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RESEARCH ARTICLE

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The attentional repulsion effect in perception and action

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Abstract The attentional repulsion effect refers to the perceived displacement of a Vernier stimulus in a direction that is opposite to a brief peripheral cue. The twofold purpose of the present study was to: (1) replicate the perceptual effect using a Vernier discrimination task, and (2) determine whether the effect would also affect action using a guided localization task. A perceptual attentional repulsion effect was found in experiment 1 and a similar effect was found in experiment 2, with a computer mouse localization task, and in experiment 3, with a guided limb localization task (in both cases pointing responses were biased in the direction opposite to that of the cue). These findings suggest that the attentional repulsion effect occurs early in visual processing, probably affecting the receptive fields of the position-coding units in primary visual cortex before "object-perception" and "object-action" information is segregated into separate pathways.

Keywords Attention · Perception · Action · Cues · Human

Introduction

The abrupt appearance of a new object in the visual field (i.e., a peripheral cue) is known to have important consequences regarding the allocation of visual attention. One such consequence is that the peripheral cue typically causes a reflexive orienting of the focus of attention to the spatial location of the cue. During the time that attention dwells at the cued location, targets that appear within the focus of attention are responded to more quickly than are targets that appear at nonattended (i.e., uncued) locations (Berger et al. 1999; Posner 1980; Yantis and Hillstrom 1994). When attention is withdrawn from the cued location, that location subsequently becomes inhibited through a mechanism known as inhibition of return. This inhibitory effect lasts for a relatively long period (perhaps as long as 3,000 ms), during which targets at the cued location are responded to more slowly than are targets at uncued locations (Posner and Cohen 1984; Bennett and Pratt 2001; for a recent review, see Klein 2000). Thus, peripheral cues are thought to initially capture attention at cued locations and then subsequently inhibit the return of attention to cued locations.

In addition to the facilitatory and inhibitory consequences of peripheral cues, Suzuki and Cavanagh (1997) have conducted a series of experiments showing that brief peripheral cues also displace stimuli away from the focus of attention. They term this an "attentional repulsion effect," and have demonstrated the effect by briefly presenting one or two peripheral cues just before a briefly presented Vernier stimulus. In a specific example of one of their experiments, two cues (the outlines of circles) were presented above and to the right, and below and to the left, of a central fixation point for 30 ms. Then, the Vernier stimulus was presented for 60 ms, with one vertical line appearing above the fixation cross and one vertical line appearing below the fixation cross. Upon the offset of the Vernier stimulus, a pattern mask was presented for 255 ms. Using two alternative forced choice responses (offset clockwise or counterclockwise), Suzuki and Cavanagh determined the spatial locations of the two lines when subjects were equally likely to make either response. In the present example, these spatial locations were when the top line was displaced to the right of the bottom line. In other words, subjects perceived the top line as being further left of the bottom line than was actually the case. They concluded that the peripheral cues caused the perceived displacement of the lines in the opposite direction of the cues (i.e., the cue repulsed the Vernier stimulus). Suzuki and Cavanagh have shown the robustness of the attentional repulsion effect by demon-

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strating that it occurs with various cue and Vernier stimulus presentation times.

Following Suzuki and Cavanagh's (1997) initial work on the attentional repulsion effect, the present study has a twofold purpose. The first purpose is to replicate the attentional repulsion effect on the perception of a Vernier stimulus. The second purpose is to determine whether the attentional repulsion effect also affects guided limb movements. This latter purpose arises from evidence that there is a dissociation between effects on object-perception and effects on perception-for-action. This dissociation is thought to occur because visual information for object perception is processed through the ventral-temporal visual pathway, whereas visual information for object-based action is processed through the dorsal-parietal visual pathway (Goodale and Humphrey 1998; Goodale and Milner 1992; Milner and Goodale 1995).

The dissociation between visual information for perception and action has been demonstrated in a variety of studies (Goodale and Murphy 1997; Wraga et al. 2000), including several that have found differential effects of the Ebbinghaus illusion on perception and action (Aglioti et al. 1995; Haffenden and Goodale 1998, 2000; Haffenden et al. 2000; but see also Franz et al. 2000; Vishton et al. 1999). The Ebbinghaus illusion has long been known to affect object-perception. The perceptual illusion is that the size of an inner target circle is mediated by the size of the surrounding distracter circles. Thus, if the surrounding circles are smaller than the inner circle, the inner circle appears larger than it really is. Likewise, if the surrounding circles are larger than the inner circle, the inner circle appears smaller than it really is. This perceptual illusion of size does not, however, affect actions made toward the inner circle. When subjects made grasping movements to an inner target disc, their grip aperture before they contacted the target disc was not affected by the size of the surrounding distracter discs. In other words, the grip aperture was based on the true size of the target disc and not the illusory size of the target disc.

