Attention Accesses Multiple Reference Frames: Evidence From Visual Neglect

Marlene Behrmann
Carnegie Mellon University

Steven P. Tipper
University of Wales

Research with normal participants has demonstrated that mechanisms of selective attention can simultaneously gain access to internal representations of spatial information defined with respect to both location- and object-based spatial coordinates. The evidence for this view comes from studies that show that patients with unilateral spatial neglect following a right-hemisphere lesion are poorer at detecting information on the contralateral left side in both location- and object-based spatial coordinates simultaneously. Moreover, the extent of the neglect is modulated by the probability of a target's appearing in either reference frame; as the frequency of a target in a particular frame of reference increases, so does the severity of neglect in that frame. These findings suggest that attention can be flexibly and automatically assigned to a reference frame depending on the contingencies of the task.

The medium on which selective attention mechanisms function has been vigorously debated. A dominant view has been that this medium is a spatial map of the environment that is internally represented. Attention is viewed as a spotlight (Broadbent, 1982; Posner, 1980) or zoom lens (Ericsson & Schulz, 1979) that moves over this spatial map, facilitating the processing of stimuli within its beam (for a recent review, see Egeth & Yantis, 1997). An alternative, more recent account is that an object-based frame of reference may be accessed by selective attention systems (Duncan, 1984; Kahneman & Treisman, 1984), and credible empirical evidence now exists favoring this perspective (e.g., Baylis & Driver, 1993; Biederman, Zemel, & Morin, 1998; Kramer & Jacobson, 1991; Kramer & Watson, 1996; Kramer, Weber, & Watson, 1997; Lavie & Driver, 1996; Moore, Yantis, & Vaughan, 1998; Routtenberg, Drury, & Huntley-Johnson, 1996; Wolfe, Kramer, & Miller, 1997). The motivation behind this alternative proposal arises from considerations about what functions attention has evolved to serve. Attention appears to be a mechanism that selects a salient item from the essentially parallel visual perceptual system in the service of the motor system. Through the operation of such a mechanism, action can be directed toward one of the many objects that potentially evoke a response (for a discussion, see Tipper & Weaver, 1998). According to this account, selective attention is crucial for coherent goal-directed behavior that is directed toward particular objects at appropriate times (Tipper, Weaver, & Houghton, 1994).

The evidence that attention is not simply determined by the spatial relationships between stimuli, as a purely spatial model would predict, has come from a number of studies. For example, the data obtained by Egeth and Eriksen (1970) showed that ignored distractor letters impeded responses to targets at fixation only when they were within 1° of the target. Such a result supports the notion that the zone less of attention has a limited resolution on the spatial map. However, several studies have shown that when objects were grouped together by common motion, the zone of attention was extended even when the distractors were spatially distant from the target (Baylis & Driver, 1992; Driver & Baylis, 1989). Clearly, such a result cannot be explained within a framework in which a limited-resolution attention mechanism simply accesses a spatial map; on the contrary, "higher level" object grouping is determining the performance of the selective attention system (see also Baylis & Driver, 1993; Kramer & Jacobson, 1991; Stuart, Marruff, & Currie, 1995).

Initially it was suggested that object-based frames might suffice as the medium of attention (Tipper, Driver, & Weaver, 1991). However, a consideration of procedural processing with stimuli that are clearly different to the ones used by the University of Pittsburgh Medical Center for providing access to patients. We are grateful to N. Winkels for his interpretation of the CT scan results. We are grateful to B. Raffol and two anonymous reviewers for their constructive comments and suggestions.

Correspondence concerning this article should be addressed to Marlene Behrmann, Department of Psychology, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213-3890, or Steven P. Tipper, Department of Psychology, University of Wales, Bangor, Gwynedd, Wales, LL57 2DG, United Kingdom. Electronic mail may be sent to either behrmann@cmu.edu or a tipper@bangor.ac.uk.
object is cued, processing of subsequent information can be impaired, a phenomenon referred to as inhibition of return (Abramsky & Posner, 1984). If an object that is initially cued then moves to a new location, the inhibition moves with the object, thus preventing the notion of object location from being represented at the location of the object itself.

It is important to note, however, that processing of information at the location initially cued results in a process of independent motion, which supports the idea of location-based inhibition mechanisms (Tipper & Chater, 1997). This process is not influenced by the notion of object location, which is independent of motion, and thus not affected by the notion of object location.

More direct evidence for the simultaneous operation of two frames of reference comes from studies by Humphreys and Riddoch (1987) who observe that patients with neglect may be unable to notice objects in the right side of space, even when naming the word, he neglected his left side. Because this patient had lesions to both the right frontal and left parietal-temporal regions, it is reasonable to surmise that these neural structures mediated the left object-based and right space-based neglect, respectively. For similar findings with normal and brain-damaged participants and for a similar theoretical proposal, see Egygi, Driver, & Riddoch (1994, 1993) and Egygi, Riddoch, Driver, & Starreveld (1994). Other work, however, has shown neglect for objects on both the left and right side, even in patients with a unilateral lesion (Costello & Warrington, 1987; Cubelli, Nichelli, Bonito, Tani, & Inghirami, 1991; Riddoch, Humphreys, Luckhurst, Burrows, & Bateman, 1995). This observation is crucial for our current purposes because it demonstrates that a unilateral lesion is not necessary to produce neglect concurrently in two frames of reference.

