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Object-Centered Not Scene-Based Visual Neglect

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Whether visuospatial attention accesses object-centered representations, in addition to location-based coordinates, was investigated in patients with hemispatial neglect who detected a target on the left or right of a single object (2 connected circles or barbell) or of 2 objects (2 unconnected circles). The object or objects either remained static (left circle in left space) or rotated by 180° (left circle now in right space). Relative to the static condition, in the rotating condition, detection times are facilitated on the left (contralateral) and inhibited on the right (ipsilateral) of space even when eye movements are controlled. This modulation of neglect was only observed for the single object, but not for the 2-object displays. The findings suggest that attention operates on object-centered as well as on location-based representations, and thus accesses multiple reference frames.

A basic question that one can ask regarding visual attention concerns the medium in which it functions. That is, what kinds of internal representations do the mechanisms of attention process? A widely accepted view has been that attention is analogous to a spotlight that moves through space. This spotlight moves from one location to another selecting particular regions of space and objects within these selected regions receive processing beyond basic perceptual analysis (e.g., Broadbent, 1982; Eriksen & St. James, 1986; Posner, 1980). That is, the functioning of the attentional system is deemed to be determined solely by spatial information and to be unaffected by the objects in a scene.

Recently, however, the view that the representation on which selective attention operates is purely spatial and that space has a unique role for visual attention has been questioned. Increasing evidence from studies with normal (not brain damaged) participants (e.g., Driver & Baylis, 1989; Duncan, 1984; Egly, Driver, & Rafal, 1994; Gibson & Egeth, 1994; Kanwisher & Driver, 1992) and with brain-damaged patients (Behrmann & Moscovitch, 1994; Caramazza & Hillis, 1990; Driver & Halligan, 1991) suggests that attention can operate on object- as well as on location-based representations and that accessing one representation rather than another may be a function of task demands (Vecera & Farah, 1994).

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When considering the behavioral function subserved by selective attention, it becomes clear that it might well have evolved to link the essentially parallel processes of the perceptual system, which creates internal representations of various objects in the environment, with the serial processes of the system that enable action to be directed toward particular objects (e.g., Tipper, Lortie, & Baylis, 1992). That is, whereas vision appears to be able to process information in parallel, action can usually be directed toward only one object at a time. For example, we can say only a single word or drink from one glass at any one time. The role of attention, therefore, is to constrain the perceptual information that controls action. In this way, attention ensures that actions are directed toward particular objects in cluttered environments so that the requisite behavioral goals can be achieved (Allport, 1987, 1989).

The important point here is that, in such a perspective, attention would be most concerned with accessing representations of the objects toward which actions were to be directed. Simple spatial models of attention do not appear to be able to account for many real-world perceptual–motor interactions. For example, when searching the environment for a particular object, inhibition of the return (IOR) of attention ensures that new locations are examined, avoiding the perseveration of attention to recently examined locations (Posner & Cohen, 1984). On this account, attention is inhibited from returning to a location recently examined. However, as Tipper, Driver, and Weaver (1991) and Tipper, Weaver, Jerreat, and Burak (1994) have pointed out, although such a mechanism would enable efficient search for static objects, it would have problems finding moving objects. If representations defined solely by space are used to guide and inhibit search behavior, a mobile object might be searched on more than one occasion because it would have moved from the inhibited location. A much more efficient search mechanism would also associate inhibition with objects, not just with space. Thus, as the object moved from one location to another, it would take its inhibition with it.

Such a mechanism would be particularly efficient and would prevent the same object from being attended repeatedly, irrespective of its spatial location.

In a series of studies, Tipper and his colleagues have demonstrated that inhibition can be associated with an object as it moves through space (Tipper et al., 1991, 1994; see also Abrams & Dobkins, 1994; Gibson & Egeth, 1994) even if the object itself was initially ignored (Tipper, Brehaut, & Driver, 1990). Just as inhibition can accompany a moving object, so can selective attention. For example, in a series of experiments, Kahneman, Treisman, and Gibbs (1992) showed that attention deployed to an object prior to motion can be carried along with the object, facilitating its processing in a subsequent novel spatial location (see Treisman & DeSchepper, 1994, for related work).

Further support for the claim that attention can be directed in coordinates defined by the object itself and can accompany the moving object comes from a recent study by Umiltà, Castiello, Fontana, and Vestri (1995) who precued participants to a single vertex of a two-dimensional drawing that is perceived as a three-dimensional cube. In the critical condition, following the precue, the cube rotated and a target then appeared either in the originally cued spatial location (i.e., location-based coordinates), or in the cued vertex of the cube that now occupied a different spatial location (i.e., object-centered coordinates). Interestingly, facilitation in target detection was not only observed when physical location was shared between cue and target, but also when the target appeared in the precued vertex defined in object-centered but not location-based coordinates. These findings are consistent with the claim that attention can be deployed not only to spatially defined locations but also to regions defined by the boundaries of an object.

Given that mechanisms of attention and inhibition can move dynamically with an object rather than remaining tied to a particular spatial location, Behrmann and Tipper (1994) studied the performance of participants with an impairment in spatial attention following brain damage and investigated whether the deficit remains fixed in spatial coordinates or whether it can also be associated with moving objects. This deficit, known as unilateral or hemispatial neglect, is characterized by the patient's failure to respond or orient to information on the side contralateral to the brain lesion. In surveying the environment, patients with hemineglect following a right-hemisphere lesion do not notice objects on the left; in reading, they may ignore the left side of a page or even the left half of a word; in eating, they may leave the food on the left side of the plate untouched; and in personal care, they may not shave or bathe the left side of their body. This contralateral neglect occurs more frequently following a right-hemisphere lesion than the converse (hence, we will refer only to left-sided neglect) and is generally interpreted as a failure in the distribution of attention to the side of space opposite the lesion (see Bisiach, 1993; Bisiach & Vallar, 1988; Halligan & Marshall, 1993, for overview; Posner, Walker, Friedrich, & Rafal, 1984). The question is, when these patients fail to attend to information on the left side, with respect to what spatial coordinates or reference frame or frames are left and right defined? The answer to this question may shed light on the nature of the internal representations accessed by attention.

In the experimental task used by Behrmann and Tipper (1994), participants were presented with a display containing, for example, a blue circle on the left and a red circle on the right. These two circles were connected with a solid horizontal bar, forming a barbell (see first display in Figure 1A, for illustration of the stimulus). In one condition, the *static* condition, after some delay, on two-thirds of the trials a target appeared in the center of one of the two circles, and the participants performed a presence or absence detection judgment. In the second condition, the *moving* condition, the barbell display appeared on the screen and then revolved slowly by 180° around its central midpoint, in either a clockwise or a counterclockwise direction. Participants watched the rotation. The crucial point is that, when the rotation was terminated, the two circles had switched positions such that the side of space and side of barbell were set in opposition (see latter two illustrations in Figure 1, Panel A). Following the rotation, therefore, the final position or end state of the circle on the original left of the barbell was on the right of space, and the circle on the original right of the barbell was on the left of space. When the rotation was terminated, on two-thirds of the trials, a target appeared either on the left (right of object) or right (left of object) side of space. Detection time in the moving condition was compared to that in the static condition.

Behrmann and Tipper (1994) reasoned that if attention could access object-centered representations, then detection of targets on the right side of space might be inhibited in the moving condition relative to the static condition as the poorly attended left side of the object now occupied the ipsilateral right side of space. Similarly, detection of targets on the left side of space might be facilitated in the moving condition relative to the static condition because the well-attended right side of the object now occupies the neglected contralateral, left side of space. In this way, through object motion, the patient's processing of information on the left side of space might be ameliorated, and the previously normal processing of information on the right side of space might be impeded. This left-sided facilitation and right-sided inhibition in the moving condition, relative to a static baseline condition, are precisely what was observed in the neglect patients, leading Behrmann and Tipper to interpret these findings as favoring a view in which attention and neglect may be directed to object-centered representations.

Although the results from this study were relatively straightforward, two concerns about these findings remain unanswered. The first is a possible methodological artifact that could account for the data. In this experiment, although the patients were trained to maintain central fixation, and were generally good at doing so from informal observation, there was no guarantee that they did so throughout the experiment. Because eye movements were not monitored systematically, there is no way of verifying the extent to which fixation was truly maintained. It is possible, therefore, that when the barbell display initially appeared, because of the neglect for the contralateral, left side of space, the participants fixated the right side of the barbell that

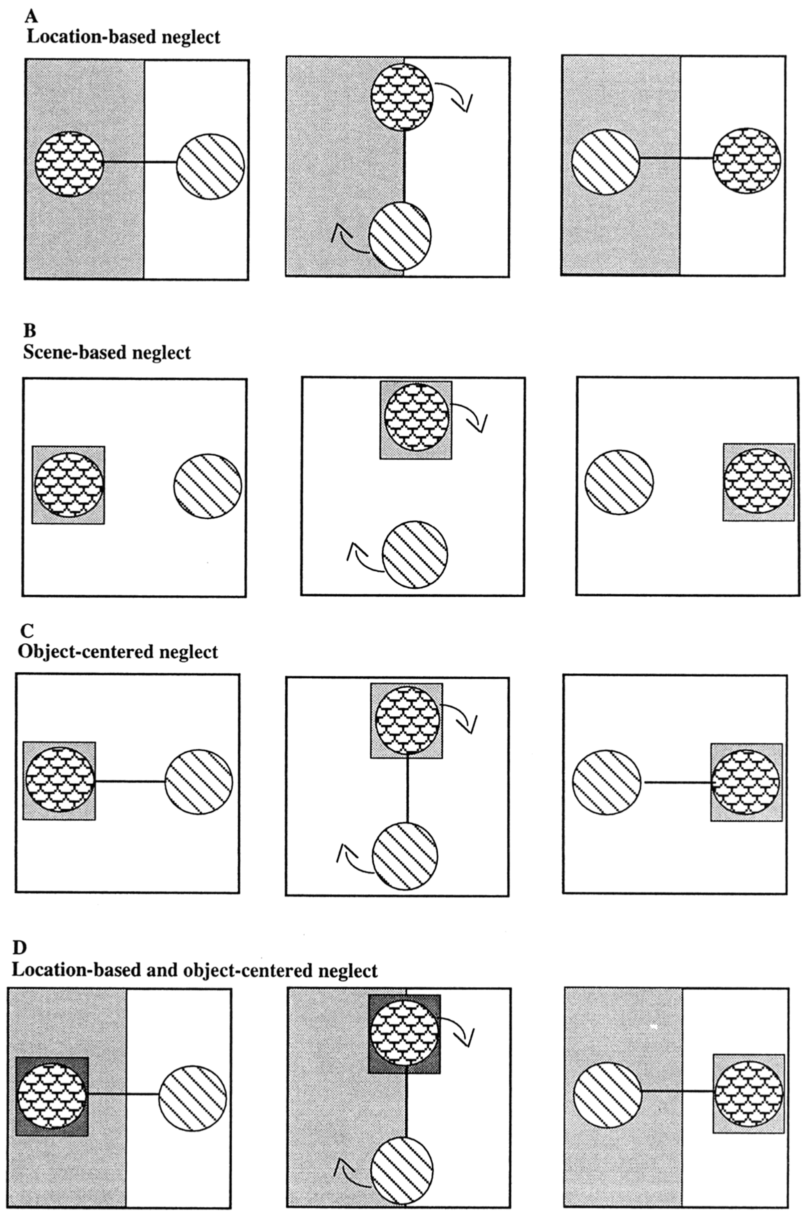

Figure 1. Schematic illustration of the impact of left-sided neglect in the rotating object or objects condition. In each column, the three pictures, respectively, show the perceived barbell prior to rotation, through the rotation, and when the rotation is terminated. Left and right are defined according to (A) location-based coordinates, (B) scene-based coordinates, (C) object-centered coordinates, and (D) location- and object-centered coordinates. The shaded area reflects the part of the display neglected by the patients under the different hypotheses.

