Running Head: Crossing the Midline: Reducing Attentional Deficits via Interhemispheric Interactions

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Short Title: Crossing the midline affects attentional deficits

Abstract

Patients with unilateral neglect and extinction show a profound lack of awareness of stimuli presented contralateral to their lesion. However, many processes of perception are intact and contralesional stimuli seem to reach a high level of representation, perceptual and semantic. Some of these processes can work to decrease the magnitude of the attentional deficit. Here, we examine two of these intact processes, feature detection and perceptual grouping. First, we demonstrate that feature detection occurs in parallel in the contralesional visual fields of neglect and extinction patients. Second, we attempt to dissociate the influence of perceptual contours across the vertical meridian from the presence of an object or higher-level perceptual unit (or group) that may be created by these contours. We find that connections across the midline affect attentional deficits independently of the objects they may create. This suggests that several effects of grouping on neglect and extinction may be mediated by long-range cortical interactions that arise from connections across the vertical meridian.

Keywords: extinction, neglect, visual search, grouping, interhemispheric interactions, colinearity, interpolation, continuation

Neglect and extinction are behavioral symptoms often seen subsequent to unilateral brain damage. Patients with neglect have a tendency to miss stimulation contralateral to their lesion (contralesional). Extinction often occurs with neglect. Patients with extinction tend to miss contralesional stimulation more often when accompanied by an ipsilesional stimulus. Because extinction occurs when a stimulus is paired with an ipsilesional stimulus, researchers have framed extinction as a competitive deficit in which the stimulus entering the damaged hemisphere (from the contralateral visual field) is at a competitive disadvantage for selection (Humphreys, Olson, Romani, & Riddoch, 1996). The proposed reasons for the competitive disadvantage are numerous and include disruptions in spatial representation, biases in spatial attention, and perceptual deficits. However, attentional accounts have been the most popular probably because several contemporary theories of attention include competitive interactions between simultaneous stimulus events (Bundesen, 1990; Desimone & Duncan, 1995; Duncan, 1996) Thus, experiments with extinction patients may provide a window through which to look at various aspects of normal attention.

Despite the profound deficit of awareness that neglect and extinction patients exhibit, many mechanisms of perception seem to be intact. A red item in a sea of blue and green items 'pops out' independently of the number of blue and green distractors (Esterman, McGlinchey-Beroth, & Milberg, 2000; Laeng, Brennen, & Espeseth, 2002; Riddoch & Humphreys, 1987). This suggests that ‘pre-attentive’ feature detection mechanisms (Treisman & Gelade, 1980) implicated in parallel visual search remain intact in the contralesional visual field.

Even though most of the evidence suggests that parallel detection of features is intact in the contralesional field (although see Arguin, Joanette, & Cavanaugh, 1993; Eglin, Robertson, & Knight, 1989; and Eglin, Robertson, Knight, & Brugger, 1994), it is not normal. In a group of patients with extinction and neglect, Esterman, et al. (2002) showed that the intercepts of the lines describing reaction time as a function of set size were significantly higher for feature search in the field contralateral to the lesion than in the ipsilesional field. This effect occurred even though the search slopes in the contralesional field supported parallel search for the patients. Using time-limited search displays, Pavlovskaya, Ring, Groswasser, and Hochstein (2002) showed that feature search performance is worse in the contralesional field than the ipsilesional field of patients with neglect. However, they did not report results of a set size manipulation so it is unclear whether feature detection occured in parallel for these patients. In addition to overall slower detection of features in the contralesional field, Eglin, et al. (1989, 1994) showed that the number of ipsilesional distractors significantly affected reaction time to detect a contralesional target. This interaction between contralesional and ipsilesional visual fields is characteristic of a competitive deficit. Unlike the other studies, Eglin, et al. also reported that the slopes of search functions within both visual fields were not flat for feature search. However, the search slopes were significantly less than those for conjunction search in these patients. Although on the whole, it seems that the parallel nature of processing may be preserved, it is unclear what mechanisms have been damaged to cause the overall slower and poorer detection of contralesional features especially in the presence of ipsilesional distractors.

For many patients with extinction and neglect, perceptual grouping also seems to be largely intact within the contralesional field (Boutsen & Humphreys, 2000; Driver, 1995; Gilchrist, Humphreys, & Riddoch, 1996; Mattingley, Davis, & Driver, 1997; Pavlovskaya, Sagi, Soroker, & Ring, 1997; Pavlovskaya, Sagi, & Soroker, 2000; Ward, Goodrich, & Driver, 1994). Perceptual grouping strongly modulates the severity of extinction when it is used to associate contralesional and ipsilesional items. Ward, Goodrich, and Driver (1994) showed that grouping contralesional items with ipsilesional items by similarity of form significantly reduced the amount of extinction. Using a different type of grouping, Pavlovskaya, et al. (1997,2000) demonstrated that co-iso-oriented, co-axial gabor patches that align across the vertical meridian are less likely to be extinguished than those that are not (example in Figure 1A). These long-range spatial interactions can be thought of as similar to the Gestalt grouping principle of good continuation (Field, Hayes, & Hess, 1993; Kellman & Shipley, 1991; Palmer, 1999). Mattingley, Davis and Driver (1997) showed that these spatial interactions across the vertical meridian extend to modal and amodally completed contours. Their patients were significantly more likely to detect contralesional probes when they were presented on a surface that connected with the ipsilesional side of the display by either a modal or amodal edge (see Figure 1B and 1C, respectively). The collinearity of edges was also a significant factor in a study by Gilchrist, et al. (1996). They showed that contralesional elements with edges collinear to those of ipsilesional elements were more likely to be seen than those without collinear edges (see Figure 1D for example of stimuli). This effect is similar to that of Pavlovskaya, et al (1997,2000). Directly linking the elements of an extinction display (Driver, 1995) is also an effective way of reducing extinction by grouping, in this case by element connectedness (Palmer & Rock, 1994). Many authors have suggested these effects of grouping on extinction allow attention to be allocated to both the contralesional and ipsilesional stimuli as if they were a single perceptual unit, thus eliminating the competition between them (Ward, et al., 1994; ,14).

INSERT FIGURE 1 ABOUT HERE

Although many types of grouping have been elaborated by the Gestalt psychologists and contemporary researchers (Palmer, 1999), only a subset have been investigated as grouping factors in extinction and neglect studies. Interestingly, the majority of these factors involve some sort of connection or edge across the vertical midline. In the case of Pavlovskaya, et al. (1997,2000) the colinearity of the gabors clearly implies a connection between the elements. For the studies of modal and amodal completion (Mattingley, et al., 1997), although the contours were not physically present, the completed surfaces connected across the vertical meridian. The stimuli used by Gilchrist, et al. (1996) also contained a connection across the midline by virtue of the collinearity of the edges of the square elements. In fact, any stimulus that involves grouping of elements by collinearity, good continuation, or common region (Palmer, 1992) will involve some sort of actual or implied contour across the vertical meridian.