An important feature of these neglect studies is that the objects in the left frame are present in the left side of the environment. This is inferred indirectly via the interpretation of complex interactions in the data pattern or are largely determined by the demands of the tasks. However, neglect may also be observed indirectly when participants engage attention on a single object, and location-based neglect is obtained when the task requires exclusive attention to that location. However, whether or not what is being observed is a spatial and object-centered neglect cannot be directly observed simultaneously. In the same way that one cannot see the object and the shape it occupies, the deficit may manifest in different representations simultaneously.

Research is based on the Behrmann and Tipper (1994) and Tipper and Behrmann (1996) findings. First, we replicate the left-right modulation of neglect by object-centered by placing the left and right circles of the barbell. Additionally, we adopt a further manipulation in which targets can appear on static spatial locations, as defined by the left and right circles of the barbell. In addition, we adopt the hypothesis that what is visible on the right side of the barbell is more important in determining what is to see on the left side. However, how the spatial distortion shame may be accounted for in different frames of reference (location - object-centered).

The presence of explicit definition what constitutes an object-centered frame in this particular paradigm is deficit. This single frame is somewhat more ambiguous. In the context of the paradigm, for most of the patients for whom the verbal presentation is foetal and the midline of the viewer is aligned with the midline of the display, the location-based frame could refer to a set of allocentric coordinates centered either on the scene or on the environment (Kochanowski & Treisman, 1984; Treisman, 1993) or could even refer to what some have called a "stimulus-centered frame" (Hillis & Caramazza, 1995). Alternatively, left and right can be defined with respect to a set of egocentric coordinates centered on the viewer, with the midline determined by the axis of the eye, head, or trunk (Karnath, Schiehler, & Fischer, 1985). Given that both the scene-based and viewer-based frames are clearly in use (most reflect behavior (Bielach, Castianni, & Porta, 1985; Farah, Bum, Wong, Wallace, & Carpenter, 1999; Ladeveze, 1985), distinguishing the implications of these two reference frames is certainly worthy of future work. For the present purposes, however, our goal was to determine whether neglect can co-occur in multiple reference frames, one of which is object-centered.

**Experiment 1**

Our purpose in this first experiment was to examine whether spatial information can be represented in more than one frame of reference simultaneously. If this is the case, responses to targets on the contralateral side defined with respect to each of the two different frames should be impaired in patients with neglect. Specifically, this would mean that targets on the left of the location-based frame would be more poorly detected than those on the right. Concurrently, targets on the left of the object-based frame, which now fall on the right side of space, will be more poorly detected than those on the right, which fall on the left side of space.

**Method**

Observers. The experimental group consisted of 8 patients with unilateral visual neglect sustained following a right-hemisphere lesion. While right-sided neglect can occur following left-hemisphere lesions, it is less common, less severe, and less long-lasting (Bielach & Veltue, 1988). For our participants showed a leftwards neglect of the contralateral side throughout this article. All patients consented to participate. Two were excluded from the sample because they failed to show the characteristic leftwards asymmetry between the barbell condition (moving vs static) and the side of space on which the target appeared. We made use of this in the present experiment for partial inclusion in the study so that we could investigate object-based neglect along with other forms of neglect.

The remaining 6 neuropsychological patients (one of whom, R. H., had participated in one of our previous studies) were all right-handed and had a left visual field or contralateral spatial neglect. As usual, no lesions included a separate object-based frame for any of the patients. In all cases we obtained CT and/or MRI images of the brain of the patients after the experiment took place.
scan and radiology reports for all patients to determine the site of lesion, it was not possible to obtain the images in all cases. Figure 2 shows the CT scans for 2 of the patients. R. B. (Patient 2; top panels) and J. T. (Patient 5; bottom panels). Although these lesion sites are fairly representative of the lesions for most of the other patients, R. B. suffered a postoperative right parietal hema-
teroma following resection of a right anterior temporal malformation. The scans show both the hemorrhage as well as the presence of surgical clips and an overlying cranial bone defect. J. T. suffered a right temporal-parietal middle cerebral artery infarction following the clipping of an aneurysm, and evidence of the operation and surgical clip can be seen on the CT scan.