appeared in the right side of space. When the barbell began to rotate, fixation may have remained on the right side of the object with the result that the eyes moved along and tracked the object through its 180° rotation. Consequently, when the target now appeared in the left of space, albeit on the right of the object, participants were fixating (and attending) that location, leading to efficient detection of the target. On this same account, targets appearing on the right of space (the left of the object) would have been farther from fixation, and hence their detection would have been impaired. According to this view, the facilitation for targets on the left of space and inhibition for targets on the right of space are not a result of object-centered processing per se, as claimed by Behrmann and Tipper (1994) but, rather, arise from precuing of overt attention through eye movements (Posner, 1980). Whether an eye movement or an object-centered interpretation accounts for this pattern of results is one of the central foci of this article. To address this, the original experiment is replicated with patients with neglect but, in this case, eye movements are controlled.

The second focus of this article is more theoretical and concerns the nature of the representations mediating the neglect behavior. Although the two circles of the barbell display were connected by a bar, making it a contiguous and unitary object, it is possible that the participants might have represented the two circles of the barbell as separate and independent objects. That is, the two circles of the barbell might have been coded in terms of a description of the spatial relationships between separate objects in a scene—we refer to this as a *scene-based* description (see Baylis & Driver, 1993; Kahneman et al., 1992). Some evidence supporting the scene-based or "stimulus-centered" spatial reference frame comes from a study of a patient with neglect who was asked to report the identity of a single letter in a visual filtering task (Arguin & Bub, 1993). The single letter was present on every trial and could appear in any one of four possible horizontal positions. The other three positions were occupied by distractors (filled circles). Moreover, the position of the entire display of four items varied across the eight possible locations relative to the environment (computer screen) with, at the end extremes, the most right-hand or left-hand item occupying the fixation position and the remaining items falling to the left or right of fixation, respectively. Speed of letter report was measured. The results showed increased slowing of letter report with leftward target placements (out of the four possible positions) defined relative to the midline of the display of four items, and this did not interact with the absolute location occupied by the horizontal array on the screen itself. The neglect for left-sided letters in a scene or array of separable items provides support for the notion that objects on the left of a display are processed less well than those occupying the relative rightward positions. If attention accesses such a scene-based description, and if the individual objects move and are accompanied by the amount of attention originally distributed to them, then the interpretation of the Behrmann and Tipper (1994) result is as follows: The inhibition of targets on the ipsilateral, right side of space in the moving barbell condition is attributed to neglect of the complete left circle, which is also the left object. Similarly, facilitation of targets on the contralateral, left side of space is attributed to enhancement from the complete right circle or right object, which rotated into the left side of space.

An alternative interpretation of the findings, and one proposed by Behrmann and Tipper (1994), was that attention accesses an object-centered representation. That is, the barbell was represented as a single connected object with the two circles forming the left and right sides of a single, continuous object. On this account, then, the observed facilitation and inhibition in target detection arise from an object-centered description, in which the structural description of the spatial relationships between the objects' component parts is computed (see, for example, Marr, 1982; Pinker, 1984; Rock, 1973; also see Gibson & Egeth, 1994, for discussion of terminology). In the original Behrmann and Tipper study, we assumed that neglect was object centered, and that, as the contralesional side of the object rotated, it took its neglect along with it, inhibiting performance in ipsilateral space and facilitating performance in contralateral space. Of course, it could also be the case that a contralateral object (the left circle), perceived as separate from other objects in the image, would also take its neglect with it as it moves into the ipsilateral side of space and the original experiment cannot exclude this possible scene-based interpretation. At this stage, therefore, we do not know whether the reversal of neglect from contralateral to ipsilateral sides of space with object motion is achieved because of a scene-based representation or because of an object-centered representation.

Although object-centered and scene-based representations are proposed as alternative hypotheses, they need not be mutually exclusive (Hinton, 1981), and the view that performance might be subserved by representations defined according to more than one reference frame is supported by several recent research findings. For example, IOR (Gibson & Egeth, 1994; Tipper et al., 1994) and negative priming (Sears, Schmidt, & Pylyshyn, 1995) have been observed in both location-based and scene-based representations simultaneously. Concurrent facilitation in both location-based and object-centered representations is also reported by Umiltà et al. (1995). The contribution of multiple reference frames to determining neglect has also been reported (Calvanio, Petrone, & Levine, 1987; Farah, Brunn, Wong, Wallace, & Carpenter, 1990; Làdavas, 1987) and the recent findings by Humphreys and Riddoch (1994, 1995) are particularly pertinent. Their patient, J.R., demonstrated a dissociation between object-centered and scene-based neglect. When reporting words from a page, J.R. omitted to report whole words from the right of the page (right scene-based neglect). In sharp contrast, when reporting one of the individual words on the page, J.R. neglected letters on the left of the word (left object-centered neglect).

The outstanding question, however, is in the case of object motion, what representation or representations are subserving the distribution of attention, and its impairment as manifested in neglect? To clarify this issue further, Figure 1 depicts potential frames of reference, all of which might subserve the deployment of attention, and it presents possible outcomes of neglect according to the nature of the representation being accessed. If attention accesses only location- or space-based representations, then there will be no difference in performance between the static and moving condition as neglect remains fixed to the background contralateral, left side of space. This is schematically depicted in Figure 1, Panel A by the shaded area in the figure, and neglect is unaffected by the presence of objects in the image. Evidence supporting the view that neglect is determined by allocentric coordinates defined by external space has been obtained in the studies by Farah et al. (1990) and by Làdavas (1987). If, however, the pattern of reaction times (RTs) changes in the moving condition relative to the static condition, this would suggest that attention is affected by the motion in the display and that representations other than or in addition to a location-based one are accessed. Thus, we might expect to see that RT to targets on the ipsilateral side of space in the moving condition would be inhibited relative to the static ipsilateral condition, and that RT to targets on the contralateral side of space would be facilitated relative to the static contralateral baseline (as attention from the good side of the object moves into the poor side of space). This result as demonstrated by Behrmann and Tipper (1994) is depicted in Figure 1 Panel C.

The critical question is whether this pattern of inhibition and facilitation holds for both the disconnected (Figure 1, Panel B) and connected (Figure 1, Panel C) displays. If the predicted facilitation and inhibition emerges only in the connected displays, in which a single object appears, but not in the disconnected display which contains two separate objects, this would suggest that attention accesses an object-centered but not a scene-based representation. If the converse holds true, the interpretation is reversed: Attention accesses only a scene-based but not an object-centered representation. By contrasting performance with the connected and disconnected display, we can adjudicate between the object-centered and scene-based interpretations.

The contrast between displays containing two separate circles with those where the circles are conjoined by a bar would seem to be a rather subtle manipulation. However, evidence from both normal individuals and neuropsychological patients attests to the difference in status between these two types of displays and suggests that this simple manipulation does indeed produce quite different internal representations. First, at a phenomenological level, participants clearly describe these two displays in quite different ways. Thus, in viewing the disconnected display, participants report a clear perception of two separate circles moving around the computer screen, whereas in viewing the connected display, participants report a perception of one coherent object revolving around its central point. Second, more objective evidence for a contrast between connected and disconnected displays emerges from studies of inhibition of return. Tipper and Weaver (in press) have examined object-based IOR in displays in which three moving squares were either disconnected and perceived as three separate objects or were connected by lines to form a single rotating triangle. Two contrasts between connected and disconnected displays were observed. First, there was a trend for IOR to be smaller in the connected display; and second, RT to detect very brief targets was faster in connected displays where attention moved within an object, than for disconnected displays, where attention moved between separate objects (see Baylis & Driver, 1993; Duncan, 1984; Kramer & Jacobson, 1991; Kramer & Watson, 1996, for converging evidence).

There is also some suggestion from neuropsychological studies that the extent to which elements are integrated into a unitary object affects performance. For example, Kartsounis and Warrington (1989) report a patient with visual neglect who correctly copied sets of overlapping shapes (such as the Olympic rings), but omitted copying all of the separate shapes even when they occupied the same spatial area. The advantage of an integrated object over its disparate parts has also been seen where it is more likely that patients report perceiving two forms, if the parts were connected by a line drawn between them than if the parts were not connected (Godwin-Austen, 1965; Luria, 1959). These findings are all consistent with the view that, under some circumstances, a representation of a coherent object affects performance differentially compared with a representation of the same display where the parts do not form a unitary entity.

The predictions spelled out above, however, all assume that the participants' performance is subserved by a single representation. If, for example, attention accesses only object-centered representations and neglect is entirely determined by the coordinates defined by the barbell, then, in the moving condition, when the left of the barbell moves into the right side of space and the right of the barbell moves into the left side of space, we would expect a complete reverse or flip of neglect from the contralateral to the ipsilateral side of space (Figure 1, Panel C). That is, detection would be significantly faster for targets on the left than it would be for targets on the right side of space. It is conceivable, as pointed out above, that attention might be operating on more than one representation at the same time. For example, if attention accesses both an object-centered representation as well as a location-based representation simultaneously, as depicted in Figure 1, Panel D, then we would not expect to see a total reversal of neglect but rather a modulation such that, relative to the static baseline condition, performance on the contralateral side might be facilitated and performance on the ipsilateral side might be inhibited. Because both object-based and location-based representations play a role, neglect does not simply follow the object and switch entirely from the left to the right side of space.

In this article, we report the results of two experiments, each designed to address one of the issues outlined above. In Experiment 1, we establish the nature of the representation accessed by attention and neglect and, in Experiment 2, we examine whether the obtained pattern of data is attributable to eye movements or not. To preview our findings: Taken together, the results from the two experiments support the notion that neglect is subserved by both location-based (Figure 1, Panel A) and object-centered (Figure 1, Panel C) frames of reference simultaneously, as depicted in Figure 1, Panel D. There is no evidence for neglect moving with separate objects represented in the scene-based frames of reference (Figure 1, Panel B). Finally, the pattern of results holds when fixation is controlled, suggesting that the findings are not simply an artifact of eye movements.