A wealth of psychophysical and physiological data have demonstrated that interactions of collinear elements are often facilitatory in nature and can occur over significant distances. Psychophysicists have described a local association field (Field, et al., 1993) in which elements formed a path in a sea of noise by virtue of their similar orientation and good continuity. The paths formed by elements that were oriented within 60 degrees relative to one another were reliably detected even when the distances between the elements were significantly larger than the elements themselves. Polat & Sagi (1993) also described facilitatory psychophysical interactions between a central gabor and iso-oriented and collinear flankers. They went on to demonstrate facilitation in neural responses (in cat primary visual cortex) related to these psychophysical effects (Polat, Mizobe, Pettet, Kasamatsu, &Norcia, 1998). Some evidence suggests that these interactions can even cross the corpus callosum between lower visual areas where the visual field representations are segregated by hemisphere. Cells in area 17 of different hemispheres with similar orientation preferences had strongly correlated responses when presented with coherent stimuli that connected across the vertical meridian (Engel, Konig, Kreiter, & Singer, 1991; Gray, Koenig, Engel, & Singer, 1989). The correlation between the cells was significantly reduced when the corpus callosum was severed. Facilitatory cortical interactions seem to play a strong role in the mechanism of grouping by collinearity and good continuation.

The existence of these long range cortical interactions related to collinearity and good continuation presents a specific hypothesis for why these grouping factors reduce competition between the collinear elements. Facilitatory interactions between the cortical representations of the elements may help to equalize the representations in the two fields. Certainly facilitation from the intact hemisphere representation may boost the representation of the stimulus in the damaged hemisphere. We hypothesize that these long-range cortical interactions may be at least part of the mechanism by which competition is reduced between grouped ipsilesional and contralesional items. Furthermore, the effect of collinearity on long-range cortical interactions may be dissociable from higher-level effects of object formation. For instance, collinearity may affect selection as described above – by facilitating the cortical representations of aligned elements without necessarily unifying them into a group. On the other hand, object formation may affect selection by uniting the elements into a common substrate for selection (as suggested by other authors mentioned above). Although the status of two elements forming a unified object or group is often confounded with collinearity or connectedness of the elements, these two factors may have independent effects.

In the present study we had two aims. First, we sought to determine whether parallel feature detection mechanisms remain intact in the contralesional field of patients with unilateral neglect and extinction. Parallel search is indicated by functions that do not vary as a function of set size in the contralesional field. However, there may be effects of ipsilesional distractors on contralesional detection that operate independent of set size (i.e. an intercept effect as described above). Second, we set out to examine the basis of a subset of grouping effects on neglect and extinction. Specifically, we examine the extant hypothesis that grouping factors, like collinearity and good continuation, create objects or higher level perceptual units that affect the allocation of visual attention. As an alternative to this, we consider stimuli which involve connections across the vertical midline. These connections form a context in which a standard feature search task will be performed. However, these connections do not clearly create uniform objects or surfaces over which to allocate attention. If we observe effects in connected, but not object, displays that are similar to the effects of grouping into clear perceptual units (or objects) then some of the effects that have been attributed to reduced competition within objects may be due to some other mechanism that is directly related to contours crossing the vertical meridian (e.g. induction of hemispheric interactions).

Patients: Case Histories

Patient S.V. was a 67 year-old female exhibiting symptoms of chronic left neglect and extinction. She suffered a right hemisphere stroke seven years prior to testing. Chronic brain computerized tomography (CT) showed a large infarct in the right middle cerebral artery territory. A reconstruction of the lesion is shown in Figure 2A. Neurological examination showed severe weakness and sensory loss of upper and lower left limbs. S.V. had intact visual fields as assessed by computerized perimetry but shows marked left neglect and extinction on confrontation testing. The Adapted Standard Comprehensive Assessment of Neglect (ASCAN) was used to measure severity of neglect and extinction. S.V. showed an average 5.0 cm rightward deviation on line bisection and left omissions in cancellation tasks. She extinguished left items on bilateral simultaneous stimulation (0/4 left items reported), while having nearly perfect report of left items on unilateral stimulation (3/4 items). S.V. had normal color vision perception as assessed with the Dvorine Pseudo-Isochromatic Plates.

INSERT FIGURE 2 ABOUT HERE

Patient J.F. was a 72 year-old male exhibiting symptoms of neglect and extinction. He suffered a right hemisphere stroke 4 months prior to testing. CT of his brain showed an infarct in the right middle cerebral artery distribution affecting the superior temporal gyrus, inferior parietal lobe, and posterior parts of the frontal lobe. A reconstruction of the lesion is shown in Figure 2B. Neurological examination showed left hemiparesis and sensory loss. J.F. showed an average rightward deviation of 2.3 cm on line bisection. He also missed left items on cancellation tasks and showed visual and auditory extinction on confrontation testing (1/8 left stimuli reported on bilateral stimulation and 8/8 reported on unilateral left stimulation). J.F. had intact visual fields as assessed by computerized perimetry and normal color vision. J.F's health declined toward the end of the study. Thus, he did not participate in all conditions.

Experiment 1

In the first experiment, we will examine feature search in the contralesional visual field of two patients with unilateral neglect and extinction, S.V. and J.F. We expect that thresholds for feature search performance will not vary significantly with the number of distractors within the contralesional field. However, the presence of distractors in the ipsilesional field should significantly slow the detection of features in the contralesional field. We also begin to examine the role of connections across the midline by introducing a simple contextual manipulation.

Methods

Participants

S.V participated in all conditions of this experiment. J.F. participated in all conditions except for conditions related to the set size manipulation.

Stimuli

Stimuli were viewed at a distance of 60 cm. Each stimulus was a search display with a number of elements (Figure 3). Each element was an outline circle 1° in diameter with a line thickness of 0.1°. The elements were arranged on an imaginary circle with a radius of 7.25° centered on fixation. In unilateral displays, the elements were equally spaced around the left or right half of the circle as shown in Figure 3A (example of unilateral left display). In bilateral displays, the elements were equally spaced around the whole perimeter of the circle (Figure 3B). No elements appeared on the vertical or horizontal axes of the display. The elements of non-target displays were all red in color. Target-present displays contained one green element. The target was presented in a randomly chosen location within each type of display. For bilateral trials, although there were elements presented on both sides of the circle, the target location was chosen from among the target locations on the side of the circle relevant to the condition. Thus, for bilateral-left-target trials, the target location was chosen randomly from among all of the locations left of the vertical midline. Arrays could contain 4 (unilateral condition only), 8 (unilateral and bilateral), or 16 (bilateral condition only) elements as shown in Figure 3. A final condition consisted of a bilateral search array of 8 elements surrounded by a circle. The circle grouped the objects into a common region and included explicit connections across the vertical midline. The circle was formed by a luminance edge between the white background of the search array and the gray surrounding region. The radius of this circle was 10° centered on fixation. All stimuli were presented on a Dell Inspiron laptop computer with an LCD screen running at the 60Hz refresh rate. The Presentation software package (**http://www.neurobs.com**) was used to present the stimuli. All procedures were reviewed and approved by the Committee for the Protection of Human Subjects at the University of California, Berkeley and the Veterans Administration Medical Center, Martinez, CA.

INSERT FIGURE 3 ABOUT HERE

Procedure

Before beginning the experiment, we obtained informed consent from both S.V. and J.F. We tested them on each condition twice each day on several days spread across two months. Before each block, the experimenter asked the patients to view arrays of circles on the computer screen and indicate whether a green circle was among the red circles. Each trial began with a fixation point for 1000 ms followed immediately by the search display for a duration that was determined as described below. The patients made an unspeeded response, "yes" (i.e. green target circle present) or "no" (i.e. no green target present), to each trial. The experimenter monitored eye movements and excluded a trial if the patient deviated from fixation or if the patient reported not seeing the trial at all. These responses totaled less than 1% of all responses and had no effect on calculation of the final threshold.

