NOTE

MECHANISMS OF SPATIAL ATTENTION REVEALED BY HEMISPATIAL NEGLECT

Argye Elizabeth Hillis[1], **J. Toby Mordkoff**[2] **and Alfonso Caramazza**[3]

([1]Department of Neurology, Johns Hopkins Hospital; [2]Department of Psychology, Pennsylvania State University; [3]Department of Psychology, Harvard University)

Abstract

We report performance by a patient, NG, with hemispatial neglect after nondominant stroke, in detecting briefly (200 msec) presented visual targets. NG's detection of targets (gaps in circles) was determined by the location of the target in the space in which stimuli appeared. Gaps on the neglected side of a circle at fixation were rarely detected when circles of uniform size were always presented at fixation. The same targets in the same location were detected far more often in blocks that also included targets presented on each side of the central circle, or in blocks that included larger target stimuli. In these blocks, the window of space in which stimuli appeared was larger, such that the target fell closer to the center of this "window". These results indicate that the spatial extent of attention, and of hemispatial neglect, can be modified on the the basis of expectations and task requirements.

Key words: spatial attention, hemispatial neglect

Introduction

One of the richest sources of evidence for determining the neural mechanisms underlying attention is the study of patients with deficits in attention due to focal brain lesions. A particularly fruitful source has been the investigation of hemispatial neglect – the failure to attend to information on the side of space contralateral to brain damage. Such studies have provided evidence that attention involves discrete operations to disengage, move, and engage attention (Posner, Walker, Freidrich et al., 1984); that each hemisphere attends preferentially to the contralateral side of space (Kinsbourne, l977; De Renzi, Gentilini, Faglioni et al., 1989), but the nondominant hemisphere attends to both sides (Heilman and Van Den Abell, 1980; Weintraub and Mesulam, 1987); and that attention operates in multiple reference frames (Mesulam, 1981; Bisiach, Capitani and Porta, 1985; Ladavas, 1987; Caramazza and Hillis, 1990; Driver and Halligan, 1991; Rapp and Caramazza, 1991; Mennemeier, Chatterjee and Heilman, 1994; Chatterjee, 1994; Humphreys and Riddoch, 1994; Hillis and Caramazza, 1995; Behrmann and Tipper, 1999). In this paper we report evidence, from a patient with hemispatial neglect due to left parietal infarct (NG), that attention is distributed over a window of space that enlarges or constricts with the demands of the task. NG's ability to detect briefly presented targets (gaps in circles) on the neglected side was determined by the relative location of the target in the space in which stimuli were likely to appear in a given test block. The results indicate that locations of expected stimuli define the size of a modifiable window of attention.

Case report

NG, a left handed homemaker, was 79 years old at the time of this investigation. She had suffered a stroke, involving the left parietal cortex, thalamus, and basal ganglia (see Figure 1)

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four years earlier. NG had persistent right spastic hemiplegia and right tactile extinction to double simultaneous stimulation. Her visual fields were full, as tested by visual confrontation and Goldman Perimetry, and extra-ocular movements were normal. She had no language impairment, but showed severe right hemispatial neglect in drawing, copying (see Figure 2), reading, writing, and other visual and exploratory tasks, such as line cancellation (see Figure 3).