Experiment 1

The purpose of Experiment 1 is to use the same paradigm as that used by Behrmann and Tipper (1994) with patients with unilateral neglect, and to contrast their performance using displays in which the left and right circles in the display are connected or disconnected. These two types of display would allow us to differentiate between an explanation of an object-centered or a scene-based internal representation.

Method

Participants. The experiment was conducted with two groups of participants: elderly participants who served as the control group, and patients with left unilateral hemispatial neglect acquired following a lesion to the right hemisphere. The diagnosis of neglect was made on the basis of a standardized battery of bedside examinations (Black, Martin, Vu, & Szalai, 1990), which includes spontaneous drawing of a clock and a daisy, a line cancellation task (modified Albert's line cancellation task, 1973), the Bells test (Gauthier, Dehaut, & Joanette, 1989), and a line bisection task. In the line cancellation task, 21 lines, each 3.3 cm in length, appeared on a page, one in the center and 10 scattered randomly on each of the left and right sides. The participants were instructed to mark or check all the lines and the number of lines omitted per side was calculated. On the Bells test, 5 target bells in black silhouette appeared intermixed with 40 distractors in each of 7 predefined vertical columns (3 left, 1 center, 3 right), making a total of 35 bells and 240 distractors. The participants were required to circle the bells and the number of omission errors was counted for the left (n = 15), center (n = 5), and right (n = 15) sides (see Gauthier et al., 1989, for instructions). Finally, on the line bisection task, the participants were instructed to put a mark through the midline of the target horizontal line. In total, the participants bisected four lines, two longer lines of 19.4 cm in length, and two shorter lines of 15.2 cm in length. The mean percentage of deviation is calculated with a positive number reflecting rightward deviation and left-sided neglect. The total neglect score, cumulative across all the screening tests, is 85 and a score exceeding eight reflects neglect, with higher scores denoting increased severity (Black et al., 1990).

The 8 elderly control participants (6 women, 2 men) who consented to take part in this study were recruited from the subject pool at the Rotman Research Institute of Baycrest Center, Toronto, Canada. All participants were right handed, none had a previous history of neurological illness, and none showed neglect on the diagnostic tests. The mean age and years of education of the participants was 67 (SD = 2.7) and 12 (SD = 1.6), respectively. To minimize testing, a between-group analysis was carried out comparing the performance of these 8 participants (who completed the experiment only with the disconnected displays) with the 13 elderly control participants from the original Behrmann and Tipper (1994) study (who completed the experiment with the connected displays). The current participants were chosen using the same criteria as those used to select the original participants, and the age and education level of the two elderly groups did not differ, age, $F(1, 19) = .43, p > .5$; education, $F(1, 19) = 1.13, p > .3$.

The experimental group consisted of 7 patients with unilateral left neglect, three of whom had participated in the original Behrmann and Tipper (1994) study. All patients were right handed, none was hemiplegic, and all showed neglect on the screening battery. The three original patients, labeled as Patients 1, 2, and 3 here, are identified in that study by their initials, E.T., F.R., and H.R.; their biographical and lesion details are included in Table 1. Data from the neglect screening battery are provided for these participants at the time of the original testing in 1992 as well as at the time of the testing for the current experiment. As is evident, all three patients still showed neglect at the second testing although some slight but not significant improvement is evident in their performance. Background information for the four new patients, R.H., A.B., J.M., and R.B., labeled Patients 4–7, are also included in Table 1. All patients had lesions involving the right parietal lobe, and with the exception of Patients 4 and 7 who had undergone surgery for a middle cerebral artery aneurysm, had suffered from infarctions of the middle cerebral artery. All patients scored beyond the normal cutoff of 8 points on the bedside screening, although the severity of their left-sided neglect varied as is evident from the scores in Table 1.

Table 1
Biographical Details and Neglect Scores for the Patients

	Original participants[a]			Current participants			
Patient data	1 (E.T.)	2 (F.R.)	3 (H.R.)	4 (R.H.)	5 (A.B.)	6 (J.M.)	7 (R.B.)
Age	76	80	75	63	64	49	62
Sex	Female	Male	Male	Female	Male	Male	Male
Years of education	12	13	10	10	19	17	11
Months since onset	22	54	78	20	27	19	15
Lesion site (CT scan)	F-P	F-T-P	F-T-O	P-T-O	P-T-O	P-T	P
Lesion type	Infarct	Infarct	Infarct	Aneurysm	Infarct	Infarct	Aneurysm
Neglect scores							
Line cancellation omissions (left/right)	0/0	10/2	0/0	0/0	9/0	0/0	3/1
Figure cancel (left/right)	6/0	4/1	9/1	8/0	9/0	7/2	14/0
Bells test, omissions (left/center/right)	8/0/1	15/5/4	15/0/0	7/0/2	1/0/2	2/0/1	15/5/2
Line bisection (%)	31	62	44	17	28	32	4
Previous neglect scores							
Line cancellation omissions (left/right)	0/0	10/2	0/0	—	—	—	—
Figure cancel (left/right)	8/0	9/0	7/2	—	—	—	—
Bells test, omissions (left/center/right)	11/1/2	14/5/2	13/0/0	—	—	—	—
Line bisection (%)	24	62	44	—	—	—	—

Note. F = frontal, P = parietal, T = temporal, O = occipital; E.T., F.R., H.R., R.H., A.B., J.M., and R.B. are initials for Participants 1–7, respectively. Dashes indicate where data are not relevant.
[a] Data from the initial and the current neglect testing are included.

Stimuli. Two circles, 2.5 cm in diameter, drawn with a black border, one colored blue and one colored red, appeared on a computer screen, positioned 8 cm apart. The two colors are necessary to disambiguate the sides of the object and the side on which the blue and red appears is counterbalanced across participants. In the connected stimulus display, the edges of the circles were joined by an 8-cm long black horizontal bar, producing a single barbell. In the disconnected stimulus display, the stimulus was identical to the connected display, except that no connecting bar was present. The full horizontal extent of both displays was 13 cm and the visual angle subtended by the stimulus was 12° with the participant seated approximately 40 cm from the screen. The target, a single white circle, was 0.75 cm in diameter.

Procedure. Stimulus presentation and response recording were controlled by an IBM 486 PC and a 15-in. color monitor. The connected and disconnected displays both appeared in two conditions, either static or moving. In both conditions, the phrase "Press start key" appeared in the center of the screen. The experimenter pressed the key when the participant was ready, and immediately thereafter, the stimulus appeared on the screen. In the static condition, the stimulus was presented, remained stationary and then, after a delay of 2.7 s, on two-thirds of the trials, the white circular target appeared in either the left or right circle with equal probability (the target-present trials). The target and barbell remained on the screen together until a key was pressed or for an additional 3 s if there was no response. On the remaining one-third of the trials, no target appeared and the stimulus remained on the screen for an additional 3 s before the trial was terminated (the target-absent trials). Participants were instructed to press a single, centrally placed key on a button box as quickly and accurately as possible when they detected the presence of the target. They were not to respond on target-absent trials. Participants responded with their dominant right hand (no patient was hemiparetic on the dominant side). RT and accuracy to detect the target were measured. Both omission and commission errors were noted and feedback, consisting of an auditory tone, was provided to the participant when an error of either kind occurred.

In the moving condition, the stimulus appeared on the screen, remained stationary for 1 s after which it underwent a 180° rotation (pivoting on the center of the bar), traversing 16 intermediate positions and giving rise to the perception of apparent motion. Each position was held for 106-ms duration, making total rotation time 1.7 s. The total time of 2.7 s prior to the appearance of the target was equivalent to that of the static condition. The direction of rotation was randomized, with an equal probability of clockwise (CW) and anticlockwise (ACW) rotation. When the stimulus had completed the 180° rotation and reached its end state, on two-thirds of the trials, the target-present trials, the target appeared randomly but with equal probability in the left or right circle (now left circle in ipsilateral space and right circle in contralateral space) and remained on the screen until a response was made or until 3 s had elapsed. On the target-absent trials, the stimulus remained on the screen for 3 s and then the trial was terminated. Instructions for responding and feedback were identical to those in the static condition, and RT and accuracy of target detection were measured as a function of end state (i.e., left or right side of space and of direction of rotation).

Design. The basic design of the experiment was $2 \times 2 \times 2$ with the factors being display (connected, disconnected), side of space of target (contralateral, ipsilateral), and condition (moving or static). In the moving condition, the barbell rotated either CW or ACW, and this was equiprobable. The connected and disconnected displays were blocked and crossed with static or moving condition, which were also blocked. Each of the four cells in the 2×2 (display $\times$ condition) contained 120 trials, making a total of 480 trials, with target-present trials making up two-thirds of the trials ($n = 320$) and target-absent trials making up the remaining one-third ($n = 160$). The contralateral and ipsilateral sides were sampled equally. The 120 trials in each of the four cells were presented as two blocks of 60 trials each, making a total of 8 blocks of 60 trials. Participants were given a break between blocks, and practice trials were given before the first block of each of the connected and disconnected stimuli.

Because data were already available from 13 normal elderly control participants from the original Behrmann and Tipper (1994) study on the connected display in both the moving and static conditions, the 8 elderly control participants who participated in this study completed only the blocks with the disconnected stimulus (both static and moving, counterbalanced across participants), and then a between-groups analysis was conducted. For the neglect participants, however, it was imperative to have display (connected, disconnected) as a within-subject factor and so, because display is a between-subjects variable for the normal participants but not for the patients, a direct comparison with group (normal, neglect) as a between-subjects factor is not possible. Thus, two separate group analyses are performed; one for the control participants and one for the neglect patients.

To obtain the within-subject data from the patients, the data obtained from the original 3 neglect patients (Patients 1–3) for the static and moving conditions with the disconnected display were analyzed along with their own data from the connected display, which were collected a year previously in the original experiment. Although, at the second testing, these patients were still shown to have neglect on the same set of bedside tests as those used initially and recovery was minimal, it is still possible that they might have learned some compensatory strategies over time (see Table 1). To conduct a more controlled within-subject analysis, the additional 4 neglect patients (4–7) completed the task with both the connected and disconnected displays, and these were run within a week or two of each other. The order of the blocks and color of the two circles of the stimulus were randomized across participants as far as possible.

In the first analysis, we present the data for the control and neglect groups separately and then describe the differences between them. Following the group analysis, we focus on the data for the neglect participants individually. The perils of averaging data across a group of patients are well known within neuropsychology, and the debate about single versus group designs using brain-damaged patients remains unresolved (see entire issue of *Cognitive Neuropsychology*, 1988, devoted to this debate). Because patients are neither homogeneous in structure nor function following brain damage, averaging their data may not be informative, and more important, it may preclude valid inferences about brain–behavior correspondences. Caramazza and colleagues (Caramazza, 1986; Caramazza & McCloskey, 1988), for example, advocate the almost exclusive use of single participants in neuropsychology research. The presence of the predicted effects in the individual data would further attest to the robustness of the findings. Others, however, have suggested that both group and single-participant studies are acceptable (Bub & Bub, 1988) but that the group effects should be verified in a more detailed analysis of the performance of each participant. In keeping with the latter suggestion, the data are analyzed first by comparing the pattern from the neglect participants as a group with that of the elderly participants as a group. Thereafter, the patterns of performance for each individual neglect participant are described.