We used an adaptive psychophysical procedure (a.k.a. staircase procedure) to adjust the presentation time of the search array until performance reached 75% correct. This gives a measure, threshold presentation time, of how long a stimulus must be on the screen for a patient to reliably detect the presence of a target. Higher threshold presentation times indicate longer searches while shorter times indicate shorter search durations. We assume that all covert searching is taking place while the stimulus remains on the screen. . If this assumption is true, then the measure should reflect primarily the amount of time that the participant is searching the display for the target. The threshold presentation time measure is different from reaction time in that it removes the influence of motor factors (e.g. time to prepare and execute the motor response and any factors that may influence this) on the estimate of search duration. Reaction time of the participant has no influence on the calculation of the threshold. No difference in threshold presentation time between conditions with similar set sizes implies parallel processing. In the case of serial processing, each stimulus location will need to be attended in order to be evaluated for the task. If the stimulus duration is too short, then not all of the stimulus locations will be attended and the participant will be forced to guess whether or not a target was present and thus be likely to make an error response. These errors will increase threshold presentation time for conditions with more distractors. Larger numbers of distractors will lead to a higher probability of not seeing the target within the duration of the stimulus and thus a larger number of errors. Longer presentation durations will be required to reduce the number of errors to the target value of the staircase procedure.

Separate, but interleaved staircases estimated threshold presentation time (TPT) for feature detection in the left and right sides of the display. Different conditions (e.g. unilateral, bilateral, set size manipulations) were run in separate blocks. Each staircase began with the search array duration at 800 ms. Presentation duration was then adjusted according to rules described by Kaernbach (1990) for convergence on 75% correct responses. The presentation duration was adjusted in increments of $\Delta T = 6 - [(r+1) - \mathrm{mod}((r+1),2)]/2$ screen frames, where r = the number of reversals encountered and $\mathrm{mod}(a,b)$ is the remainder after division of a by b. Each screen frame was approximately 16.6 ms long. The staircase terminated after 10 reversals. The last 8 reversals were used to calculate an estimated threshold presentation time via the midpoint estimate procedure. On each trial there was a 0.5 probability that the trial would contain a target.

Both S.V. and J.F. participated in 6 blocks of each condition. Two blocks of each condition were collected on each day. The patients were tested on 3 separate days spread across 2 months. The order of the blocks on each day was random. The patients were allowed to rest for a few minutes between each block.

Results

We obtained a threshold presentation time for each condition in eight testing sessions for S.V. and six sessions for J.F. Patient S.V. saw all five types of displays; unilateral 4, unilateral 8, bilateral 8, bilateral 16, and the condition with the surrounding circle (connected condition). Her data were entered into a 5 (type of display) x 2 (side containing target, left or right) ANOVA. Patient. J.F. saw the unilateral-8, bilateral-8, and connected conditions. His data were entered into a 3x2 ANOVA. J.F. was unable to participate in the set size manipulation because of declining health at the time we decided to add this manipulation to the study. The random factor in both ANOVAs was the sessions in which the patients participated.

INSERT FIGURE 4 ABOUT HERE

The data averaged across the various sessions are shown in Figure 4A for S.V. and Figure 4B for J.F. For S.V., there was a main effect of the type of display, $F(4,28) = 18.80$, $p < 0.001$, a main effect of the side of the target, $F(1,7) = 470.94$, $p < 0.0001$, and a significant interaction of these two factors, $F(4,28) = 19.12$, $p < 0.001$. To characterize the interaction, we first analyzed the simple effect of the type of display factor for right side conditions and found no significant effect, $F(4, 28) = 0.18$, n.s. As a result, we will include only left-side conditions in all further analyses for S.V. To test for a set size effect for S.V. we evaluated planned comparisons between the unilateral-4 and unilateral-8 conditions as well as the bilateral-8 and bilateral-16 conditions. There was no significant difference between the two unilateral conditions, $F(1,28) = 0.001$, n.s., or the bilateral conditions, $F(1,28) = 0.09$, n.s. However, there was a significant difference between bilateral and unilateral displays of the same set size (unilateral-8 vs. bilateral-8), $F(1,28) = 37.28$, $p < 0.001$. This difference was revealed by a planned comparison. The unilateral-4 condition also showed a significantly lower TPT than the bilateral-8 condition, $F(1,28) = 25.10$, $p < 0.01$. Two final planned comparisons revealed an effect of the surrounding circle. Here, we compared the circle condition to the bilateral condition (with no surrounding circle) of the same set size (bilateral-8) and found a significant reduction of TPT, $F(1,28) = 55.60$, $p < 0.001$ for the circle condition. The TPT in the circle condition was not significantly different from that of the unilateral-8 condition, $F(1,28) = 1.82$, n.s. or the unilateral-4 condition, $F(1,28) = 1.32$, n.s.

We replicated these basic results with J.F. For J.F., there was a main effect of the type of display, $F(2,10) = 7.24$, $p < 0.02$, a main effect of the side of the target, $F(1,5) = 13.49$, $p < 0.02$, and a significant interaction of these two factors, $F(2,10) = 7.68$, $p < 0.01$. As expected, there was no effect of the type of display for detection of ipsilesional targets, $F(2,10) = 0.07$, n.s. and thus results for this side were not analyzed further. TPT for contralesional targets was significantly longer on bilateral trials than on unilateral trials, $F(1,10) = 24.79$, $p < 0.01$, replicating our finding in S.V. A planned comparison between the bilateral and circle conditions again showed that the circle significantly reduced TPT, $F(1,10) = 13.76$, $p < 0.01$. The circle condition was not significantly different from the unilateral condition (unilateral-8 vs. circle), $F(1,10) = 1.61$, n.s.

Discussion

In Experiment 1 we demonstrated that feature detection can occur in parallel in the contralesional visual field. This is consistent with several other studies of feature search in patients with neglect and extinction. Additionally, distractors in the ipsilesional field significantly slowed the detection of targets in the contralesional field. A similar effect found by Eglin, et al. may have reflected a motor component of neglect because patients were pointing to targets in that study. Because our staircase procedure removes this motor component from the estimate of the threshold, our results suggest that this effect is due to perceptual and attentional factors rather than a motor component of neglect. Most importantly, the contralesional slowing was significantly reduced by drawing a circle around the search display. This circle created explicit connections across the midline and thus should have caused interactions between the hemispheres across the corpus callosum. The results of this experiment are mirror those found in several studies of grouping effects on visual attention deficits. However, with the evidence presented in Experiments 2 and 3, we will argue for a new mechanism that may be at work in generating at least part of the effect.

One way to interpret the reduction of deficit in the circle condition would be to attribute it to grouping the left and right sides of the search array together. In this case, the grouping factor of common region (Palmer, 1992) may be at work. Interestingly though, another strong grouping factor, proximity of the search array elements, did not seem to affect performance in the task. As set size increased, the inter-element distance decreased, effectively manipulating the proximity of the elements. One may have expected that this would have caused a stronger grouping of the array into a circle and thus reduce extinction. This was not the case.

The surrounding circle introduced several extraneous stimulus changes unrelated to the connections across the midline. Although the local environment of all of the search elements remained the same, the background region outside the contour of the circle became significantly darker. This could have increased the overall salience of all of the elements within the search array. Thus, the reduction of deficit could be due to these factors rather than the connections across the midline. To control for this factor, we undertook a second experiment.

