target on an array. Her limited capacity represents a reduced ability to perform a consecutive, serial task, and may imply pathologic limitations of sustained attention or persistence, rather than limitations of simultaneous information processing or motor preparation (selective attention or selective intention). Such a hypothesis would be consistent with findings from patients with unilateral brain damage [6, 13] and split-brain patients [7], linking the right hemisphere with maintenance of an attentional set.

Cancellation tasks place three demands on attentional and intentional systems. One demand is phasic (i.e. searching and acting on a target) and two are tonic, repeated cancellations within a trial and repeated cancellations over trials. Our subject was less successful in directing attention or intention to the far left over trials in the alternating condition of Experiment 3. Additionally, she demonstrated a limited capacity to cancel targets within a trial, which is what we have focused on in this report. FLEET and HEILMAN demonstrated a decline in performance on cancellation tasks over trials. This decline was reversed by providing the subject with feedback, a procedure known to increase arousal [9]. There may be limitations of resources employed in specific aspects of performance [18, 21] or there may be a global capacity limitation. Future studies should help sort out the nature of attentional and intentional capacity limitations demonstrated by patients with neglect.

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