Results

Before reporting the results, it is worthwhile to be explicit about the patterns of performance which would allow us to draw conclusions about the form of representations accessed by attention. The first thing to do, however, is to set aside the factor of rotation direction as a variable that might potentially influence performance. There is no obvious reason that direction of rotation should affect the RT data and the results of the original Behrmann and Tipper (1994) study showed that this variable does not influence performance significantly. It is included here, however, for the sake of completeness and, as will be observed in the results below, it does not affect performance in this experiment either and, therefore, is of no relevance in spelling out the predictions. If the Behrmann and Tipper results were determined by an object-centered frame of reference rather than one that is scene based, the predicted result for the neglect patients is of a three-way interaction between side of space, condition (moving, static), and display (connected, disconnected). This interaction should not, of course, be observed for the control participants. The basic prediction for the neglect participants is that, relative to the static baseline, detection times in the connected (object-centered) moving condition should be facilitated for targets on the contralateral, left side of space and inhibited for targets on the ipsilateral, right side of space. This modulation of neglect, however, should not be obtained for the moving disconnected (scene-based) display.

Control participants. The means of the median RTs for the normal subjects for both the connected and disconnected stimuli (between participants) as a function of side of space of the target and condition, either static or moving, are shown in Figure 2. These data include only target-present trials. Errors constituted fewer than 4% of the trials and are excluded from the RT analysis.

Before conducting the analysis of the data, the effect of rotation direction in the moving condition alone was examined in an analysis of variance (ANOVA) with direction of rotation (CW or ACW), display (connected or disconnected), and side of target (left or right). The direction in which the display rotated was not significant nor did it interact significantly with any of the other variables ($F < 1$). Con-

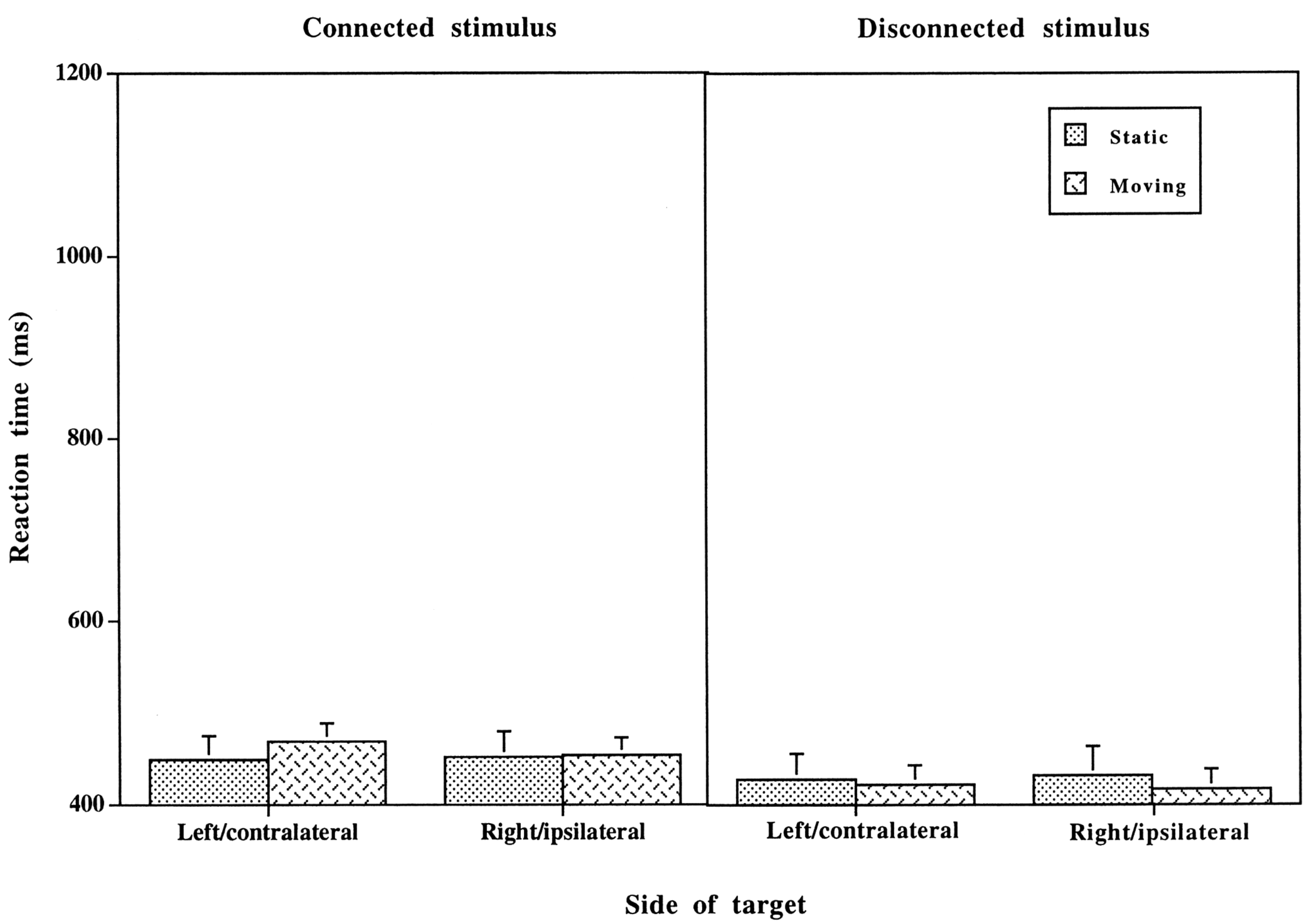

Figure 2. Mean of median reaction time for normal control participants for targets on the left and right side of space in the moving and static condition plotted separately for connected and disconnected displays. Standard error bars are included.

sequently, the data are pooled across rotation for subsequent analysis. A three-way ANOVA with stimulus (connected, disconnected) as a between-subjects variable, and condition (moving, static) and side of space (contralateral or left, ipsilateral or right to be consistent with the patients) as within-subjects variables was then conducted with RT as the dependent measure. As is evident from Figure 2, there was no significant difference in RTs for the connected and disconnected stimuli[1] or a difference in performance for the moving and static conditions ($F < 1$). More important, the side of space on which the target appeared also did not influence performance significantly. There were also no significant two-way interactions of any of these variables with each other. These findings are straightforward and suggest that there are no inherent biases or asymmetries in the performance of the control participants. Of particular relevance for the study with the neglect patients is that, in control participants, there is no effect on detection time of the side of space of the target.

Neglect patients. Having established that there is no individual or joint effect of the crucial variables on the performance of the control participants, we can use these data as a benchmark against which to compare the data obtained from the patients. An analysis of the data from the 7 patients as a group is presented next followed by the findings for the patients individually. Because the direction of rotation does not affect errors or RTs in the moving condition ($F < 1$), this factor is dropped from the analyses. Across the patient group, there was a 4% error rate (SD = 4.8). A three-way repeated measures ANOVA on the error data with condition (moving, static), display (connected, disconnected), and side (left, right) revealed only a main effect of condition, $F(1, 6) = 12.6$, $MSE = 9.14$, $p < .05$, with a mean of 2.2% and 1.6% errors on the moving and static conditions, respectively. The means of the median RTs across the 7 participants for connected and disconnected stimuli as a function of side of space for moving and static trials are shown in Figure 3.

The three-way repeated measures ANOVA using the same variables as for the error analysis but with correct RT as the dependent measure revealed that targets on the contralateral side were detected more slowly than those on the ipsilateral side, $F(1, 6) = 10.1$, $MSE = 46{,}837.3$, $p = .02$. There was no significant main effect on performance when the display was connected compared with when it was not connected ($F < 1$) nor when the barbell was moving compared with when it was static ($F < 1$), nor was there a significant two-way interaction between any of the three variables, condition, display, and side ($F < 1$). Of critical importance, however, is the significant three-way interaction between display, condition, and side of space of the target, $F(1, 6) = 6.02$, $MSE = 30{,}449.3$, $p < .05$. Pairwise planned comparisons of the interaction using a Tukey post hoc test with $p < .05$ of the connected condition revealed that, on the contralateral side of space, detection in the moving condition is significantly faster than that on the baseline static condition. In contrast, on the ipsilateral side of space, detection is significantly inhibited in the moving over the static condition. In the disconnected condition, the pattern is very different and an interesting and unexpected finding was a trend, albeit nonsignificant, toward the converse result. On the contralateral side of space, detection is slowed in the moving condition relative to the static baseline but, on the ipsilateral side, detection is not significantly different in the moving than the static condition. The major result of this study is a replication of the contralateral facilitation and ipsilateral inhibition in the connected display, as demonstrated by Behrmann and Tipper (1994), and the absence of this pattern in the disconnected display.

Individual patient data. To examine the individual data more closely, we present examples of the performance of some individual participants. Although there is some variability in the data, the critical three-way interaction was observed in most patients. Figure 4 illustrates data from a subset of the participants, including Patients 1, 4, and 7, two of whom also participate in Experiment 2. Thus, these data may also be used for comparison with the findings of the next experiment.

It is important to note that from Figure 4 all 3 participants show the predicted facilitation on the contralateral side of space and the inhibition on the ipsilateral side of space for the connected but not the disconnected display in the moving condition, thereby verifying the object-centered effect in the individual data. Also of relevance is that, for some participants (seen in Patient 4 and also in Patient 7), RTs are still slower for contralateral than for ipsilateral responses, revealing the presence of a location-based frame of reference in addition to the object-centered one described above.

Figure 5 reflects the costs and benefits (as difference scores) for all 7 participants in the moving over the static baseline separately for the connected and disconnected displays. As is evident from Figure 5, for all of the participants, RTs to targets on the contralateral side of space are facilitated in the moving relative to the static condition. Patient 6 also shows the trend in this direction, although the presence of the object-centered effect in his data is small. Furthermore, for all of the participants, again to varying degrees (see, for example, the minimal result for Patient 6 in Figure 5), RTs to targets on the ipsilateral side are inhibited in the moving condition relative to the static condition. On the disconnected display, there is no obvious evidence for the contralateral facilitation or the ipsilateral inhibition. Rather, in most of the patients, there is a trend for RTs to targets in the moving condition to be slowed relative to the static baseline on the contralateral side of space. In general, then,

[1] The lack of a significant main effect between connected and disconnected displays contrasts with the data observed in our studies of inhibition of the return of attention (IOR) (see Tipper & Weaver, in press, for discussion). In the latter IOR studies, target detection was more efficient when attention moved within connected than between separate objects. We suspect that this within-object advantage will only be observed when the task is demanding. Thus, in the IOR experiments small targets were very briefly presented, and there were three possible target loci. In the present barbell study relatively large targets were presented for long periods (until detection response) and there were only two potential target loci.