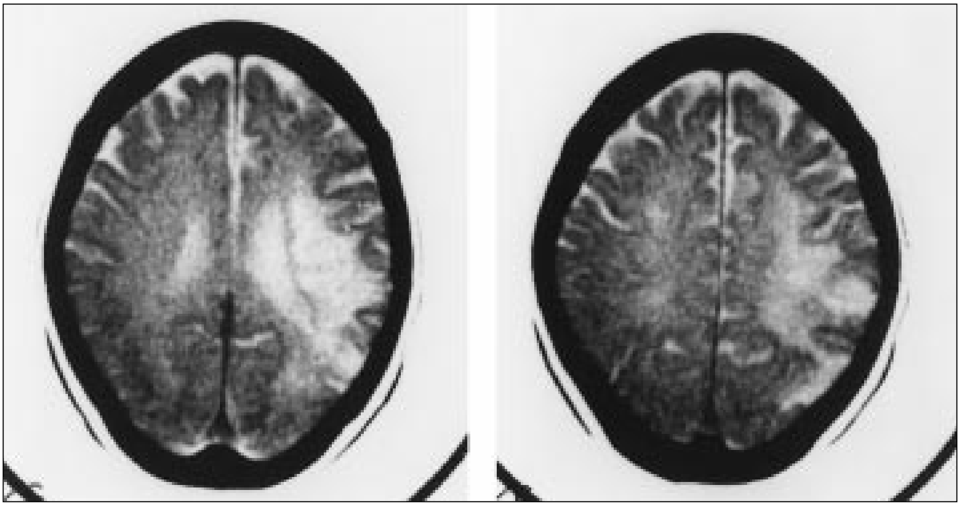

Fig. 1 – *Computed tomography showing NG's left parietal infarct.*

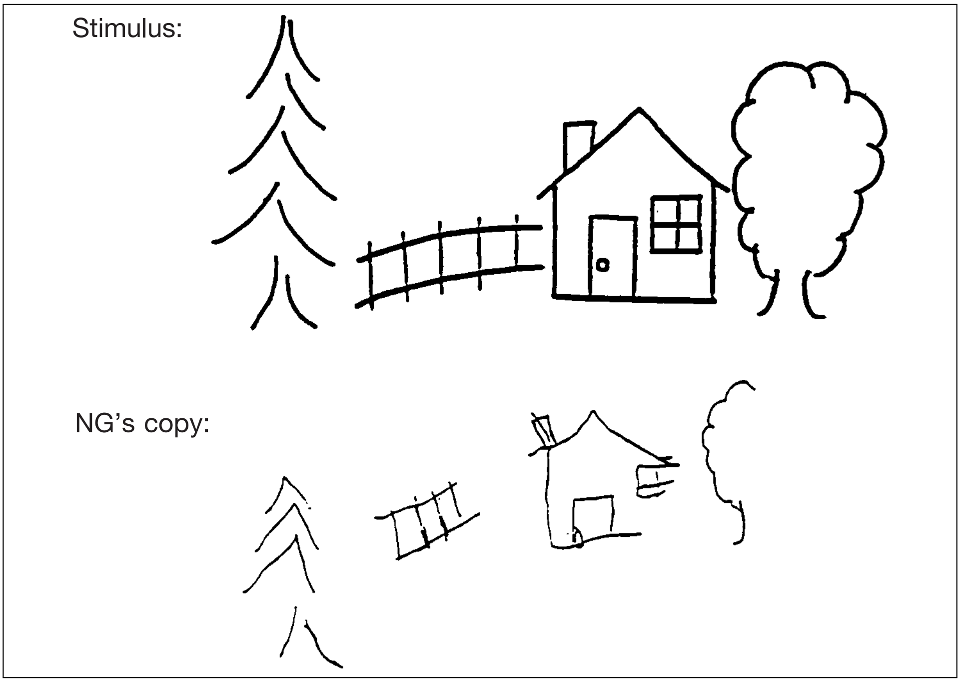

Fig. 2 – *NG's performance in copying.*

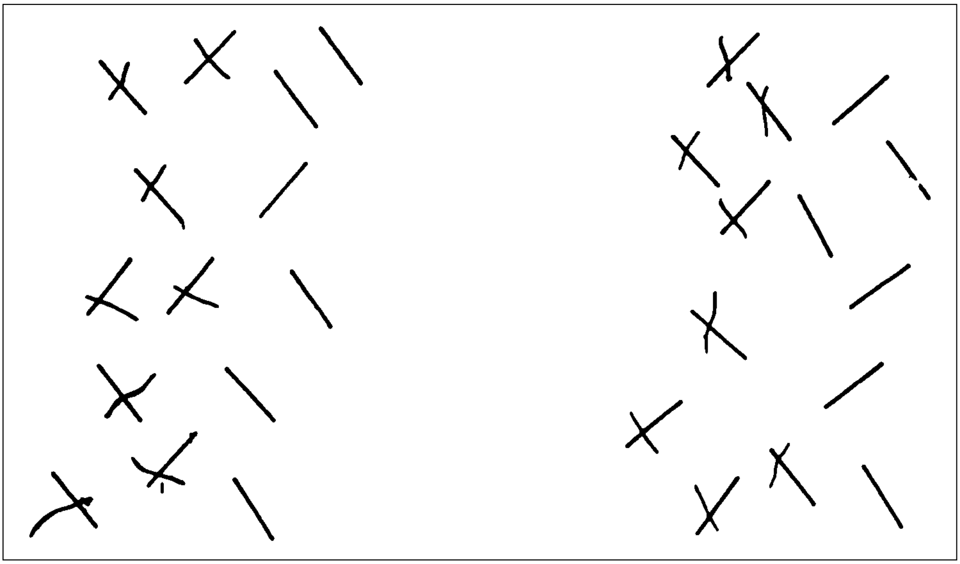

Fig. 3 – *NG's performance in line cancellation.*

Details of her performance in reading, spelling and nonlexical visual tasks, which remained remarkably stable between previous studies and the current one, are reported in Hillis and Caramazza (1990) and in Caramazza and Hillis (1990a, 1990b).

Materials and Methods

We developed a series of tasks to determine if NG's probability of detecting a target on the neglected (right) side of a stimulus presented in a particular location could be influenced by modifying the size of space in which she expected target stimuli. In all of the tasks, described individually for each experiment, NG was asked to fixate on a cross presented in the center of the screen before each trial. She was told that a circle would appear in each trial and was instructed to hit the spacebar if there was a gap anywhere in the circle. If the circle was complete she was not to make any response. Sizes and positions of the circle were varied across blocks of trials, as described below.

NG was tested in 1 to 2 hour sessions, up to 3 times per week, as an outpatient. She was tested in these experiments over a period of 2 months, during which her performance remained stable. The experiments were conducted on an IBM PS2/50 computer. NG was seated directly in front of a computer monitor at eye level. Eye movements were recorded by videocamera facing NG, with a grid behind her head to measure the angle of any eye movements. NG made no detectable eye movements after fixation in any of the experimental trials recorded.

Experiment 1

Changing the Size of the Attentional Window by Presenting Circles in Varied Locations

Procedures

In this experiment, the stimulus circle was always 45 mm in diameter, and the gap comprised 20 degrees of the circle on the right or left side. In all 3 types of blocks, 50% of the stimuli in each position contained a gap (25% of stimuli had gaps on the right, 25%