Two of the patients, Patients 4 and 5, had visual field defects, and for them, the displays were presented entirely in their intact visual fields. Because neglect is not a sensory deficit, even when informa-
tion is presented solely in the intact visual field, information on the relative left is processed less well than that on the relative right (D’Emme, Robertson, Bertolino, Daniele, & Gauthier, 1992; Linden, Petrides, & Ummels, 1990). The diagnosis of neglect was made on the basis of a standardized battery of behavioral examinations that included spontaneous drawing of a clock and a day, a line cancellation task (a modified version of Albert’s, 1973, line cancellation test), a figure cancellation test, the Bells test (Gauthier, Delair, & Joseph, 1989), and a line bisection test. A score was assigned for each subset which reflected the degree of neglect relative to the performance of a group of age-matched normal control participants. A total neglect score, cumulative across all the screening tests, was then calculated (Black et al., 1984; Black, Vo, Martin, & Stark, 1990). The cumulative maximum neglect score based on these four tests was 10, with a score of 6 or greater being classified as neglect and higher scores denoting increased severity. Scores over 75 indicate severe neglect, scores below 70 indicate mild neglect, and those in between indicate moderate neglect. All patients obtained a score greater than 25. Table 1 presents the behavioral data, lesion information, and neglect scores for the 8 patients. Examples of the left-sided neglect performance of some of the patients on a variety of their neglect screening tests are presented in Figure 3.

A control group consisting of 6 right-handed elderly control participants, all of whom consented to participate, was recruited from the community through an outreach program run by the Academy for Lifelong Learning at Carnegie Mellon University. Participants were matched pairwise to the 6 patients on age and gender. All control participants were right-handed, none had a previous history of neurological disease, and none scored higher than 6 on the diagnostically test of neglect. The mean age of the control participants was 65 years (range = 58-69 years), not significantly different from that of the patients, F(1, 10) = 1.7, n.s. (3) All two-handed circles, 2.5 cm in diameter and subtending a visual angle of 5° appeared on a computer screen. They were connected by a solid bar, which made the entire object resemble a barbell. One circle was colored blue and one was colored red. The two different colors were necessary to distinguish the left and right sides of the object, and the colors on which the blue and red circles appeared were consistent for each participant throughout the testing sessions and were counterbalanced across participants. The distance between the nearest inner edges of the circles was 7.2 cm (90°). The length of the entire barbell was 11.4 cm (162°) In addition to this barbell, two gray squares, 3.1 cm and subtending 3° of visual angle, were placed along the horizontal middle of the circle, as depicted in Figure 1. The distance between the edges of the squares was 5.5 cm (79°). The target, a single white circle, was 0.7 cm in diameter (1°).

Procedure. Stimulus presentation and response recording were controlled by a Macintosh Powerbook 540c with a built-in 153 × 148 mm screen with 640 × 480 resolution. The display was approximately 40 cm from the screen. The phrase “Press start key” appeared in the center of the screen before each trial. The experimenter pressed the key when the participant was ready, and immediately thereafter, the display appeared on the screen The joint barbell-square displays appeared in two conditions: with the barbell either static or moving. The squares remained static in both conditions.

In the static condition (see Figure 1A), the display was presented, it remained stationary for 2.964 ms, and then, on two thirds of the trials, the white square moved either to the left or right circle of the barbell or the left or right square, all with equal probability but randomly ordered (the target-present trials). The target and display remained on the screen together until a key was pressed for an additional 3 s if the trial was no response. On the remaining trials, the squares appeared, no target appeared, and the display remained on the screen for a further 3 s before the trial was terminated (the target-absent trials). Participants were instructed to press a single, centrally placed key on a buttonbox as quickly as possible when they detected the presence of the target. They were not to respond on target-absent trials. Participants were informed of their dominant right hands. Reaction time (RT) and accuracy in detecting the target were measured. Omission and commission errors were noted, and feedback consisting of an auditory tone was provided to the participant on each trial when an error of either kind occurred.

In the moving condition (see Figure 1B), the display appeared and remained stationary for 1 s with the barbell displayed 37.5° from horizontal. The barbell then underwent a 112° rotation (pointing on the center of the bar), traversing 14 intermediate positions (15 "jumps" of 7.66° each) and giving rise to the perception of apparent motion. Each position was held for 121 ms, for a total rotation time of 1.864 ms. The total time prior to the appearance of the target was equated to that in the static condition. The direction of rotation was randomized, with an equal probability of clockwise and counterclockwise rotation. When the stimulus had completed the rotation and reached its "end scale," on the target-present trials, which consisted of two thirds of the trials, the target probe appeared randomly but with equal probability in the left or right circle (now the left circle on the ipsilateral right side and the right circle on the contralateral left side) or the left or right square. The target remained on the screen until a response was made or until a further 3 s had elapsed. On the remaining, target-absent trials, the display remained on the screen for a further 3 s and then the trial was terminated. As is evident from Figure 1, Table 1

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Biographical, Lesion, and Neglect Data for the 6 Experimental Participants</th>
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<tbody>
<tr>
<td>Age (In Years)</td>
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<tr>
<td>Figure cancellation (left/right)</td>
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<tr>
<td>Line bisection (left-right)</td>
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<tr>
<td>Target score</td>
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</tbody>
</table>

Note: F = female; M = male; P = partial; T = temporal; O = occipital; * = bilateral.

* I and J. K. did not complete the Bells test, and so neither a score on that test nor a cumulative neglect score could be calculated for them.