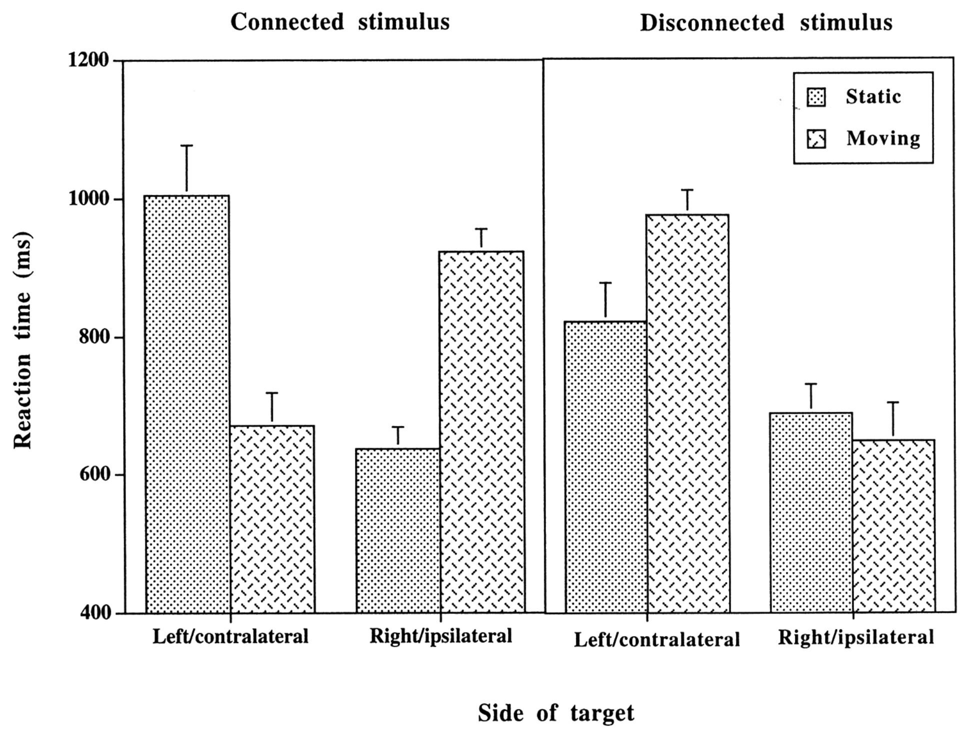

Figure 3. Mean of median reaction time for the group of 7 neglect participants for targets on the left (contralateral) and right (ipsilateral) side of space in the moving and static condition plotted separately for connected and disconnected displays. Standard error bars are included.

the pattern of findings appears to hold even in the individual data. There is some variability, however, and it is possible (as in the case of Patient 6) for the object-centered effect to be reduced even when the location-based effect remains strong (as manifested by overall slower contralateral than ipsilateral responses).

Discussion

The goal of this study was to examine the nature of the representations that guide spatial behavior in patients with unilateral neglect, an acquired deficit of attention. For example, in these patients, following a right parietal lesion, the processing of information on the left or contralateral side of space is disrupted. The critical question is whether an object-centered spatial reference frame is used at all to determine left and right. The first major finding from this study is that the data replicate the original results of Behrmann and Tipper (1994): Detection to contralateral targets is facilitated and detection of ipsilateral targets is inhibited relative to the static baseline.

The second important result is that this pattern occurs only when the two circles are joined by a connecting bar and not when the two circles are independent and separate. These data are consistent with the prediction of an object-centered representation as displayed in Figure 1, Panel C. The results demonstrate that the predicted costs and benefits of the moving over the static condition are observed only when the stimulus is interpreted as a single, coherent entity with the two circles indicating its left and right ends, but not when the circles are merely two separate objects in the field. If, however, it were the case that only object-centered representations were accessed by attention, then one would expect to see the contralateral neglect in the static condition being transferred entirely to the ipsilateral side in the moving condition (i.e., neglect would follow the object and not be influenced at all by the side of space of the target), defined by the location-based coordinates. This complete flip of neglect is not observed in all participants, suggesting that, with some forms of brain damage, attention accesses more than just an object-centered representation. That there is a modulation of the neglect in most patients, rather than a complete reversal from the contralateral to ipsilateral side, and that the main effect of neglect for the left side persists, suggest that neglect for the contralateral side is defined by a location-based or space-based representation as well as by an object-centered representation, and that these two representations coexist.

Taken together, the results of this study are consistent with the view that multiple representations are being accessed by attention (Arguin & Bub, 1993; Calvanio et al., 1987; Driver & Halligan, 1991; Farah et al., 1990; Làdavas, 1987): One representation is defined by the coordinates of the object and one is defined by spatial coordinates. These representations coexist and the presence of a single moving object may modulate the severity of the neglect deficit by

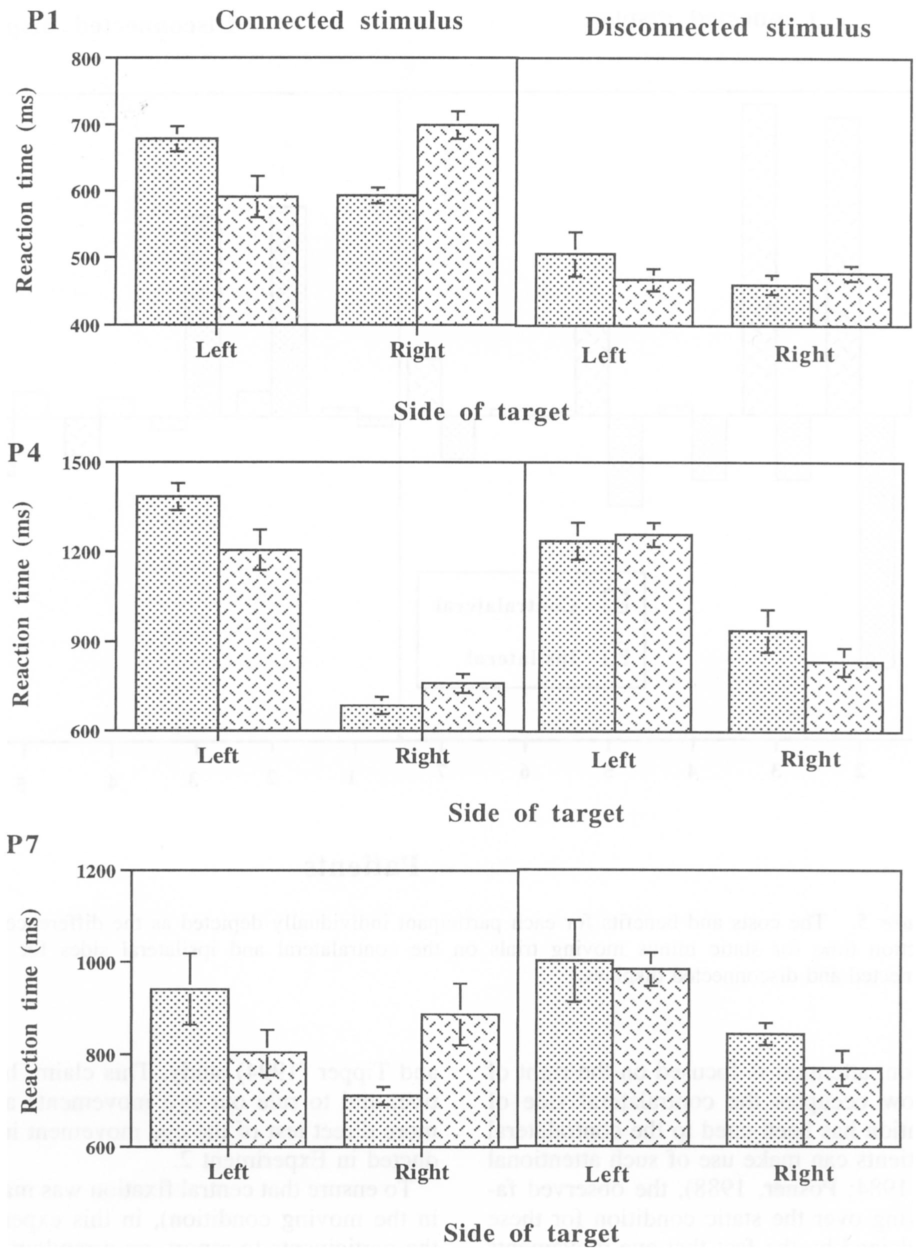

Figure 4. Median reaction time and standard errors for three individual patients (P) for targets on the left (contralateral) and right (ipsilateral) side of space in the moving and static condition plotted separately for connected and disconnected displays. Bars with dots = static condition and bars with lattice = moving condition.

facilitating or inhibiting detection relative to the static baseline condition. The observation that this modulation occurs only when a single object is present, but not when two separate objects occupy the visual display, suggests that, under these conditions, attention does not access a scene-based representation.

Experiment 2

The results of Experiment 1 provide an answer to the first issue addressed in this article concerning the nature of the representations accessed by attention. Those data argue in favor of the view that multiple representations coexist in the mediation of spatial attention. There is still, however, one possible interpretation for the results, namely, that the observed facilitation in contralateral space and inhibition in ipsilateral space in the connected moving condition are an artifact of eye movements and have nothing to do with the internal representation accessed by attention. This interpretation would suggest that the neglect participants deploy their attention to the right of the barbell, and then move their eyes along the trajectory of the moving objects. At the