had gaps on the left). In Block Type 1 the circle always appeared in the center of the screen for blocks of 40 trials each. In Block Type 2 the circle appeared randomly on the left or the right (20 trials on each side). In Block Type 3, the circle appeared randomly on the left, on the right, or in the center (positions were the same as those in trial types 1 and 2); 20 trials in each position were run for a total of 60 trials per block. The left-most point of the circles presented in the center, and the right-most point of circles on the left, were presented 22.5 mm to the left of the fixation point. Also, the right-most point of the central circles and the left-most point of circles on the right were presented 22.5 mm to the right of fixation. The circles were presented for 200 msec. The inter-trial interval was 2000 msec. The set of 3 blocks was repeated, so that she completed 2 to 3 sets each session for a total of 10 sets in 4 sessions (and an extra set of 20 trials of trial type 1 was run). Each block began with 8 practice trials, which were not scored, to ensure that she understood the task and knew where, and what types of, stimuli were to be presented.

Results

Error rates are shown in Table I. Several aspects of these data are notable. Irrespective of Block Type, NG failed to detect gaps on the right side of a circle presented in the center of the screen much more often than she failed to detect a gap on the left side of the circle (e.g., miss rate of 94% vs. 7%; $\chi^2 = 164$; d.f. =1; $p < .0001$; in Block Type 1). However, her miss rate on the right gap of central circles was much lower if circles were also presented to the left and the right in the same block (46% vs. 94%; $\chi^2 = 46.6$; d.f. =1;

TABLE I

NG's Error Rate as a Function of Location of Stimuli and Block Type

Block Type 1: Circles always presented in the center			
Position	Gap location	Miss rate (%)	N
Center	left	7	110
Center	right	94	110
		False-alarm rate (%)	
Center		0	220
Block Type 2: Circles presented randomly on the left or right			
Position	Gap location	Miss rate (%)	N
Left	left	0	50
Left	right	0	50
Right	left	54	50
Right	right	94	50
		False-alarm rate (%)	
Left		4	100
Right		1	100
Block Type 3: Circles presented randomly on the left, on the right, or in the center			
Position	Gap location	Miss rate (%)	N
Left	left	2	50
Left	right	0	50
Center	left	2	50
Center	right	46	50
Right	left	50	50
Right	right	88	50
		False-alarm rate (%)	
Left		1	100
Center		0	100
Right		1	100