Figure 2. Two slices from CT scan obtained for Patients R. B. (A) and J. T. (B). R. B.’s scans reveal a postoperative right parietal-occipital hematoma and an overlying cranial bone defect. J. T.’s scans reveal a right temporal-parietal middle cerebral artery infarction. Surgical clips are evident in both patients’ scans.
condition and flow in the moving condition, for a total of 480 trials, with block order counterbalanced across participants. Within each block, there were 40 target-present trials, with an equal crossing of side of space on which the target appeared and shape of display (circles vs. squares). Participants were given a break between blocks, and practice trials were given before the first block of each of the static and moving stimuli. RT analyses were performed only on correct target-present trials. For the patients, RTs that exceeded the mean by 2 SDs were removed. The median RT was used for the control participants. All post hoc testing was done using Tukey's honestly significantly difference test with $p < .05$. A comparison of the RTs in the moving condition for clockwise compared with counter-clockwise trials was conducted first. Because direction of rotation in the moving condition did not influence RTs significantly (as was also the case in our previous studies), the remaining analyses was collapsed across rotation direction.

Results

The central question addressed by these data is whether neglect can occur for the left in location-based coordinates (left vs. right square) concurrently with neglect in object-based coordinates (left vs. right side of the barbell). An analysis of variance (ANOVA) with one between-subjects variable (group) and three within-subject variables (condition [static or moving], frame of display [square or circle], and target side [left or right]) was performed on the RT correct data. The findings revealed a significant four-way interaction indicating a difference in the performance of the two groups, $F(1, 10) = 9.04$, $MSE = 3.817.6$, $p < .05$. To highlight these differences in performance across the groups, we describe the data for the two groups separately, and the findings for each are plotted in Figure 4. The error rates were 1.3% and 2.8% for the control and neglect groups, respectively, and they were too low to be subjected to statistical analysis. This low error rate is not surprising given that exposure duration was sufficiently long for participants to perform this simple target detection task.

Control participants were able to detect the target 9 ms faster when it appeared in the squares than when it appeared in the circles, $F(1, 5) = 8.5$, $MSE = 127.1$, $p < .02$, with a difference of 18 ms between the circle and the square in the moving conditions and no difference between the circle and the square in the static conditions, $F(1, 5) = 9.7$, $MSE = 80.02$, $p < .05$. No other effects were significant. There is no obvious interpretation for the slight advantage for the squares over the circles and no obvious reason why this was especially so when the circles of the barbell rotated. Of note here, and perhaps most important for the present investigation, is that the control participants demonstrated equivalent detection times for left- and right-sided events and did not exhibit any asymmetry for the side on which the target appeared, nor did side interact with the frame of the display (circle or square). These findings suggest that there are no fundamental biases with regard to side that might be important when interpreting the findings for the neglect participants.

For the neglect participants, the major finding was that the three variables, frame of display (square or circle), side of space on which the target appeared (left or right), and the side of the display in which the target probe finally appeared was identical in the static and moving conditions. In the moving condition, however, because of the rotation, the left of the barbell was on the right of the space, and the right of the barbell was on the left of the space. A comparison between the static and moving conditions, therefore, allows one to determine the contribution of the object frame to detection time in these patients with neglect. Interactions for responding and feedback in the moving condition were identical to those in the static condition, and RT and accuracy of target detection were measured.

Design. The design of the experiment was a $2 \times 2 \times 2 \times 2$ factorial with group (control or neglect) as a between-subjects factor and position of target (in the circles of the barbell [circled object] or in the squares [location]) side of space (left or right), and condition (moving or static) as within-subject factors. Participants performed 8 blocks of 60 trials, four in the static and four in the moving condition.
Condition (static or moving), affected detection time interactively, \( F(1, 5) = 14.9; MSE = 7.58, p < .05 \). It is important to note, however, that a group of the neglected participants showed the significant object-centered effect, which was manifested in an interaction between condition and side of space for targets in the circles. \( F(1, 5) = 38.8, MSE = 1.42, B = 0.005 \) Relative to the static barbell, in the moving condition, the non-affected participants were 11 ms faster to detect the left target and 155 ms slower to detect the right target (see the left panel in Figure 4B). This significant left-sided facilitation and significant right-sided inhibition replicated the findings of our previously established object-centered effect (Benhammi & Tierper, 1994; Tierper & Behrmann, 1996). This result is not surprising, however, given that neglected participants were selected for inclusion in this sample only if they showed either left-sided facilitation or right-sided inhibition in their individual data.

The pattern of data is quite different for the squares compared with the circles; detection was 141 ms faster for targets on the right side of the display, on the right side of the display, and this left-sided inferiority held regardless of whether the barbell moved or remained static (see the right panel in Figure 4B). There was also a joint effect on RT of frame display with the side of the space on which the target appeared, \( F(1, 5) = 65.8, MSE = 1.4153, B = 0.005 \); collapsed across conditions, RTs to targets on left squares for the left target and right target were essentially equal to those on right squares.