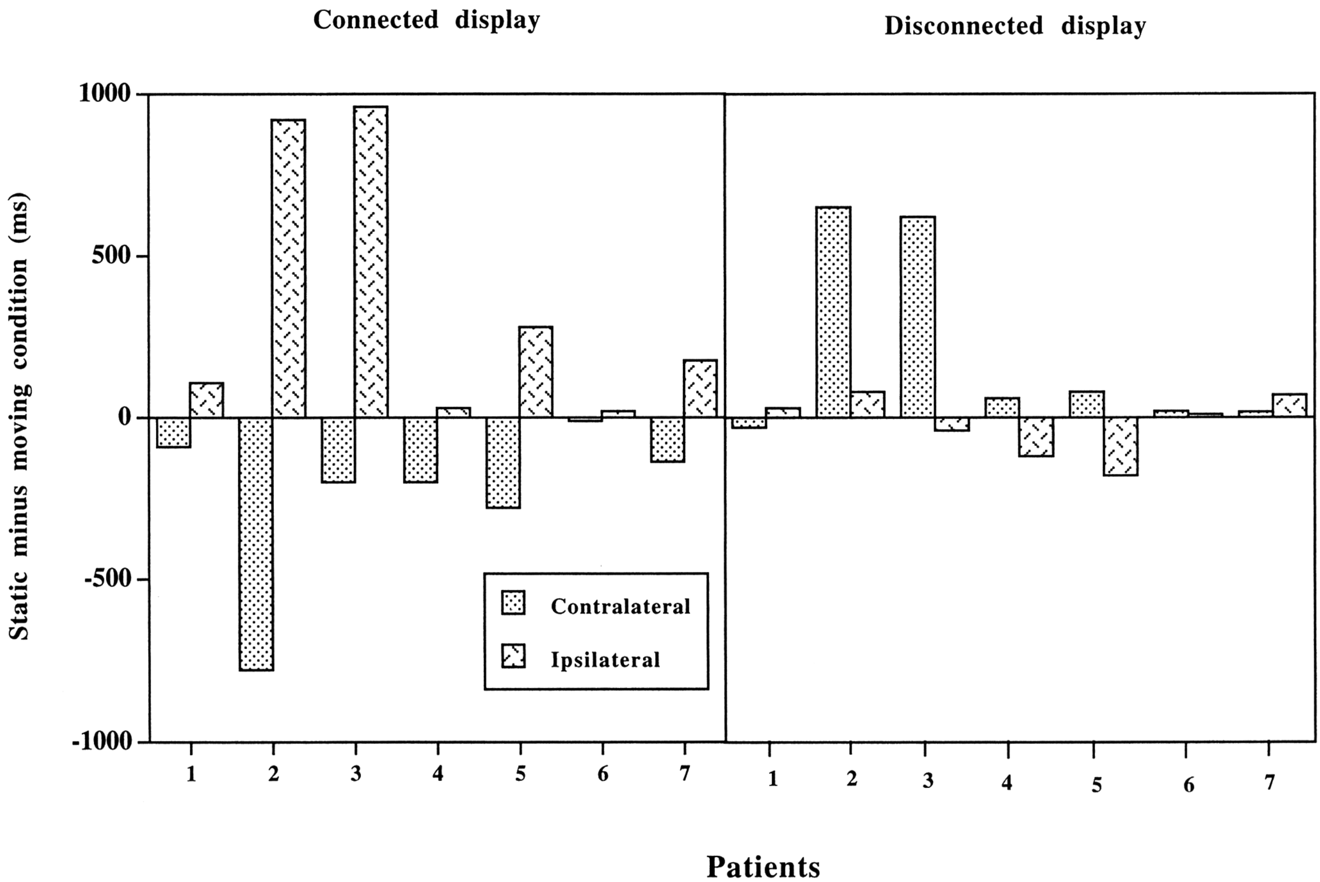

Figure 5. The costs and benefits for each participant individually depicted as the difference in reaction time for static minus moving trials on the contralateral and ipsilateral sides for the connected and disconnected displays.

termination of rotation, attention is focused on the right of the object which now occupies the contralateral side of space. Because attention has been cued to the contralateral side, and neglect patients can make use of such attentional cues (Posner et al., 1984; Posner, 1988), the observed facilitation in the moving over the static condition for these targets might be explained by the fact that eye movements are executed during object motion.

The data from Experiment 1, although not conclusively ruling out the eye movement explanation, do suggest an indirect answer to this potential interpretation. If it were true that the participants simply tracked the objects overtly by following the circle that appears initially on the ipsilateral side of space, one might expect that this would happen equally for both the connected and disconnected displays. Thus, the tracking of the right-sided circle should take place irrespective of whether it is a separate object or just the right side of a single object—removal of the connecting bar should not differentially affect eye movements. That we see a difference between the connected and disconnected displays suggests that eye movements cannot fully explain the pattern of results of this experiment and, by extension, cannot account for the findings from the original Behrmann and Tipper (1994) study. This claim, however, is speculative, and to rule out eye movements as an explanation, a more direct test of the eye movement interpretation is conducted in Experiment 2.

To ensure that central fixation was maintained (especially in the moving condition), in this experiment, we required the participants to report, on a random subset of trials, the identity of a digit presented in the fixation point. The digit, which appeared on 10 out of 60 trials, was presented at an exposure duration too brief for eye movements. If the participants were fixating anywhere other than the fixation point, it would not be possible to identify the digit. These catch trials, therefore, provide a means of controlling the position where the neglect participants are fixating. This controlled fixation procedure has been used repeatedly and successfully in the literature on hemispheric specialization in which fixation must be controlled to ensure that the stimulus is presented to only one cerebral hemisphere (Klein, Moscovitch, & Vigna, 1976; McKeever & Huling, 1971). For example, Hellige, Kujawski Taylor, and Eng (1989), in a study of hemispheric differences in information processing, controlled eye movements by presenting consonant–vowel–consonant (CVC) syllables to either the left or right hemisphere tachistoscopically. Every syllable appeared together with a digit in the fixation position, and participants reported the digits and the CVCs. They excluded trials on which the digit was incorrectly reported and showed that the pattern of CVC errors was different for right versus left hemisphere presentation, suggesting that the two hemispheres process the information in qualitatively different ways. This eye movement control procedure has also been used in neuropsychology. For example, Cohen and Rafal (1991) used it in the study of the illusory conjunction errors in response to information in the unattended contralesional side made by a patient with a parietal lobe lesion. In their study, to ensure that the patient was maintaining central fixation and the information was being presented to one or the other side of fixation, the patient was required to report the identity of two digits that were presented foveally. The use of a digit positioned in the fixation point has thus become a fairly standard technique in neuropsychological and cerebral lateralization studies and is considered to be a robust and reliable method.

To determine whether or not the pattern of performance documented in Experiment 1 is an artifact of eye movements, we adopted this digit report procedure to control fixation. If the data from Experiment 1 (and from Behrmann & Tipper, 1994) are a consequence of eye movements, then, when participants maintain central fixation, the contralateral facilitation and ipsilateral inhibition observed with the moving connected display should no longer be observed. If, however, the pattern of performance is not a function of eye movements per se but is a reflection of the representations accessed by attention, then the same pattern as seen in Experiment 1 should be obtained even when eye movements are controlled through this fixation maintenance procedure.

Method

Participants. Two of the neglect participants, R.H. or Patient 4 and R.B. or Patient 7, who had taken part in Experiment 1, were available for additional testing and completed this experiment. This experiment was run approximately 6 months following Experiment 1 for Patient 4, and the neglect battery was repeated to ensure that she (R.H.) still showed neglect of the same severity as originally observed. The surgery for her aneurysm had taken place 27 months prior to the first testing period and there was no fluctuation in her condition. She was considered medically and neurologically stable and there was no change in her performance on the neglect testing. Experiments 1 and 2 were completed within 2 weeks of each other for Patient 7 and the neglect battery was not readministered.

Stimuli. The stimuli used were identical to those of Experiment 1.

Procedure. The procedure was identical to that used in Experiment 1, and both the connected and disconnected displays were used. The only modification to the procedure was the addition of the control for eye movements. This consisted of the appearance of a single digit ranging from one to nine that appeared in the fixation point on a random 10 trials in a block of 60. In the connected bar condition, when it was present, the digit appeared just above the horizontal bar. The digit appeared in 24-point New York bold black font, subtending a visual angle of 0.6° and 0.9° horizontally and vertically, respectively. The course of a single trial was as follows. The trial began with the phrase "Press start key" that appeared in the center of the screen. The experimenter pressed the key when the participant was ready. The digit appeared on a random subset of the trials and when present, it appeared prior to the appearance of the target at a random time throughout the interval during which the barbell rotated (on moving condition) or remained static. In this way, it was not possible for the participant to predict when the target would appear and fixation would need to be maintained throughout the trial.

Prior to starting the experiment, a training period was undertaken to set the threshold exposure duration for the digit and to accustom the participant to the task. Initially, blocks of 20 trials (drawn randomly from all conditions of connected or disconnected × static or moving) were run in which 12 trials (60%) contained the digit. In the first block, the digit was exposed for 350 ms to accustom the participant to the task and the participants were explicitly instructed to maintain central fixation. Verbal feedback was provided about the accuracy of performance. If the participant was able to report the digit correctly on at least 11 out of the 12 trials, the exposure duration was dropped by 50 ms on each subsequent block until it reached 200 ms or less and accuracy of digit report remained high. At 200 ms, Patient 4 was still able to report the digit in more than 90% of the trials and this exposure duration was selected. For Patient 7, an exposure duration of 150 ms was chosen. Because eye movements in patients are known to be longer than those of neurologically intact individuals, particularly in patients with parietal lobe lesions (Behrmann, Watt, Black, & Barton, 1996; Duhamel, Goldberg, Fitzgibbons, Sirigu, & Grafman, 1992), 150–200 ms was judged to be too brief for these participants to shift their eyes to the center of the screen if they were not already fixating there. Informal observation of the participants' performance (with the experimenter standing behind the screen and watching the participants' eyes) indicated that the participants were indeed maintaining fixation. The rest of the procedure was identical to that of Experiment 1 and the 480 trials (320 present, 160 absent) were conducted in 8 blocks of 60 trials in which a random subset of 10 of the 60 trials was preceded by the digit. The participants were instructed to perform the target detection first and then to report the identity of the digit.

Results

Out of a total of 80 digits, 10 from each of the 8 blocks presented at 200 ms, Patient 4 failed to report 11 digits, and these arose roughly equally from the static and moving conditions and from the connected and disconnected displays. Patient 7 failed to report 7 digits (although on two of these 7 trials, he did report the presence of a digit, just the incorrect digit). These findings suggest that, on the whole, the manipulation to control eye movements was effective and that, even at very brief exposure durations, the 2 participants were able to report the identity of the centrally located digits reasonably well. The patients also made relatively few target detection errors with 11% and 8% for Patients 4 and 7, respectively, showing that the addition of the digit reporting task did not hamper performance substantially.

To determine whether there was any difference in performance in the digit reporting condition and in the experiment without the digits (Experiment 1), a four-way ANOVA was done with display (connected, disconnected), condition (static, moving), side of target (ipsilateral, contralateral), and testing procedure (with digit, without digit) with RT as the random factor. This was done separately for Patients 4 and 7. The median RTs for target detection in the moving and the static conditions for the connected and disconnected display for the 2 participants individually are shown in Figure 6. This figure contains only the data from the digit report procedure but can be compared with those in Figure 4 in which there was no digit reporting procedure.

Prior to the statistical analysis, data exceeding more than two standard deviations in a cell were removed. In both cases, RTs were slower in the digit report than in Experiment 1, possibly because of the additional demands of the digit report, Patient 4: $F(1, 526) = 3.9, p < .05$; Patient 7: $F(1, 553) = 4.2, p < .05$. More important is the fact that a significant four-way interaction of the variables was seen for Patient 4, $F(1, 526) = 4.4, p < .05$. This discrepancy between performance with and without the digit was attributable to a difference on the ipsilateral side in the disconnected display in the digit report procedure relative to the result from Experiment 1 when there was no digit present. Whereas detection on the ipsilateral side in the disconnected condition without the digit was facilitated in the moving over the static condition, when Patient 4 had to report the digit, detection was even more facilitated. Aside from this pairwise difference, performance was very similar for the other cells whether or not the fixation control procedure was used. There was no significant four-way interaction for Patient 7 and the factor of testing procedure (with digit, without digit) did not interact with any of the other variables.