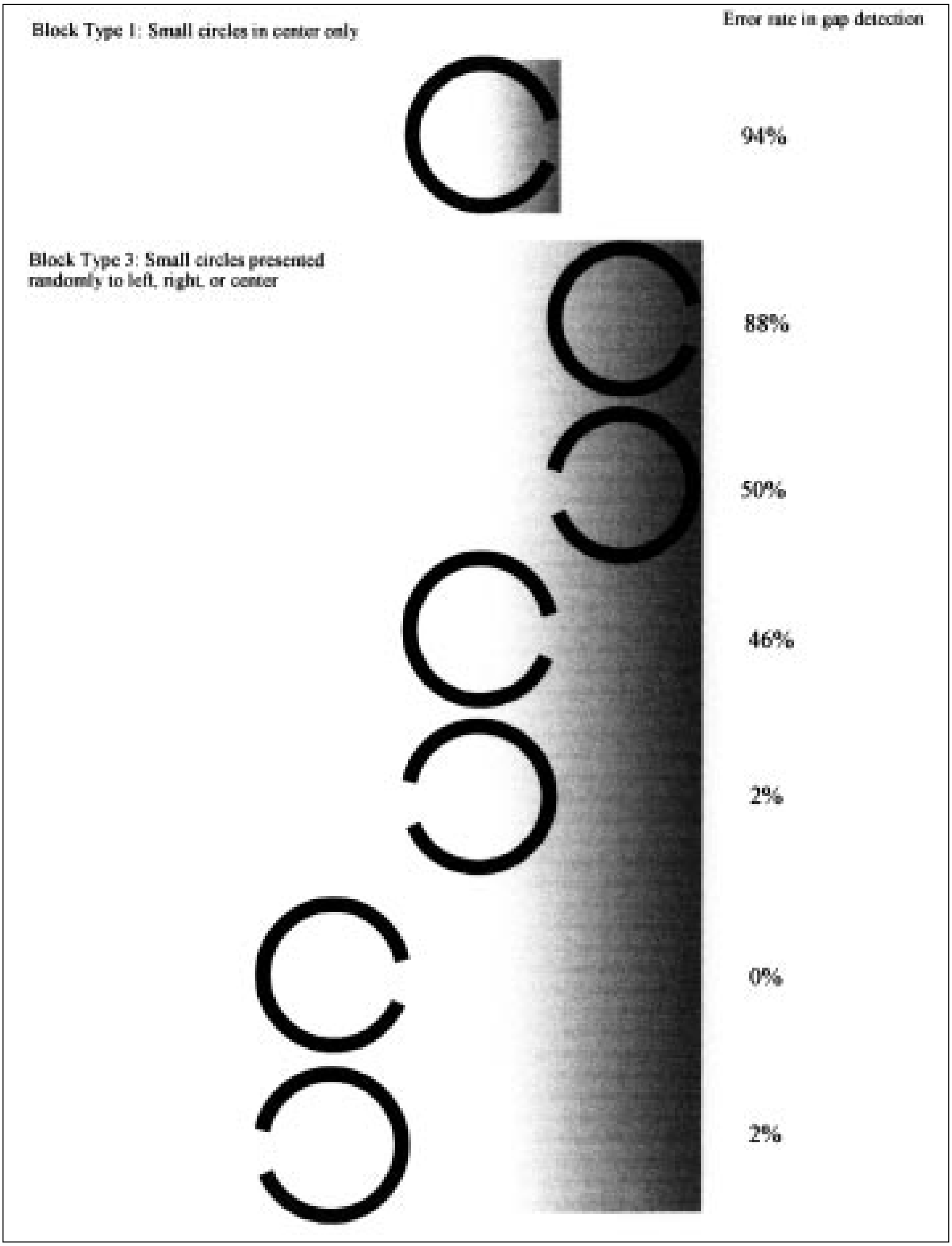

Fig. 4 – *A schematic representation of NG's error rates in gap detection in Experiment 1 as a function of the density of neglect, which increases from the center to the right in the space in which stimuli are presented in a given Block Type. The shading represents the proposed gradient of hemispatial neglect across the "window of attention" which varies with expectations of the different Block Types. The top panel shows that in Block Type 1, all circles were presented in the same place, so the right gap in the central circle appears on the "edge" of the window of spatial attention, where neglect is most dense. The bottom panel shows that in Block Type 3, circles were presented randomly on the right, center, or left, so that the right gap in the central circle appears closer to the center of the window of spatial attention, where neglect is less dense.*

$p < .0001$; in Block Types 3 and 1, respectively). The fact that NG's accuracy was *higher* on central circles when they were mixed with other circles is remarkable, because in most circumstances increasing the stimulus uncertainty (the types or locations of stimuli) *lowers* performance (Garner, 1962). One possible basis for NG's improved performance in detecting right-sided gaps in central circles in Block Type 3 is that her "attention" was shifted to the right by preceding stimuli on the right side of the screen. However, this cannot be the entire explanation. Even when the central circle was preceded by 2 or more circles on the *left*, her error rate on these stimuli was lower (56%) than when only central circles were presented (56% vs. 94% errors; $\chi^2 = 25.0$; d.f. =1; $p < .0001$). Furthermore, NG's miss rate on the right gap of the central circle in Block Type 3 was not significantly influenced by the position of the circle in the preceding trial. Her miss rate on these gaps was 44% if preceded by a left circle, 63% if preceded by a central circle, and 31% if presented by a right circle ($\chi^2 = 3.17$; d.f. =1; n.s.).

A second result is worth noting in Block Type 3: NG' miss rate at a given position on the screen (say, 22.5 mm to the right of the fixation point) was essentially identical whether this gap occurred on the right side of a circle presented in the center (46% misses) or on the left side of a circle presented on the right (50% misses; $\chi^2 = 0.16$; d.f. =1; n.s.), indicating that her error rate was determined by the distance to the right from the center of the space to which she was attending. Her rate of "false alarms" (erroneous responses when there was no gap) was very low in all types of blocks.