Discussion

The first major question addressed in this study concerns whether detection would be observed in both object-centered and location-based frames simultaneously. The key finding from this experiment was that in a group of neuropsychological patients with neglect, the left-sided neglect was observed, manifest as left-sided facilitation and right-sided inhibition for moving over static displays, we also observed poorer performance on the right for targets defined in location-based coordinates. Thus, in a situation in which the left and right sides of two different coordinate frames were presented in a single block of trials, simultaneous performance deficits for targets on the contralesional side of the space can be observed with different reference frames. In this way, we can avoid the neutralization of the left-sided neglect that occurs when targets are defined in a single side of the space. This effect is observed even when the spatial relationship is reversed, in such a way that the right side of the space is represented as the left side, and vice versa.

Experiment 2

Having established the existence of neglect in more than one spatial reference frame, we now turn to a second question which concerns the distribution of attention or the relative extent of neglect in these two frames. It is interesting that the degree of neglect (the difference between mean RT on the left and right over the average of left and right) in Experiment 1 was roughly equal in the two reference frames in the moving condition, with neglect severities of 29.9% and 27.9% in the object and location frames, respectively. What is unclear is whether attention is always equally distributed in these two frames or whether this is simply a response to the contingencies of the sampling of targets in the previous experiment. The probability of target occurrence was equally balanced in the location-based (squares) and object-centered (barbells) frames, and one might imagine that the relative weights of the information in each frame were approximately equal.

To determine whether the distribution of attention or weighting between the frames can be altered so that neglect may be increased or decreased as a function of the target contingencies, in Experiment 2 we manipulated the probabilities of the probe's occurrence in the two reference frames. For example, in some blocks of trials the target appeared in the barbells of the space in the squares only 20% of the time. If attention is equally allocated between the two frames by default and this holds irrespective of the contingencies, then the target probability manipulation should have no effect on RTs. On the other hand, if neglect reflects a pathology of attention, and attention can be flexibly allocated according to the demands or contingencies of the task.

Application of this competition interpretation to the case of neglect is as follows. The brain damage imposes an exaggerated negative bias on left-sided stimuli, and these stimuli are always disadvantageous in a competition between potential left- and right-sided targets. Within such a competitive framework, the effects of the probability manipulation may work in the following fashion. When one frame of reference is probed with probability 72%, the gain on the spatial bias is exaggerated such that the salience of information on the ipsilesional right is enhanced and that on the contralesional left is reduced. This marked left-right difference yields little competition, and the right-sided targets easily win out over the poorly detected left-sided targets, giving rise to right-sided neglect. Left-sided neglect is increased further by decreased probability on the right.

Figure 5 Mean reaction time (RT) for targets on the left and right in object and location coordinates as a function of condition, plotted for the 6 patients (F = patient) individually.
Method

The stimuli and displays used in Experiment 1 were also used in this experiment. The only two methodological differences between the two experiments were that, first, only the neglect patients participated in this experiment and, second, two further training sessions took place for each neglect patient. The same 6 neurophysiological patterns that participated in Experiment 1 took part in this experiment. In these additional sessions, the weighting of a particular reference frame was manipulated within subjects. In one session, there was 80% probability that the targets would appear in the object-centered frame and a 20% probability they would appear in the location-based frame. In the second session, these probabilities were reversed. For half of the participants, the sessions proceeded in the order described above, and for the remaining half, the order was reversed. Within each probability level, eight blocks of 60 trials were run, for a total of 480 trials. At the 80% probability, the number of target-present trials on each of the left and right sides was 128, and at the 20% probability, there were 32 targets on each of the left and right sides, for a total of 336 target-present trials. The remaining 160 trials were target-absent trials. The participants were 100% certain of the particular probabilities at the start of each session, and a block of 60 practice trials was run with this contingency. The analysis procedure used was identical to that in Experiment 1.

Results

If the demands of the task affect the salience or weighting assigned to a representation and if the patients exploit these contingencies, then one might expect to see differing patterns of RT data reflecting the relative sampling probabilities in the two different frames of reference. As in Experiment 1, the error rates in Experiment 2 were extremely low, comprising fewer than 3% of the trials. The analysis of the RT data involved a repeated measures ANOVA on the correct target-present trials with proportion (20% or 80%), frame of display (circle or square), condition (static or moving), and side of space (left or right) as within-subject variables. RT values that exceeded 2 SDs from the mean of a given cell were rejected, and RTs were collapsed across direction of rotation in the moving condition. Figure 6 shows the mean RT and standard error across patients in the static and moving conditions for targets appearing on the left and right as a function of sampling probability and as a function of whether the targets appeared in the circles (object coordinates) or squares (location coordinates).