In a set of tasks more analogous to the attentional repulsion paradigm used in the present study, Goodale and Humphrey (1998) report a separation between object-perception and perception-for-action in the visual agnosia patient D.F. When D.F. was presented with a slot that could be oriented in a number of different orientations, she showed tremendous inaccuracy in verbally indicating the orientation of the slot. Indeed, this inaccuracy persisted when she was asked to rotate a hand-held card to match the orientation of the slot. However, if she was asked to insert a card into the slot (this task is called a "posting" task because it is similar to posting a letter in a mailbox), her performance was very similar to that of control subjects. Thus, her performance was very good when asked to make an action to the slot, but her perception of the slot was greatly impaired.

Given the dissociation between object-perception and perception-for-action that has been found with other tasks (Aglioti et al. 1995; Haffenden et al. 2000; Wraga et al. 2000), there is reason to suspect that the attentional repulsion effect might affect only the perception of the Vernier stimulus and not actions directed toward it. To examine this possibility, it must first be determined that an attentional repulsion effect can be found for perception with a methodology that can then be directly adapted for action-based responses.

Experiment 1

The present experiment is a modified version of the paradigm that Suzuki and Cavanagh (1997) used to find the attentional repulsion effect. Similar to Suzuki and Cavanagh, two simultaneous brief peripheral cues (either top left + bottom right or top right + bottom left) were presented before a brief Vernier stimulus, which was then masked. However, in this version of the task, the bottom Vernier line was always aligned with the central fixation point, whereas the top Vernier line could occur at one of five locations (two left, two right, one center). Subjects were required to make a forced-choice decision as to whether the top line appeared to the left or right of the bottom line. The expectation, based on Suzuki and Cavanagh, was that top-left + bottom-right cues would bias the perception of the top line to the right of the bottom line, whereas top-right + bottom-left cues would bias the perception of the top line to the left of the bottom line.

Methods

Subjects

Eight undergraduate students from the University of Toronto participated in the experiment in exchange for course credits. All subjects had normal or corrected-to-normal vision and were naïve to the purpose of the experiment. In addition, all subjects gave their informed consent prior to their inclusion in the experiment.

Apparatus and methods

The experiment was conducted on a PC computer with a VGA monitor, and a head/chin rest was used to ensure a viewing distance of 44 cm. Each subject was tested individually in a dimly lit, sound-attenuated room.

All stimuli appeared in white (30.0 cd/m^2) on a black (0 cd/m^2) background, and the basic trial sequence appears in Fig. 1. The initial display consisted of a central fixation point (0.2° in diameter) that appeared for 1,000 ms. Then, two cues (empty circles, 1.0° in diameter) appeared for 50 ms in either the top-left and bottom-right areas of the display or the top-right and bottom-left areas of the display. These locations were displaced 3.5° in the vertical and horizontal directions from the central fixation point. Following the removal of the cues, there was a delay of either 50 ms or 100 ms. Then the fixation point was removed and the Vernier target appeared, consisting of two vertically aligned lines. Each line was 1° long and 0.1° wide. The bottom line always appeared directly below the location that the fixation point had previously occupied. The top Vernier line could appear in one of five locations; directly above the bottom line (0° position), to the left of the bottom line (−0.6°, −0.3° positions), or to the right of the bottom line (+0.6°, +0.3° positions). In terms of pixels from the center location, the five