These results are consistent with the hypothesis that NG's neglect increased as a function of the distance to the right of the center of the space in which stimuli were presented. When circles were presented (and expected) only in the center of the screen (Block Type 1), the space to which she was directing attention was confined to the center of the screen, the area in which the central circles were presented. Thus, the gap on the right side of the central circle was on the right "edge" or most neglected part of the space. When circles were presented on the left and right, as well as center, of the screen (Block Type 3), the space to which she was attending was larger, covering all locations in which stimuli were presented. In these blocks, the right-sided gap in the central circle was closer to the center of attended space, where neglect was "less dense". These results can be explained by proposing that there is a modifiable window of spatial attention, which in this task corresponds to a space on the screen in which stimuli are expected, as defined by the practice block preceding the experimental block. The fact that NG's error rate increased further to the right of this space (see Figure 4) indicates that there is a gradient of impairment (hemispatial neglect) in this attentional window.

Experiment 2

Changing the Size of the Window of Attention by Varying the Size of the Stimuli

Procedures

In this experiment, all circles were presented in the center of the screen. In Block Type 1 only large circles (85 mm) were presented; in Block Type 2 only small circles (45 mm) were presented, and in Block Type 3 either a small or a large circle was presented randomly each trial. Again, 50% of the circles contained a gap (25% of stimuli had gaps on the right, 25% on the left, determined randomly), and 50% contained no gap. The small circles in experiment 2 (Block Types 2 and 3) were identical to the central circles in Experiment 1. The left-most point of and right-most point of each small circle were 22.5 mm from the fixation point. The left-most point of and right-most point of each large circle were 42.5 mm from the fixation point. The circles were presented for 200 msec. The inter-trial interval was 2000 msec.