The most notable finding is that there is a four-way interaction, F(1, 5) = 8.2, MSE = 2,892.7, p < .05. If we consider the pattern of data separately for the circles (Figure 6A) and squares (Figure 6B), the nature of the interaction becomes clearer as is evident from Figure 6A, in both the 20% and 80% probability situations, the signature of object-centered neglect is evident; that is, there is significant left-sided facilitation and right-sided inhibition in the moving condition relative to the static condition. This replicates the pattern of data obtained in Experiment 1 (see Figures 4 and 5 for comparison). There is, however, an effect of the probability manipulation on the severity of object-centered neglect. Although object-centered neglect is observed under both manipulations, the extent of the effect is more pronounced in the 80% condition than in the 20% condition. This increase in the object-centered effect comes about predominantly because of the increased inhibition for targets on the right in the moving condition relative to the static condition. Whereas for left-sided items the difference between the static and moving circles was 140 ms in the 80% probability condition and 164 ms in the 80% probability condition, revealing only a trend toward increased facilitation in the 80% condition, the corresponding difference was marked for right-sided items. Inhibition on the right in the moving condition was only 53 ms in the 20% probability condition but was 166 ms in the 80% probability condition. These findings reflect an increase in the neglect pattern in object-centered coordinates when this frame is probed more often, but the increase is more pronounced for targets on the right.

Turning to the squares, we see location-based neglect in both the 20% and 80% probability conditions, as reflected in the slowed RTs to left targets compared with right targets. It is interesting that whereas there was only a 55-ms difference between detection time for left and right targets in the 20% condition (collapsed across static and moving conditions), patients were 152 ms slower to detect left targets than right targets in the 80% condition, as is evident from Figure 6B. This again reflects an increase in the extent of the neglect as the sampling probability increases.

These findings are summarized in Figure 7, which illustrates the increase in neglect in each of the two reference frames as the probability increases. To illustrate the influence of target probability on neglect in the two reference frames, we have replotted the data in terms of a difference score between RTs for targets on the left and RTs for targets on the right (\( y\)-axis) for static and moving displays separately. The \( x\)-axis refers to the sampling probability. The effect in the circles (or object coordinates; see Figure 7A) is considered separately from the effect in the squares (or location coordinates, see Figure 7B). The error bars reflect the standard error of the differences across the patients between RTs for left and right targets.

If we consider the situation when the display is static, the severity of neglect increases with the probability of the target, as is evident from the left sides of Figures 7A and 7B, but this is much more salient in the case of the circles of the barbell than in the case of the squares. Thus, as probability increases from 20% to 80%, neglect increases from 82 ms to 116 ms in the squares, whereas neglect increases from 93 ms to 176 ms for the barbell circles. Even more striking, when the barbell stimulus, we see a marked effect of the probability of sampling in both the squares and circles. For the circles, neglect increases in the object-centered frame as the sampling probability increases, and because object-centered neglect is reflected as a slowing in right-sided RTs and a speed-up in left-sided RTs, we see negative RT difference scores between the left and right in Figure 7A. Whereas the RT difference between left and right is \(-81\) ms on average in the 20% condition, it is \(-152\) ms in the 80% condition. For the squares, neglect increases from 29 ms to 159 ms in the location-based frame as sampling increases from 20% to 80% probability, as can be seen in the right side of Figure 7B. Taken together, these findings indicate an exaggeration of the neglect effects as the weighting of a particular frame is increased.

Discussion

There are two major results that emerged from Experiment 2. The first finding is that neglect can occur in both location-based and object-centered representations concurrently, which replicates the results obtained in Experiment 1. The second and novel finding is that there is a modulation of the severity of neglect when the sampling probabilities of targets appearing within the location-based or object-centered representations are systematically varied. It is interesting, and perhaps counterintuitive, that as the targets in one frame are probed with a higher probability, the extent of the neglect increases in that frame. Thus, these findings go further than demonstrating the coexistence of neglect in more than one coordinate system by showing that the contingencies of the task can alter the severity of the neglect. As the sampling probabilities are altered, so attention can be
flexibly and strategically allocated between reference frames to accomplish the goals of the task. A particularly interesting aspect of the findings is that the facilitation and inhibition associated with the circles appear to have no obvious effect on the detection of the targets in the squares that is unattenuated by the barbell rotation. Thus, attentional resources allocated to the barbell prior to its rotation do not have benefits for the detection of the square (where detection in the circle is facilitative relative to the static circle) or a disadvantage for the right square (where detection in the circle is inhibitory relative to the static circle). Even when in the high-probability sampling trials in the circle, in which we see the maximum effect of the rotation, there is still no significant difference between the squares when the barbell rotates. This is consistent with when it remains stationary. Thus, despite the physical proximity of the squares and the circle, the costs and benefits associated with the circle do not transfer to the square. These findings have two important implications: First, there appears to be no transfer of the spatial biases between the squares and circles, which suggests that the different frames of reference are independent. Second, the well-established attentional facilitation for one set of stimuli located near a target (C. W. Ericsson & Hoffman, 1972; Hoffman & Nelson, 1981; Tall & Lavie, 1988) is based not solely on proximity, defined as physical distance between stimuli on the screen, but on whether the stimuli both appear within the same reference frame. Although the findings are clear up to this point, there are some aspects of these data that do not match the predictions and call for further discussion. One concerns the pattern of data for squares in the static condition: Although there is an increase in the severity of neglect as probability goes down from the left to the right side, the greater severity in the squares in the moving condition, this is not the case for squares in the static condition. Increasing the probability of detection for squares in the blank condition does not significantly affect the neglect severity in the squares in the static condition, although the 34-ms increase in RT from the 20% to the 75% condition is the same direction as for the other conditions. We suspect that this failure to observe the probability effects in this one condition may be due to inadequate statistical power, but this remains to be demonstrated in future work.