Experiment 2

In Experiment 2 we control for some of the extraneous stimulus factors that confounded the interpretation of the connected condition of Experiment 1. To achieve this we designed a stimulus that was physically identical between connected and not connected conditions except for a 90° rotation around fixation. The condition is identical to the connected condition of Experiment 1 except that the circle was broken into two parts either along the vertical midline (not connected condition, Figure 5A) or the horizontal midline (connected condition, Figure 5B). A break across the horizontal midline preserves connections across the vertical midline while a break across the vertical midline destroys these connections between the fields.

Methods

Participants

S.V was the only participant in this experiment.

Stimuli

The stimuli were identical to those of the "connected" condition of Experiment 1 (Figure 2E), except that the surrounding circle was broken into two segments. The break extended either along the vertical midline or the horizontal midline and consisted of extending the background gray along the appropriate midline. The width of the break was 2.1°. The medial corners of the semicircles were removed and replaced with diagonal edges to disrupt collinearity and ensure that the edges of the circle were less likely to be perceived as connected. The stimuli are shown in Figure 5.

INSERT FIGURE 5 ABOUT HERE

Procedure

All procedures and parameters of the experiment were identical to Experiment 1 except for the testing session arrangements. S.V. completed six blocks of each condition across two subsequent days. She completed 3 blocks of each condition on each day. The order of the conditions on each day was randomized. A few minutes break was given between each block.

Results

We obtained average threshold presentation times for both the vertically-split and horizontally-split displays for both left and right-side targets. The threshold presentation times for each condition were averaged across sessions. The results are shown in Figure 6. The 2 x 2 ANOVA revealed that threshold presentation time was significantly greater for left targets than for right targets, $F(1,5) = 38936$, $p < 0.000$. Threshold presentation time was significantly less when the display was split horizontally than when it was split vertically, $F(1,5) = 24.03$, $p < 0.004$. The interaction of these two factors was also significant, $F(1,5) = 20.79$, $p < 0.006$. The difference between horizontally-split and vertically-split displays was evident only in left target conditions. An analysis of the simple effects showed that the split manipulation had a significant effect for left side targets, $F(1,5) = 46.31$, $p < 0.01$, but did not have a significant effect for right side targets, $F(1,5) = 0.127$, n.s.

Discussion

By introducing the displays used in Experiment 2, we could directly compare a context in which there were connections across the midline to one in which there were no connections across the midline. For displays with targets on the left side, there was a clear advantage to having connections between the two visual fields. Because the two displays were simple 90° rotations of one another, the effects cannot easily be attributed to low-level stimulus differences. Nevertheless, the results might still reflect an object-based effect rather than differences due simply to the connections across the midline. The condition with connections broken across the horizontal meridian (Figure 4B) creates an object that continues across the vertical midline. This may allow the visual system to select the entire object region and treat it as one item to be processed rather than separate right and left pieces. This object-based account (Gilchrist, et al., 1996; Ward, et al., 1994) may be able to explain our results without a need to address the connections across the midline by themselves. In fact, Farah, Wallace, and Vecera (1993) found similar results in an experiment with horizontally and vertically-oriented blobs (or groups)[1]. They provided an object-based attention account of their findings. Thus, in a final experiment we attempted to dissociate the object and connections effects that have been working together in the previous two experiments.

Experiment 3

To minimize object effects in the stimulus, we created displays in which the search elements were the same as before but not fully enclosed within a region. We then placed two flanking lines either above and below or to the left and right of the array. When the lines were above and below the search array, the horizontal lines extended across the vertical midline. In the other condition, the vertical lines did not cross the vertical midline when they were to the left and right of the display. A direct comparison between these conditions allowed us to evaluate the effect of connections across the vertical midline independent of the creation of an object on which the search array is located. Low-level visual characteristics of the display were controlled because the two displays were 90° rotations of one another.

Methods

Participants

S.V. was the only participant in this experiment.

Stimuli

The stimuli consisted of search arrays identical to the bilateral, 8 element condition of Experiment 1. All parameters were the same except that a pair of straight black lines was introduced. These lines appeared either at the top and bottom of the array (connected condition, Figure 7A) or to the left and right of the array (not connected condition, Figure 7B). The center of each line was situated 9° from fixation. Each line was 10° long and 0.1° thick. The lines extended about half as far into each visual field (from midline) as the search array itself. There was also a third condition in which no flanking lines were present. This condition was identical to the Bilateral-8 condition of Experiment 1 (Figure 3C).

INSERT FIGURE 7 ABOUT HERE

Procedure

All procedures and parameters of the experiment were identical to Experiment 1 and 2 except the testing session sequence. S.V. completed six blocks of each condition across two subsequent days. She completed 3 blocks of each condition on each day. The order of the conditions was randomized each day. A few minutes break was given between each block.

Results

We averaged the threshold presentation times across sessions for each condition. The data from the vertical lines and horizontal lines conditions were entered into a 2 x 2 ANOVA. The results of the No Lines condition will be discussed separately below. The results are shown in Figure 8. Threshold presentation time was greater for left targets than for right targets, $F(1,5) = 933.9$, $p < 0.001$. Additionally, the orientation of the flanking lines significantly affected the threshold presentation time. Threshold presentation time was lower for horizontally-oriented flanking lines that crossed the vertical meridian than for vertically-oriented lines, $F(1,5) = 13.83$, $p < 0.02$. These two factors interacted significantly, $F(1,5) = 10.5$, $p < 0.03$. An analysis of the simple effects showed that horizontal flanking lines reduced threshold presentation time for left side targets, $F(1,5) = 22.34$, $p < 0.01$. The simple effect of the connections manipulation was not significant for right side targets, $F(1,5) = 1.07$, n.s. The threshold presentation time in the No Lines condition (left targets) was significantly greater than that in the vertical lines condition (left targets), $F(1,5) = 31.766$, $p < 0.002$.

Discussion

In Experiment 3, we attempted to isolate the effect of connections across the midline and dissociate it from effects that could arise from the existence of an object created by the enclosure of the search array. To accomplish this, we flanked the search array with two lines either above and below or to the right and left (Figure 7). The horizontal flankers created connections across the midline while vertical ones did not. Even in the absence of a clear object, connections across the vertical midline significantly diminished the attentional deficit compared to connections that did not cross the vertical midline.

Our claim that no object is created under these conditions is difficult to justify but this is due, in part, to the fact that it is unclear what an object is beyond giving a description of our own intuition. Some have attempted to give formal definitions of what constitutes an object (Feldman, 2003), although none is widely accepted. In our displays, one could argue that partial closure of the region created an “object” or perceptual unit that encompassed the search array. In this case, one may be able to explain our effects by appealing to extant models of how grouping influences extinction and neglect (e.g. by forming one perceptual unit and thus eliminating competition). However, the degree of “objecthood” caused by the flanking lines should be identical in the horizontal flanker and vertical flanker conditions. Thus, even if there is an object formed by the flanking lines, it cannot explain the difference between our vertical and horizontal flanker conditions. This suggests that connections across the vertical meridian of the viewer have an effect on extinction independent of whether they create an object or perceptual unit that encompasses the search array.

The difference between the vertical and horizontal flanker conditions could be attributed to differential cuing between the two conditions. Vertical flanker conditions contain a large line in the periphery of the visual field that may capture attention on the right side of space and thus increase the threshold presentation time on the left side of space relative to the horizontal line condition. If the vertical right line was causing a capture of attention, one would expect that it would cause higher threshold presentation times on the left for the vertical flanker condition than for the No Lines condition.