Results

NG's error rates are reported in Table II. There were two main findings. First, NG consistently (> 90% of the time) failed to detect a gap on the right side of the circle (but

TABLE II

NG's Error Rate as a Function of Size of Stimuli in Eeach Block

Size	Gap location	Miss rate (%)	N
Block Type 1: Large circles (all presented in the center)			
Large	left	0	84
Large	right	98	84
		False-alarm rate (%)	
Large		0	160
Block Type 2: Small circles			
Size	Gap location	Miss rate (%)	N
Small	left	0	86
Small	right	92	86
		False-alarm rate (%)	
Small		2	172
Block Type 3: Large or small circles (presented randomly)			
Size	Gap location	Miss rate (%)	N
Large	left	0	70
Large	right	99	70
Small	left	0	70
Small	right	60	70
		False-alarm rate (%)	
Large		0	140
Small		0	140

never failed to detect a gap on the left of the circle), whether the circle was small or large, when all circles in the block were the same size. However, when small circles were presented on some trials and large circles on other trials within the block, her miss rate on the right side of the small circles was much lower (60% vs. 92% for the *same* stimuli, presented in block 1 vs. block 3; χ^2 = 22.5; d.f. =1; $p < .0001$). Again, NG's performance improved, despite the increased stimulus uncertainty. These results provide further evidence for a variable-sized window of attention and for a gradient of hemispatial neglect, increasing from the center to the right side of the space covered by any of the stimuli in the block. That is, for any block, neglect was very dense on the far right of the largest space covered by stimuli in that block, so that NG missed nearly all gaps presented on the far right of that space. However, neglect was less dense toward the center of that space. So, in blocks where both small and large circles were presented, the space covered by the stimuli was the size of the large circles. When the gap was on the right side of a large circle, it was on the far right of the space, and so it was nearly always missed. When the gap was on the right of a small circle, it was closer to the center of that space, and so it was detected 40% of the time (see Figure 5). Therefore, the largest stimulus in the block and the preceding practice block defined the "window of attention" for this task.

Conclusions and Discussion

NG's performance in gap detection allows two conclusions about normal and impaired spatial attention. First, subjects can modify the size of space to which they attend in a given task, on the basis of expectations about where stimuli are likely to appear. When targets are expected only in a small area of space, subjects can "zoom in" on that area. When targets are expected in a broader area, attention can "zoom out" to cover a larger window of space. This conclusion fits with intuitive experience of attention (Halligan and Marshall, 1994b)