Another puzzling aspect of the data concerns the RTs on the right side of the squares in the frequently probed frame of reference. If it is the case that the "gain" is turned up on the competition, then one might predict that just as the contrast of the squares is increased on the right side, the RTs to the ipsilateral high-probability targets will be facilitated. This was not obvious so, although a detailed examination of the data reveals the following: The mean RT for the right circle in the static condition with 20% probing was 559 ms, whereas it was 556 ms with 80% probing, a difference of 45 ms. A comparison of the RTs for the squares for the different positions across static and moving conditions, reveals median times of 585 ms and 564 ms for the 20% and 80% conditions, respectively, a difference of 21 ms. Although the effect of these RTs reflects significance, they are both in the correct direction. The lack of significance, as in the case mentioned above, may have arisen from the reduced power in such a small sample of the task. A potential concern is that the barbell is operating at the limits of its ability and that we are observing a floor effect. These are elderly, brain-damaged patients, and it may be that these RTs cannot be spaced up much more.

In sum, this experiment confirms that neglect is a delay in detection of the target object. The difference between the circles and squares in the right side of space after rotation produces pattern of behavior that are not statistically different from each other. These results can be explained by the presence of an object. The presence of the left side of space is facilitative for the left circle, whereas the right side of space is inhibitory for the right circle. The facilitation and inhibition can be explained by a view in which information on the left does not contribute to the detection of the target. So, the contralateral spatial information is necessary for the detection of the target object. Furthermore, we have demonstrated that participants are able to orient attention flexibly to particular frames of reference depending on the likelihood of a target's appearance. The pathology of attention, revealed by neglect, is most salient in the frame of reference toward which attention is oriented.

General Discussion

These experiments were designed to determine whether the deficit in processing, contourless stimuli is observed in two different frames of reference. More specifically, we wished to determine whether object-centered neglect might be observed concurrently with neglect in a different set of spatial coordinates. The experiments were motivated by three factors: First, in both the left and right visual field processes clearly show that objects are not perceived in isolation but rather that object perception is determined by the context in which they are found. This context was shown to play a role in spatial attention and neglect (Humphreys & Riddoch, 1979). Second, attentional mechanisms function in both spatial and object-based frames simultaneously in normal participants engaged in the same task (Egly, Driver, et al., 1994; Egly, Raffat, et al., 1994), and their relative contributions can be influenced by task instructions (Vecera & Farah, 1994). Third, the evidence of a frame of reference effect was also observed in the squares but was more clearly seen when the barbell was moving than when the entire display was static (Egly, Driver, et al., 1994). The observation of this frame of reference effect, which we attribute to the notion that neglect is a pathology of attention, because the nature of the neglect, as determined by which frame of reference was dominant, is substantially altered by the patient's participant's attentional strategies (Baylis et al., 1993).

The finding that spatial information is represented in more than one frame is important for theories of neglect. The present data, from single-unit recordings in parietal cortex of nonhuman primates, for example, in relatively early work, Andersen, Bax, and Siegel (1983) and from recent studies with considerable suggestive evidence that neglect can be observed in two frames of reference but that the extent to which neglect manifested itself varies. The evidence for this task (Humphreys & Riddoch, 1994, 1995; Riddoch, Humphreys, Burroughs, et al., 1995; Riddoch, Humphreys, Luckhurst, et al., 1995). Multiple Spatial Representations

What have we demonstrated for the first time is that patients with visual neglect, like normal control patients (Egly, Driver, et al., 1994), represent information in both object-centered and spatially centered frames simultaneously in the same task (see also Bubring & Moscovitch, 1994). This suggests that when targets are presented in close spatial proximity, the objects may have more than one type of visual display, detection performance can be quite different. For example, after the barbell has rotated, detection of targets on the left side of the squares collapsed across static and moving conditions, reveals median times of 585 ms and 564 ms for the 20% and 80% conditions, respectively, a difference of 21 ms. Although the effect of these RTs reflects significance, they are both in the correct direction. The lack of significance, as in the case mentioned above, may have arisen from the reduced power in such a small sample of the task. A potential concern is that the barbell is operating at the limits of its ability and that we are observing a floor effect. These are elderly, brain-damaged patients, and it may be that these RTs cannot be spaced up much more.

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A further issue addressed in this article concerns whether the distribution of salience across the two sets of reference frames is fixed and invariant or is flexible and influenced by task demands (Humphreys & Riddoch, 1995; Vecera & Farah, 1994). By manipulating the probability of targets appearing within the mobile object or the static loci we showed that the pattern of neglect also varied. Specifically, as the probability of a target appearing in the mobile object was increased, the severity of neglect, reflected as a difference between detection of left and right targets, also increased. The increase in severity of neglect was maintained, even when the barbell was not also observed in the squares but was more clearly seen when the barbell was moving than when the entire display was static (Egly, Driver, et al., 1994). The observation of this frame of reference effect, which we attribute to the notion that neglect is a pathology of attention, because the nature of the neglect, as determined by which frame of reference was dominant, is substantially altered by the patient's participant's attentional strategies (Baylis et al., 1993).