However, the results of the No Lines condition suggests that this is not the case. The threshold presentation time in the No Lines condition is significantly greater than that in the vertical lines condition.

Another interpretation of the results is that the patient may have seen the dots grouped into pairs horizontally in the horizontal lines condition and into vertical pairs in the vertical line condition. This would provide horizontal “objects” over which attention could be distributed in an object-based account. To rule this out, we asked S.V. how she perceived the organization of the dots in the various conditions of Experiment 3. In no case did she describe them as paired horizontally or vertically. In addition to recording her spontaneous response to this question, we also asked her directly whether she saw them as pairs of dots in either condition. She indicated that she could see them that way but that she had never noticed that before. We also asked 10 normal participants in other studies in the lab to make similar judgments about the displays of Experiment 3. None of the subjects spontaneously reported seeing the dots grouped into pairs. When asked directly whether they perceived the dots as grouped into pairs, the participants indicated that they could see them that way but that it was not their natural organization of the stimulus. We believe that this makes it unlikely that grouping the dots into horizontal vs. vertical pairs accounts for the results.

General Discussion

Our results support two major conclusions. First, feature detection can occur in parallel in the contralesional field of patients with unilateral neglect and extinction. Second, the threshold presentation time for detecting a target in the extinguished field can be affected by a simple contextual manipulation, connections across the midline. The results of our first experiment are consistent with the majority of published studies examining feature detection in the contralesional field of patients with neglect or extinction. Features seem to pop-out in the contralesional field regardless of the number of distractors present within the same field. However, contralesional feature detection is not normal. Contralesional features appear to be registered more slowly and this slowing increases when ipsilesional distractors are also present.

The effect of connections across the vertical meridian cannot be accounted for by the creation of an object or perceptual unit that reduces competition between the sides of the search array. Rather, the connections seem to have an independent effect. We propose that connections across the vertical meridian in visual stimuli promote long-range cortical interactions across the corpus callosum. The existence of such facilitatory interactions has been established by work in both psychophysics and physiology (9). These interactions between the hemispheres may boost other processing such as feature detection in the damaged hemisphere resulting in less attentional deficit.

The connections used in our stimuli were completely contextual to the search display and they were task-irrelevant. Given that the facilitatory interactions described by others have occurred primarily between neurons tuned to similar features such as orientation and collinearity, it is unclear why two simple contextual lines would affect feature encoding of the search array elements. We would argue that the facilitation arising from the connections is not constrained to the representations of the inducing lines alone. Certain experiments on visual extinction are consistent with this global influence. As discussed earlier, Mattingley, at al. (1997) observed that a probe was extinguished less frequently when it was within a region that constituted an illusory surface formed by collinear edges than when the surface was not present. This effect occurred even though the probes were not the items actually being grouped to create the illusory contours. The inducing elements were also task irrelevant and a significant distance from the probes. A prediction of our account would be that the probes would be better detected in the condition with the illusory surface even when the probes were not on the illusory surface itself. Instead, the probes could be flanking the inducers of the surface. This prediction has not been tested, but such evidence would be consistent with our proposal that contextual manipulations in attentional deficits can influence the perception of a large area and not only the elements that are involved in creating the context. The mechanism for this may be related to arousal mechanisms cited by Robertson, Mattingley, Rorden, & Driver (1998) in their explanation of general alerting effects on extinction behavior. They found that loud alerting noises caused a general improvement in performance in the contralesional visual field. **.** The mechanism of this effect is thought to be mediated by tonic arousal mechanisms associated with ascending thalamic-mesencephalic projections that react to the salience of events in the world. It may be the case that the increased perceptual salience of items on the contralesional side of space caused by the facilitatory long-range cortical interactions activates this system to a small extent and thus redirects some attention to the contralesional visual field. Importantly, these effects can be non-stimulus specific, affecting all stimuli within the visual field,

Because our patients showed symptoms of both neglect and extinction in clinical tests and our experiments, we can not determine whether our contextual manipulations primarily affected the extinction deficit or the neglect deficit. However, all of the previous research cited in the introduction was done using extinction paradigms.

Furthermore, our patient J.F. showed very little evidence of neglect in our task. His threshold on unilateral left trials was not significantly different from that of unilateral right trials. Thus, in his case, any effect of the grouping manipulation must have been a reduction of extinction. Unfortunately, because J.F. was not able to participate in the other experiments, this conclusion cannot be extended to the effects of connections across the midline. Further research in which the connections across the midline manipulation is done with both unilateral and bilateral displays should allow this issue to be addressed.

Explanations of grouping effects on neglect and extinction may need to be reconsidered in light of our results. Experiments like those of Pavlovskaya, et al. (1997, 2000) and others have demonstrated modulations of attentional deficits when grouping between the right and left fields is induced. The results have been suggestive of a role for grouping that reduces competition between elements by creating a single perceptual unit. However, we have shown that some portion of these effects may be attributed to the connections across the midline alone. Future research will hopefully elucidate the neural mechanisms by which these connections have their effect.

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Author Notes

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Footnotes

1. We thank an anonymous reviewer for bringing this paper to our attention.

Figure Captions

Figure 1: Stimuli from experiments demonstrating effects of colinearity and grouping across the midline as well as contour integration. (A) A subset of the stimuli used by Pavlovskaya, et al. (1997, 2000). Colinear, iso-oriented elements (left panel) reduced extinction relative to aniso-oriented or non-collinear elements (right panel). (B) Mattingley, Davis, and Driver (1997) used illusory contours to connect the two visual fields. In the left panel, the inducing pacman-shaped elements form illusory contours across the vertical midline while those in the right panel do not. The stimuli with the illusory contours reduced extinction. (C) A representation of stimuli used by Mattingley, Davis, and Driver (1997) to show the effects of amodal completion on extinction. The left panel shows two parts of an occluded black bar. The right panel shows the same two parts of the bar with a gap between them and the occluder. This causes them to be perceived as unconnected. Extinction is greater in the unconnected case than in the connected case. (D) The left panel shows two squares that have greater collinearity between themselves than the two circles in the right panel (Gilchrist, et al., 1996). The squares form a better connection by virtue of their collinear top and bottom edges. (E) The left panel shows a representation of the stimuli used by Driver (1995) to demonstrate the effects of element connectedness on extinction. The right panel shows the control condition without grouping.

Figure 2: Reconstruction of brain lesions. Both patients underwent computerized tomography of the brain. **A.** S.V. lesion reconstruction. **B.** J.F. lesion reconstruction.

Figure 3: Stimulus displays for Experiment 1. Black circles represent the target. Targets were green in color in the experiment. Gray circles represent the red distractors. **A.**

unilateral display, set size 4. **B.**unilateral display, set size 8. **C.** bilateral, set size 8. **D.** bilateral, set size 16, **E.** bilateral array with connecting contours, set size 8.

Figure 4: Average threshold presentation times (TPTs) for Experiment 1. Filled bars: left visual field targets. Unfilled bars: right visual field targets. **A.** Average TPTs (in ms) for S.V. plotted as a function of the type of display and the visual field of the target **B.** Average TPTs for J.F. Error bars represent standard errors of the mean.

Figure 5: Stimulus displays for Experiment 2. Black circles represent the target. Targets were green in color in the experiment. Gray circles represent the red distractors. A. The connections across the vertical midline have been broken by extending the background along the vertical midline. B. This is a simple rotation of the stimulus in panel A. Now, the connections across the vertical midline have been restored while those across the horizontal midline have been broken.