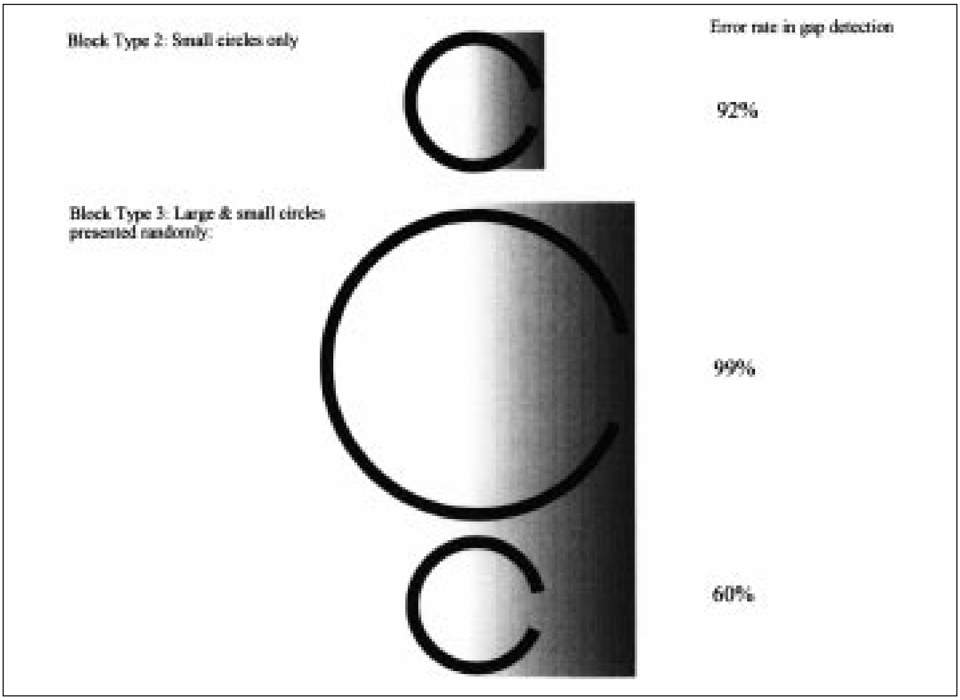

Fig. 5 – *A schematic representation of NG's error rates in gap detection in Experiment 2 as a function of the density of neglect, which increases from the center to the right in the space in which stimuli are presented in a given Block Type. The shading represents the proposed gradient of hemispatial neglect across the "window of attention" which varies with expectations of the different Block Types. The top panel shows that in Block Type 2, only small circles were presented, so the right gap in the small circle appears on the "edge" of the window of spatial attention, where neglect is most dense. The bottom panel shows that in Block Type 3, both small and large circles were presented randomly, so that the right gap in the small circle appears closer to the center of the window of spatial attention, where neglect is less dense.*

and with data from normal subjects showing that subjects can attend to a wide space with relatively low resolution of detail or a narrow space with relatively high resolution of detail (Eriksen and St. James, 1986; Johnston and Dark, 1986). It is also consistent with recent evidence from single cell recordings in monkeys, showing that distinct populations of neurons in the parietal cortex each respond to a part of visual space defined by different coordinates, and that their responsiveness is enhanced by tasks that demand allocation of attention to that part of space (Colby, Duhamel and Goldberg, 1996; Andersen, Snyder, Bradley et al., 1997) . Our data show that this ability to modify the attentional window can be spared in the face of hemispatial neglect, and thus constrains the nature of the attentional impairment.

It has frequently been reported that the presence of "cues" or additions to the visual stimulus that remain in the visual field (e.g., a colored dot on one side or a vertical line on one side of a line to be bisected; e.g., Halligan and Marshall, 1994a) can modify hemispatial neglect, perhaps by enlarging the "window of attention". This study provides evidence that preceding stimuli *that are no longer present in the visual field* can also enlarge the attentional window. However, not all patients with hemispatial neglect are able to widen the attentional window to improve responsiveness to a given stimulus. For example, Halligan and Marshall (1993) reported that their patient with left hemispatial neglect, RB, was able to "zoom out" attention to a page in order to mark its corners, or "zoom out" attention to an array of lines to name the color of each line, but having done so did not improve his performance in subsequently canceling each line in the array. That is, “panoramic cueing” to the full extent of the visual display did not improve RB’s performance on the task. In contrast, widening the extent of the display on previous trials within a block of trials resulted in “zooming out” of NG’s attention during the entire block, effecting improved responsiveness to the right (neglected) side of small, centrally-located circles.

These contrasting results between patients underscore the heterogeneity of deficits that comprise the clinical syndrome of hemispatial neglect. In fact, we have found that many patients, most of whom have left hemispatial neglect due to right hemisphere stroke, do not show the effects demonstrated by NG in these same experiments. That is, they do not reliably show improved performance on the small, central circles when preceding trials in the same block involve a display with a wider spatial extent. NG’s performance, then, provides unique evidence that the ability to modify the attentional window, and maintain the modification across trials, can be spared in the face of persistent hemispatial neglect.

The second conclusion to be drawn from NG’s performance is that damage to the non-dominant parietal lobe can result in a *gradient* of impaired attention (hemispatial neglect), such that neglect is least severe at the center of the attentional window, and most severe at the edge of the attentional window on the side contralateral to brain damage. The proposal of a gradient of hemispatial neglect also draws support from studies of hemispatial neglect patients whose errors at particular letter positions in reading or spelling words increase as a function of the distance of the letter from the center of the word to the neglected side (Baxter and Warrington, 1983; Warrington, 1981; Hillis and Caramazza, 1995) or whose errors in crossing out targets in an array increase linearly from the non-neglected to the neglected side (Halligan, Burn, Marshall et al., 1992), or whose errors in responding to transient targets appearing in boxes on the left, center, or right increase toward the neglected side (Ladavas, 1990). Together, these results challenge the view that hemispatial neglect is always defined by the absolute distance from the center of the viewer and/or the environment (Farah, Brunn, Wong et al., 1990).

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Argye Hillis, M.D., Department of Neurology, Meyer 2-222, Johns Hopkins Hospital, 600 North Wolfe Street, Baltimore, MD 21287, U.S.A. E-mail: argye@JHMI.edu

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