Discussion

The results from this experiment, replicated on 2 participants who had also taken part in Experiment 1, suggest that the observed pattern of costs and benefits in the moving

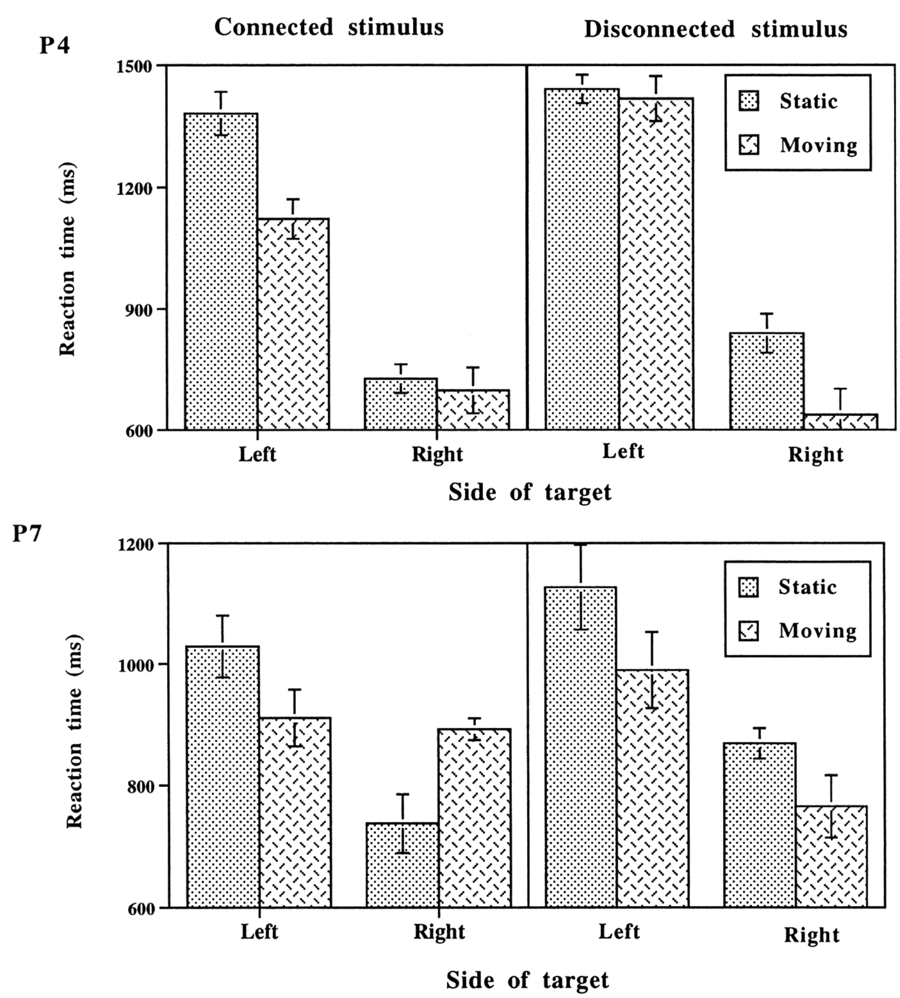

Figure 6. The median reaction time and standard errors to detect targets as a function of the side of the target and the condition (static or moving) shown separately for the connected and disconnected displays for Patients (P) 4 and 7 with associated digit report.

over the static conditions was not differentially affected by the eye movement control procedure. These findings suggest that the results of Experiment 1 cannot be attributed to eye movements per se. Rather, as discussed in Experiment 1, the pattern of performance may be explained as a result of the internal representations (object centered and location centered) accessed by attention during this target detection task.

General Discussion

Whether visuospatial attention accesses representations other than those that are location based has been the subject of considerable debate (Duncan, 1984; Egly et al., 1994; Kanwisher & Driver, 1992) and recently, data from neuropsychological patients has been used to address this issue (e.g., Humphreys & Riddoch, 1994, 1995). In a study with five patients with acquired brain damage affecting the parietal lobe, Behrmann and Tipper (1994) showed that neglect of information on the left or contralateral side of space could be ameliorated. This facilitation for detecting contralateral targets was accompanied by the concurrent elevation of RTs to detect targets on the intact right or ipsilateral side of space. Behrmann and Tipper interpreted these results as demonstrating that attention could be directed to object-centered representations; when decreased attention was deployed to the left of a barbell object, and that part of the object rotated into the "good," ipsilateral space, target detection was inhibited. Conversely, when attention was deployed to the right of an object and that part rotated into the neglected contralateral side of space, performance was facilitated relative to a static baseline condition. Although Behrmann and Tipper took these results as supporting a model of object-centered attention, and thus challenged models that assume solely space-based or location-based representations, other interpretations of those findings are possible. The focus of the current study was to examine the original result in the light of these alternative interpretations, and more generally, to evaluate whether visual attention operates in a medium that is solely spatial or whether object-centered effects are also observable, as originally claimed.

One possible alternative interpretation for the original results is that attention does not access object-centered representations, which describe how the various components of an object are conjoined; rather, it may be argued that attention accesses scene-based representations, where the visual world is represented in terms of different objects and the spatial locations they occupy (Kahneman et al., 1992). This alternative hypothesis was tested by repeating the original Behrmann and Tipper (1994) experiment but, in addition to the original display, a condition was added in which the circles of a barbell were not connected by a horizontal bar. These two separate circles represent independent objects in a visual scene. If attention accesses object-centered but not scene-based representations, the prediction is that the contralateral facilitation and ipsilateral inhibition will only be observed when the two circles are joined to form the barbell, but not when they are separated in the disconnected condition.

The results of this study are clear on this point. In stark contrast to the findings of Behrmann and Tipper (1994), which are replicated here in Experiment 1, when the two separate or disconnected objects rotate by 180°, left-sided neglect is not diminished, and the inhibition in RT on the right side, relative to static condition, is also not observed. In fact, under these latter conditions, left-sided neglect is somewhat increased relative to the static left-sided control condition. The difference in performance with connected and disconnected or separated displays suggests that the attention mechanisms impaired in these neglect patients access object-centered but not scene-based representations in this particular task.

These findings are consistent with previous work that has suggested that neglect may arise in object-centered coordinates. For example, Driver and Halligan (1991) showed that the left side of an object, as defined by its principal intrinsic axis (see Marr & Nishihara, 1978), was neglected even when it was presented to the right of the viewer's midline (see also Driver, Baylis, Goodridge, & Rafal, 1994). Similarly, Caramazza and Hillis (1990) showed that their patient, N.G., who had right-sided neglect, failed to read letters in the terminal positions of words, regardless of the word's orientation (e.g., mirror reversed or vertical; see also Humphreys & Riddoch, 1995). Neglect for the final letters in a word, irrespective of the word's absolute position or orientation, suggests that the positions of letters in a word are determined relative to the midline of the word itself. Following a lesion, N.G. neglected information to the right of this internal midline. Object-centered neglect may also be observed in the copying performance of neglect patients; when copying multiple objects from a scene, some neglect patients fail to copy the contralateral side of each individual object rather than entirely neglecting complete objects on the contralesional side of the display (Gainotti, Messerli, & Tissot, 1972; Halligan & Marshall, 1993).

Our data support these studies, all of which reveal that the spatial coordinates that determine neglect may be defined relative to the object itself. In most of the 7 participants, the predicted three-way interaction between side of space, condition (moving or static), and display (connected or not) was obtained. Clearly, therefore, whether a single object is perceived and the two circles parsed as components of the same object, or whether two separate objects (circles) are perceived, is crucial to the pattern of data observed. In the present study, the contrast between object-centered and scene-based frames of reference has emerged in two important ways. First, neglect either reverses or is reduced when the single connected object rotates by 180°, suggesting that the neglect is associated with the rotating object-centered representation and that this counters a simple explanation of location-based neglect. Second, in some patients, contralateral, left neglect is increased when two separate objects rotate by 180°, relative to the static disconnected trials. This last result was not predicted, but it may arise because attention is captured by the entry of a new object into the already well-attended right side of space.

It is important to note, however, that we are not arguing that object-centered frames of reference have priority over scene-based representations. On the contrary, we think that our results are probably limited to particular groups of patients and experimental tasks. In particular, we propose that attention is a highly flexible and dynamic system that is able to access and manipulate a variety of different forms of internal representation, depending on current task demands (Vecera & Farah, 1994). As discussed above, there is clear evidence in both brain-damaged (Humphreys & Riddoch, 1994, 1995) and normal participants (Kahneman et al., 1992) for attention having access to scene-based frames of reference. For example, in the studies conducted by Tipper and colleagues (Tipper et al., 1990, 1991), inhibitory mechanisms of attention are associated with separate individual objects, and not with components within an object.

Furthermore, the complex nature of our data suggests that neglect, within a particular task, cannot be accounted for simply by one frame of representation. Rather, we believe that multiple frames can exist simultaneously (Calvanio et al., 1987; Farah et al., 1990; Làdavas, 1987), probably interactively (Egly et al., 1994; Tipper et al., 1994), and that complex patterns of data emerge from their combined presence. In the data of Experiment 1 we see, for example, that Patients 4, 5, and 6 do not produce the complete reversal of neglect when the connected object rotates 180°. Rather, even when there is evidence for reduced neglect on the contralateral side of space when the barbell rotates into that location, detection is still worse overall than for ipsilateral targets. Therefore, we suspect that both location-based and object-centered frames of references, as shown in Figure 1, Panel D, are determining the observed behavior.

Even in the neglect cases, it seems that the degree to which the different reference frames are expressed may differ, as seen in the variability between the participants reported here. One possible explanation for this variability is the severity of the neglect deficit. For example, Patients 4, 5, and 6 show less evidence for object-centered neglect than do Patients 1, 2, and 3 and Patient 7, and, indeed, the former patients have less severe neglect than their counterparts (as is obvious from the neglect scores in Table 1). It should be noted that Patient 6, probably the least severe neglect patient, did not show any evidence for object-centered representations and showed neglect only in a spatial (location-based) frame of reference. These data may imply that there are multiple frames of reference in which neglect arises, and that the variety of lesion sites or severities will influence these multiple frames in different ways. Similar observations regarding the effect of severity on performance have been made by Behrmann, Black, and Murji (1995) and by Driver and Halligan (1991). This participant variability may be used to great advantage in future research. Identifying which forms of neural damage are most associated with particular forms of representation, and the intriguing possibility that recovery from neglect may have a sequential form, where object-centered neglect recovers before location-based neglect, could provide interesting converging evidence for our understanding of visual perception and attention.

References

Abrams, R. A., & Dobkins, R. S. (1994). Inhibition of return: Effects of attentional cuing on eye movement latencies. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 467–477.

Albert, M. (1973). A simple test of visual neglect. *Neurology, 23,* 658–664.