Figure 6: Results for Experiment 2. This graph presents the average threshold presentation time for detection of the target as a function of the side of the target and whether or not the display was connected across the vertical midline. The dark bars indicate conditions in which the target was on the left and the clear bars indicate conditions with the target on the right. Error bars represent the standard error of the mean.

Figure 7: Stimulus displays for Experiment 3. Black circles represent the target. Targets were green in color in the experiment. Gray circles represent the red distractors. A. Connections across the midline are present in this stimulus. They are formed by the two lines flanking the search array above and below. B. The connections across the vertical midline are removed by rotating the previous display by 90 degrees.

Figure 8: Results for Experiment 3. This graph presents the average threshold presentation time for detection of the target as a function of the side of the target and whether or not the display was connected across the vertical midline. The dark bars indicate conditions in which the target was on the left and the clear bars indicate conditions with the target on the right. Error bars represent the standard error of the mean.

Figure 1:

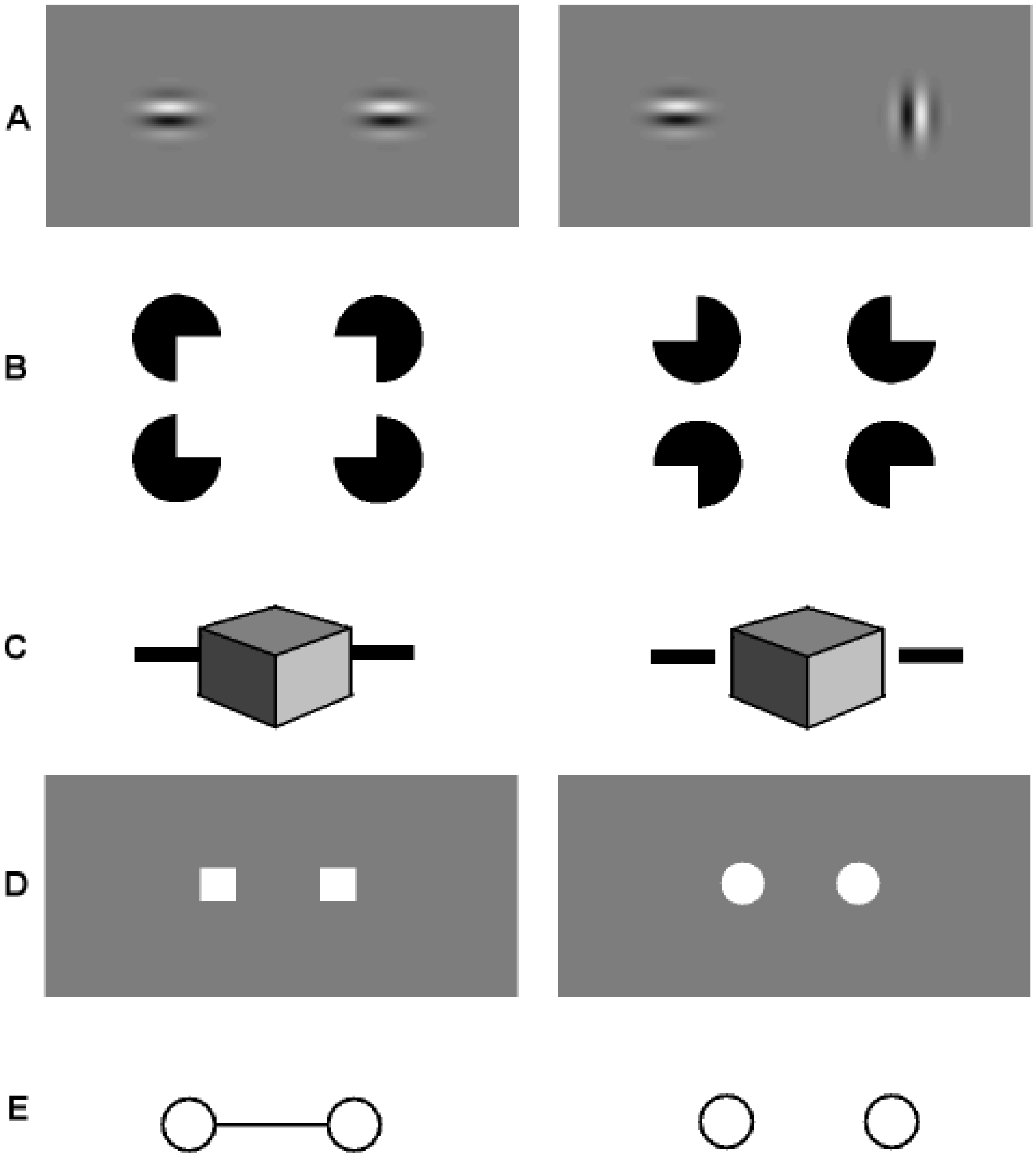

Figure 2: Lesions

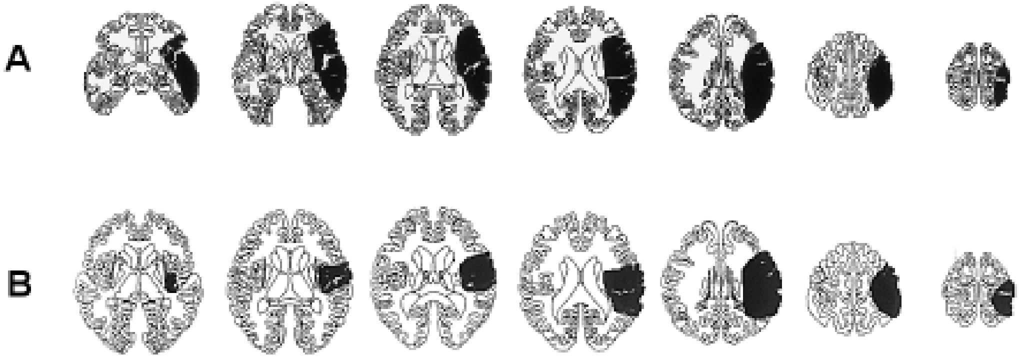

Figure 3: Experiment 1 Stimuli

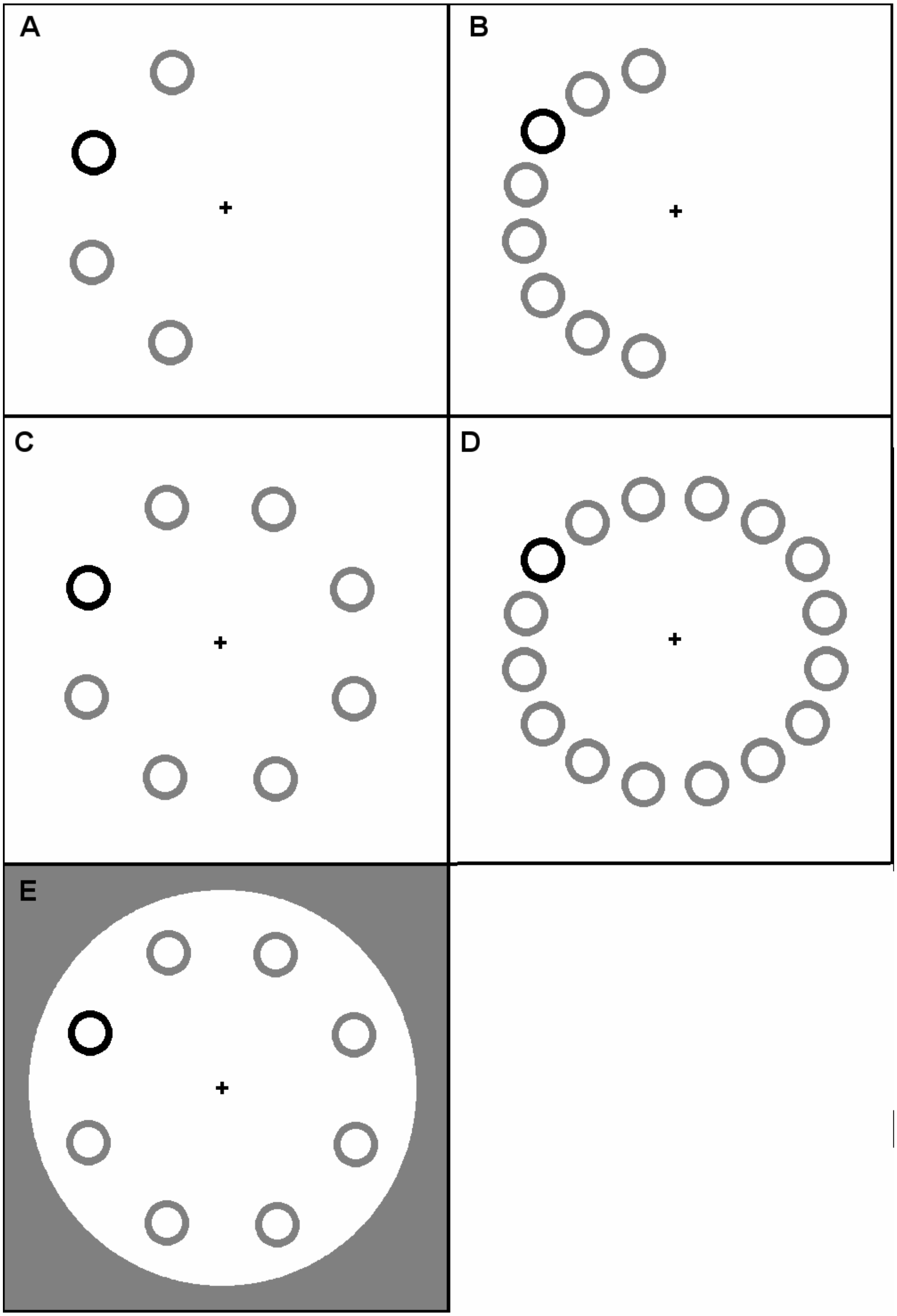

Figure 4: Experiment 1 Results

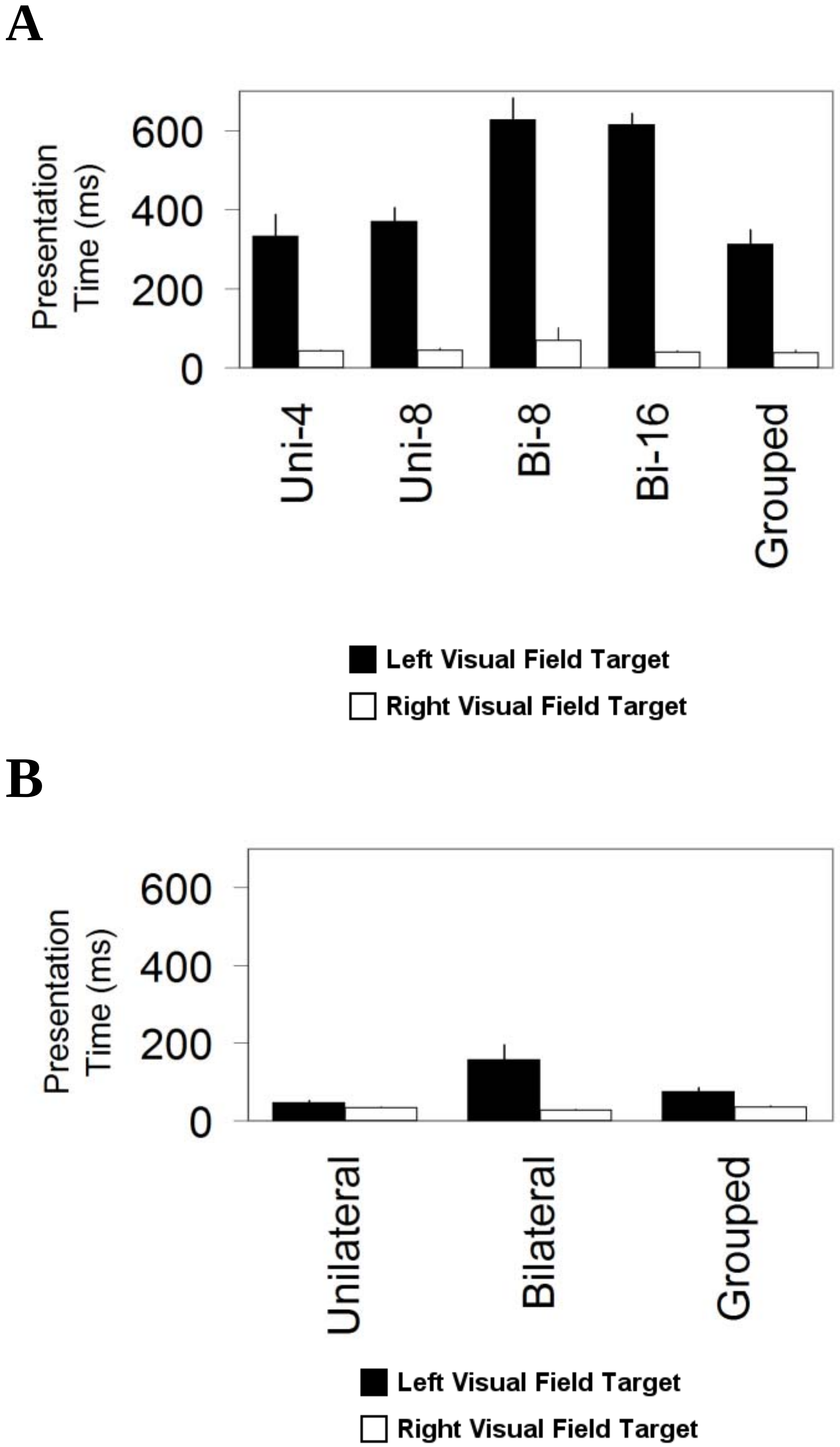

Figure 5: Experiment 2 Stimuli

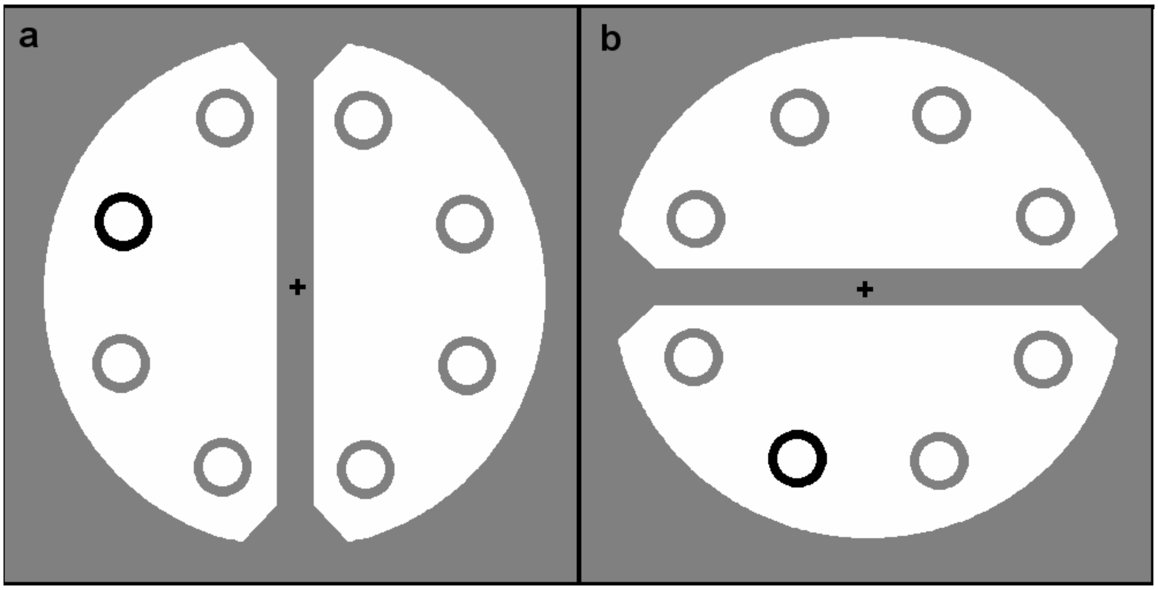

Figure 6: Experiment 2 Results

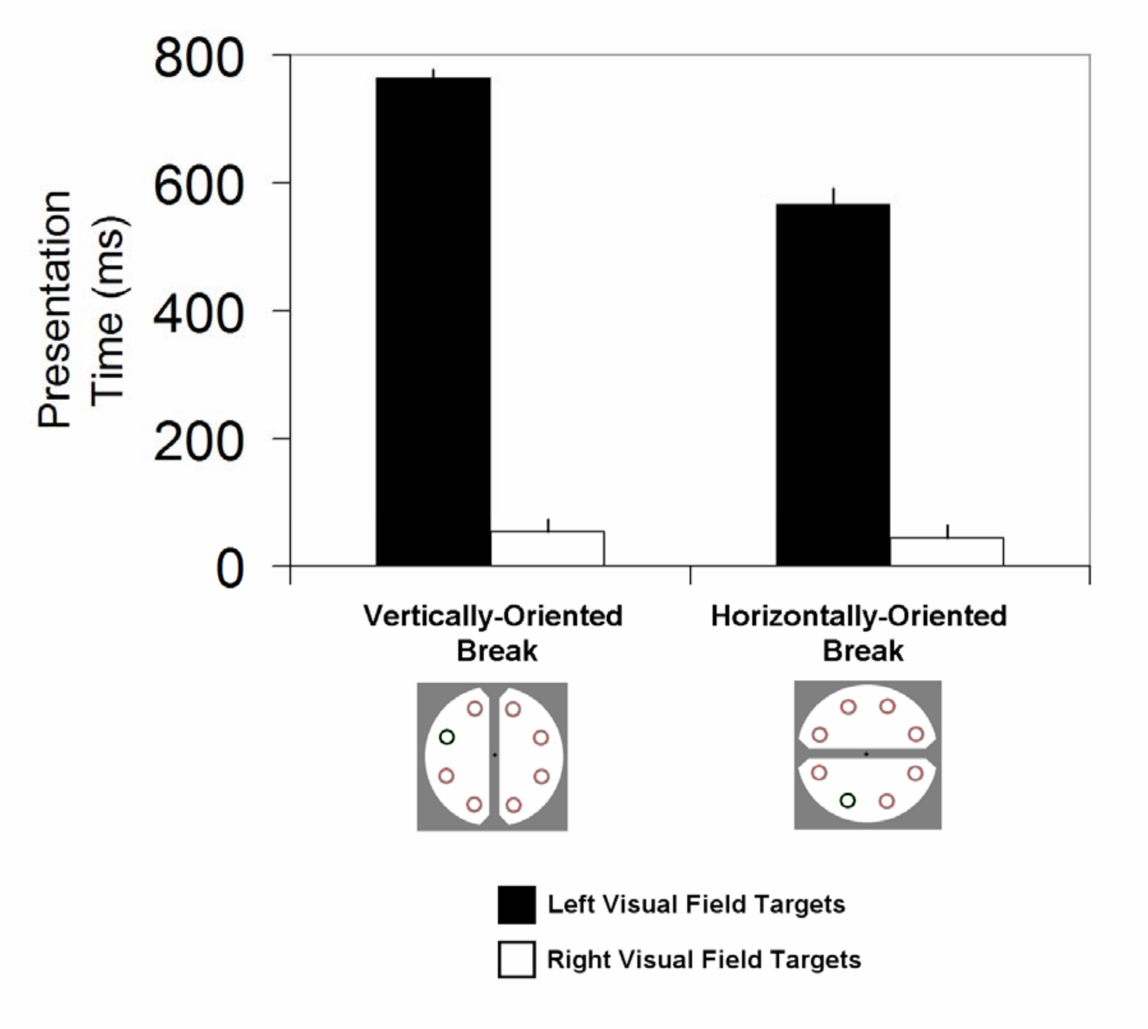

Figure 7: Experiment 3 Stimuli

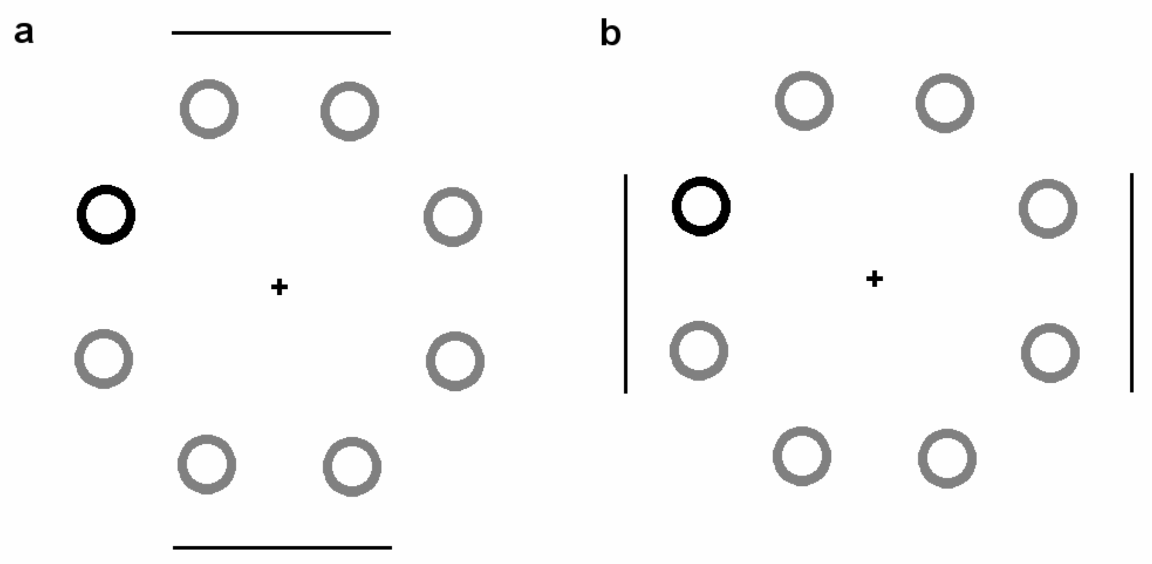

Figure 8: Experiment 3 Results