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moving and static conditions (see Figure 4 and Figure 6b). What was observed instead (and to an equivalent extent in the moving and static conditions) was that detection of the target object, located 14° away from the hypothesized fixation, was relatively good. These findings provide further evidence for the claim that eye movements are not responsible for the detection of objects in other experiments. Rather, the findings are compatible with the claim that spatial information may be represented in two different frames of reference and that neglect may be observed in both simultaneously.

What Are the Exact Reference Frames?

Although we have established that spatial information may be represented in multiple frames of reference, we need to examine exactly what these reference frames are. We consider the squares and circles in turn. We have argued that the argument in terms of a contrast between location-based and object-based attention, but one might argue that the distinction is better cast as a distinction between two objects, one foreground and one background. The barbell would constitute the foreground object as we have already proposed, but now the squares would form just part of a single background object and not constitute a location-based representation. Under this interpretation, there is neglect only for the left of the object-based representations, with two independent representations for the foreground and background. Given these limitations that normal participants display when processing more than one object at a time (Duncan, 1984; Neisser, 1967), we think this hypothesis is unlikely. Also, it is our suspicion that if we presented a display consisting of only two squares to normal participants, they would be unlikely to consider them as a single object. If we favor the interpretation, therefore, that the squares are part of a non-object-based representation. For example, Patients though, as discussed previously, there are several potential contexts for this finding. This finding is difficult to interpret within some standard accounts of attention that have proposed that the main function of attention is to facilitate processing (Baddeley, 1986; Posner, 1980) and that attending to a stimulus should therefore yield faster RT’s. We have suggested, however, that the increase in neglect is compatible with the idea that patients fail to compete for selectivity. When one item is disadvantaged, as in the case of one item on the left in patients with right-hemisphere lesions, this item will come out more often. The time needed to detect and process it, then, will be substantially increased.

The two implemented mechanistic accounts that incorporate such a competitive processing only in the context of spatial attention, and both predict performance consistent with the view proposed here. Cohen, Romero, Servan-Schreiber, and Frith (1994), for example, explicitly demonstrated in the context of a neural network model that the competition from between left and right stimuli and that neglect patients’ failure to process the left-sided stimuli may be captured by imposing a negative spatial bias on the units representing the left side. Similarly, Moor and colleagues (Moor and Blakemore, 1988; Moor, Holigian, & Marshall, 1997) “lesioned” a neural network, previously designed to simulate aspects of normal attentional behavior, by imposing a greater probability across the spatial or input layer to the attentional mechanism. The probability with which the left-sided information is available is a function of this reduced gain. This is less steep such that left-sided information is being activated to some extent, neglect would be less severe. In the lesioned network, the more likely that left-sided information will be selected as the “winner” and the more severe the neglect.

A possible neural correlate of the exaggeration of neglect as attention to a particular frame of reference is increased is the greater neural activity associated with behavioral intention (Bashford, Goldberg, & Robinson, 1981; Colby, 1990). These increases in the activity of the brain will set the threshold for the competition and increase the differential between information on the left and right, resulting in greater suppression of competition. There is little agreement as to how the frames of the experiments reported here, then, an increase in the extent of left-sided neglect arises from increased competition, the frequently quoted reference frame, and this leads to a heightened asymmetry in the more dominant frame.

Support Frame “Exclusion” for the Competition Hypothesis of Neglect

We have claimed that a view of selective attention as the outcome of a competitive mechanism can account for the findings obtained in this study. This view has also received support from other recent studies on brain-damaged patients with lesions in parietal cortex who show “exclusion” of stimuli that are partially occluded. “Exclusion” refers to the pattern of performance of these patients, who are significantly impaired at processing information on the contralesional left side but only when this information is presented simultaneously with ipsilesional information. For example, A C. N. and C. B. (Ward, Goodrich, & Driver, 1994) reported the presence of a single bar or a single dot on the left side of the display in 75% and 95% of the trials, respectively. When this left-sided information was presented concurrently with right-sided information, report of the single dot or bar fell to about 25% and 9%, respectively, for the 2 patients. It is interesting that the competition between two stimuli, one on the left and one on the right, and extinction of the left stimulus can be observed even when the two stimuli are presented sequentially but within 600 ms of each other (d Pellegrino, Russo, & Frassinetti, 1997). There are other important differences between the pattern in neglect, in which even information appearing alone on the contralesional side is poorly processed. There are other important differences between the pattern in neglect, in which even information appearing alone on the contralesional side is poorly processed. There are other important differences between the pattern in neglect, in which even information appearing alone on the contralesional side is poorly processed. There are other important differences between the pattern in neglect, in which even information appearing alone on the contralesional side is poorly processed. There are other important differences between the pattern in neglect, in which even information appearing alone on the contralesional side is poorly processed. There are other important differences between the pattern in neglect, in which even information appearing alone on the contralesional side is poorly processed.