Allport, A. (1987). Selection for action: Some behavioral and neurophysiological considerations of attention and action. In H. Heuer and A. F. Sanders (Eds.), *Perspectives on perception and action* (pp. 395–420). Hillsdale, NJ: Erlbaum.

Allport, A. (1989). Visual attention. In M. I. Posner (Ed.), *Foundations of cognitive science* (pp. 631–682). Cambridge, MA: MIT Press.

Arguin, M., & Bub, D. N. (1993). Evidence for an independent stimulus-centered spatial reference frame from a patient with visual hemineglect. *Cortex, 29,* 349–367.

Baylis, G. C., & Driver, J. (1993). Visual attention and objects: Evidence for the hierarchical coding of location hypothesis. *Journal of Experimental Psychology: Human Perception and Performance, 19,* 451–470.

Behrmann, M., Black, S. E., & Murji, S. (1995). The status of attention in the mental architecture: Evidence from neuropsychology. *Journal of Clinical and Experimental Neuropsychology, 17,* 220–242.

Behrmann, M., & Moscovitch, M. (1994). Object-centered neglect in patients with unilateral neglect: Effects of left–right coordinates of objects. *Journal of Cognitive Neuroscience, 6,* 1–16.

Behrmann, M., & Tipper, S. P. (1994). Object-based attentional mechanisms: Evidence from patients with unilateral neglect. In C. Umiltà and M. Moscovitch (Eds.), *Attention and performance XV. Conscious and nonconscious processing and cognitive functioning* (pp. 351–375). Cambridge, MA: MIT Press.

Behrmann, M., Watt, S., Black, S. E., & Barton, J. (1996). *Impaired visual search in patients with unilateral neglect: An oculographic analysis.* Manuscript submitted for publication.

Bisiach, E. (1993). The Twentieth Bartlett Memorial lecture: Mental representation in unilateral neglect and related disorders. *Quarterly Journal of Experimental Psychology: 46A,* 435–461.

Bisiach, E., & Vallar, G. (1988). Hemineglect in humans. In F. Boller and J. Grafman (Eds.), *Handbook of neuropsychology* (Vol. 1). Amsterdam: North-Holland.

Black, S. E., Martin, D., Vu, B., & Szalai, J. (1990). Evaluation of a bedside battery for hemispatial neglect in acute stroke. *Journal of Clinical and Experimental Psychology, 12,* 102.

Broadbent, D. (1982). Task combination and selective intake information. *Acta Psychologica, 50,* 253–290.

Bub, J., & Bub, D. N. (1988). On the methodology of single-case studies in cognitive neuropsychology. *Cognitive Neuropsychology, 5,* 565–582.

Calvanio, R., Petrone, P. N., & Levine, D. N. (1987). Left visual neglect is both environment-centered and body-centered. *Neurology, 3,* 1179–1183.

Caramazza, A. (1986). On drawing inferences about the structure of normal cognitive systems from the analysis of patterns of impaired performance: The case for single-patient studies. *Brain and Cognition, 5,* 41–66.

Caramazza, A., & Hillis, A. E. (1990). Internal spatial representation of words: Evidence from unilateral neglect. *Nature, 346,* 267–269.

Caramazza, A., & McCloskey, M. (1988). The case for single-patient studies. *Cognitive Neuropsychology, 5,* 517–528.

Cohen, A., & Rafal, R. D. (1991). Attention and feature integration: Illusory conjunctions in a patient with a parietal lobe lesion. *Psychological Science, 2,* 106–110.

Driver, J., & Baylis, G. (1989). Movement and visual attention: The spotlight metaphor breaks down. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 448–456.

Driver, J., Baylis, G. C., Goodridge, S. J., & Rafal, R. D. (1994). Axis-based neglect of visual neglect. *Neuropsychologia, 32,* 1353–1365.

Driver, J., & Halligan, P. W. (1991). Can visual neglect operate in object-centered coordinates? An affirmative single-case study. *Cognitive Neuropsychology, 8,* 475–496.

Duhamel, J. R., Goldberg, M. E., Fitzgibbons, E., Sirigu, A., & Grafman, J. (1992). Saccadic dysmetria in a patient with a right fronto-parietal lesion. *Brain, 115,* 1387–1402.

Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology, 113,* 501–517.

Egly, R., Driver, J., & Rafal, R. D. (1994). Shifting visual attention between objects and locations: Evidence from normal and parietal lesion subjects. *Journal of Experimental Psychology: General, 123,* 161–177.

Eriksen, C. W., & St. James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & Psychophysics, 40,* 225–240.

Farah, M. J., Brunn, J., Wong, A. B., Wallace, M. A., & Carpenter, P. (1990). Frames of reference for allocating attention to space: Evidence from the neglect syndrome. *Neuropsychologia, 28,* 335–347.

Gainotti, G., Messerli, P., & Tissot, R. (1972). Qualitative analysis of unilateral spatial neglect in relation to laterality of cerebral lesions. *Journal of Neurology, Neurosurgery and Psychiatry, 35,* 545–550.

Gauthier, L., Dehaut, F., & Joanette, Y. (1989). The Bells test: A quantitative and qualitative test for neglect. *International Journal of Clinical Neuropsychology, XI,* 49–54.

Gibson, B., & Egeth, H. (1994). Inhibition of return to object-based and environment-based locations. *Perception & Psychophysics, 55,* 323–339.

Godwin-Austen, R. B. (1965). A case of visual disorientation. *Journal of Neurology, Neurosurgery and Psychiatry, 28,* 453–458.

Halligan, P. W., & Marshall, J. C. (1993). The history and clinical presentation of neglect. In I. H. Robertson and J. C. Marshall (Eds.), *Unilateral neglect: Clinical and experimental studies* (pp. 3–28). Hove, United Kingdom: Erlbaum.

Hellige, J. B., Kujawski Taylor, A., & Eng, T. L. (1989). Interhemispheric interaction when both hemispheres have access to the same stimulus information. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 711–722.

Hinton, G. E. (1981). A parallel computation that assigns canonical object-based frames of reference. *Proceedings of International Joint Conference on Artificial Intelligence,* 683–685.

Humphreys, G. W., & Riddoch, M. J. (1994). Attention to within-object and between-object spatial representations: Multiple sites for visual selection. *Cognitive Neuropsychology, 11,* 207–241.

Humphreys, G. W., & Riddoch, M. J. (1995). Separate coding of space within and between perceptual objects: Evidence from unilateral visual neglect. *Cognitive Neuropsychology, 12,* 283–311.

Kahneman, D., Treisman, A., & Gibbs, B. J. (1992). The reviewing of object files: Object specific integration of information. *Cognitive Psychology, 24,* 175–219.

Kanwisher, N., & Driver, J. (1992). Object, attributes, and visual attention: Which, what, and where. *Current Directions in Psychological Science, 1,* 26–31.

Kartsounis, L., & Warrington, E. K. (1989). Unilateral visual neglect overcome by cues in stimulus arrays. *Journal of Neurology, Neurosurgery and Psychiatry, 52,* 1253–1259.

Klein, D., Moscovitch, M., & Vigna, C. (1976). Attentional mechanisms and perceptual asymmetries in tachistoscopic recognition of words and faces. *Neuropsychologia, 14,* 55–66.

Kramer, A. F., & Jacobson, A. (1991). Perceptual organization and focussed attention: The role of objects and proximity in visual processing. *Perception & Psychophysics, 50,* 267–284.

Kramer, A. F., & Watson, S. E. (1996). Object-based visual selection and the principle of uniform connectedness. In A. F. Kramer, M. G. H. Coles, & G. D. Logan (Eds.), *Converging operations in the study of visual selective attention* (pp. 395–414). Washington, DC: American Psychological Association.

Làdavas, E. (1987). Is the hemispatial deficit produced by right parietal lobe damage associated with retinal or gravitational co-ordinates? *Brain, 110,* 167–180.

Luria, A. L. (1959). Disorders of "simultaneous form" perception in a case of bilateral occipitoparietal brain injury. *Brain, 83,* 437–449.

Marr, D. (1982). *Vision.* San Francisco: Freeman.

Marr, D., & Nishihara, H. K. (1978). Representation and recognition of the spatial organization of three-dimensional shapes. *Proceedings of the Royal Society of London, B200,* 269–294.

McKeever, W. F., & Huling, M. P. (1971). Lateral dominance and tachistoscopic word recognition performance obtained with simultaneous bilateral input. *Neuropsychologia, 9,* 15–20.

Pinker, S. (1984). Visual cognition: An introduction. *Cognition, 18,* 1–63.

Posner, M. I. (1980). Orienting of attention. The VIIIth Sir Frederick Bartlett Lecture. *Quarterly Journal of Experimental Psychology, 32,* 3–25.

Posner, M. I. (1988). Structures and functions of selective attention. In T. Boll and B. Bryant (Eds.), *Clinical neuropsychology and brain function: Research, measurement and practice* (pp. 173–202). Washington, DC: American Psychological Association.

Posner, M. I., & Cohen, Y. A. (1984). Components of visual orienting. In H. Bouma and D. G. Bouwhuis (Eds.), *Attention and performance X.* Hillsdale, NJ: Erlbaum.

Posner, M. I., Walker, J. A., Friedrich, F. J., & Rafal, R. D. (1984). Effects of parietal lobe injury on covert orienting of attention. *Journal of Neuroscience, 4,* 1863–1874.

Rock, I. (1973). *Orientation and form.* Academic Press: New York.

Sears, C., Schmidt, A. C., & Pylyshyn, Z. (1995). *Negative priming in a location task: Inhibition of distractor objects or distractor locations.* Manuscript submitted for publication.

Tipper, S. P., Brehaut, J., & Driver, J. (1990). Selection of moving and static objects for the control of spatially directed action. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 492–504.

Tipper, S. P., Driver, J., & Weaver, B. (1991). Object-centered inhibition of return of visual attention. *Quarterly Journal of Experimental Psychology, 43,* 289–298.

Tipper, S., Lortie, C., & Baylis, G. C. (1992). Selective reaching: Evidence for action-centered attention. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 891–905.

Tipper, S. P., & Weaver, B. (in press). The medium of attention: Location-based, object-centered, or scene-based? In R. Wright (Ed), *Visual attention.* London, England: Oxford University Press.

Tipper, S. P., Weaver, B., Jerreat, L., & Burak, A. (1994). Object-based and environment-based inhibition of return of visual attention. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 478–499.

Treisman, A., & DeSchepper, B. (1994). Object tokens, attention, and visual memory. In T. Inui and J. L. McClelland (Eds.), *Attention and performance XVI.* Cambridge, MA: MIT Press.

Umiltà, C., Castiello, U., Fontana, M., & Vestri, A. (1995). Object-based orienting of attention. *Visual Cognition, 2,* 165–182.

Vecera, S., & Farah, M. J. (1994). Does visual attention select objects or location? *Journal of Experimental Psychology: General, 123,* 146–160.

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