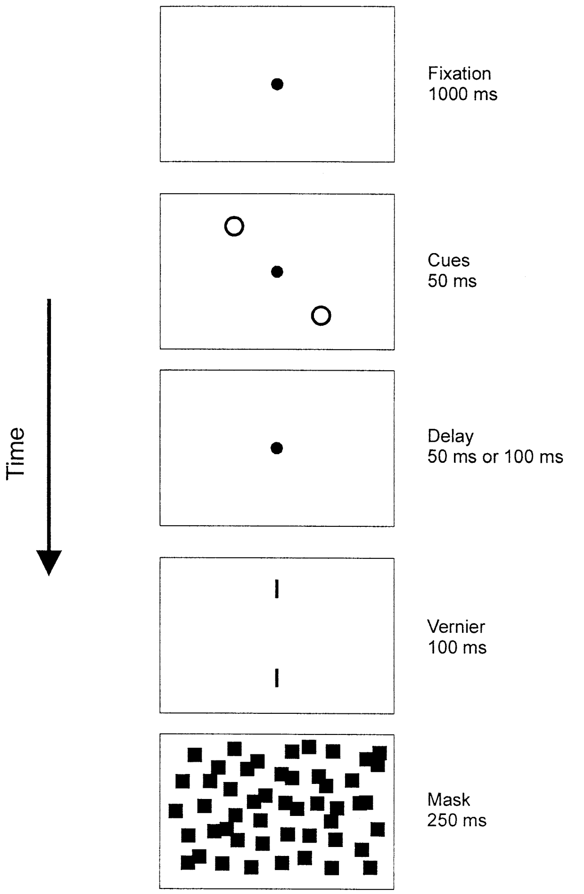

Fig. 1 The basic trial sequence used in experiments 1, 2 and 3

possible target locations were −12, −6, 0, +6, +12 pixels, respectively (pixels from the center location will be used throughout the three experiments). The Vernier target was displayed for 100 ms and then removed and replaced by a pattern mask (consisting of 150 randomly positioned small squares) that was presented for 250 ms. Subjects were instructed to remain fixated throughout each trial and to determine whether the top Vernier line was to the left or right of the bottom Vernier line. If they perceived the top line was to the left, they were to press the "z" key with their left hand. If they perceived the top line was to the right, they were to press the "/" key with their right hand. After each response, there was a 1,500-ms intertrial interval before the fixation point reappeared to start the next trial.

Each subject completed 400 trials. Over the course of each session, it was equally likely that the cues would be the top-left + bottom-right combination or the top-right + bottom-left combination. The five positions of the upper Vernier target line were also randomized across the session.

Results and discussion

For purposes of the analysis, the percentage of "left" responses (i.e., the top line appeared to the left of the bottom line) was calculated for each of the five top-line positions. These data appear in Fig. 2 and were analyzed with a 2 (ISI: 50 or 100 ms) × 2 (cue: top left + bottom right or top right + bottom left) × 5 (top Vernier line position: −12, −6, 0, +6, +12) analysis of variance

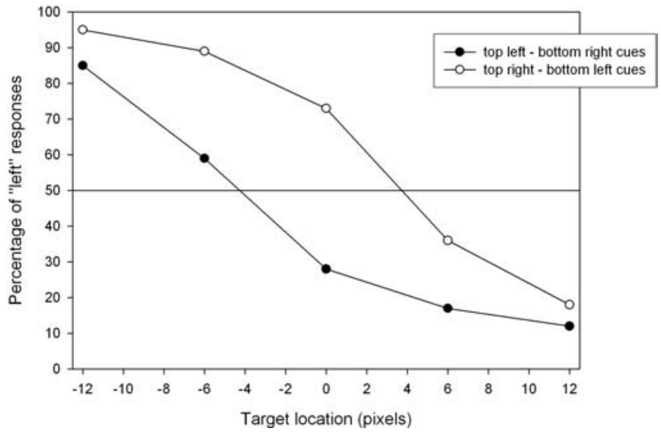

Fig. 2 The mean percentage of "left" responses regarding the perceived position of the top line relative to the bottom line of the Vernier stimulus

(ANOVA). A main effect of line position was found ($F_{4,28}$=43.9, P<0.0001), with the percentage of "left" responses greatest for the leftmost target and the least for the rightmost target (90.1% at −12, 73.9 at −6, 50.6 at 0, 27.1 at +6, and 14.7 at +12). This indicates that subjects were able to discriminate between the 5 positions. In addition, a main effect was found for cue ($F_{1,7}$=23.7, P<0.003), with top-left + bottom-right cues producing a lower percentage of "left" responses (40.4%) than top-right + bottom-left cues (62.2%). This indicates that there was an attentional repulsion effect present. The main effect for ISI did not reach significance ($F_{1,7}$<2.1, P>0.19).

Only one interaction, the cue by target interaction, was significant ($F_{4,28}$=11.4, P<0.0001), with the attentional affect being greatest with targets at the 0° position and decreasing with increasing line position eccentricity. The difference in the percentage of "left" responses was 43.6% at the 0° position, 24.7% at the −6 and +6 positions, and 8.2% at the −12 and +12 positions. This pattern occurs because the chance of the attentional repulsion effect altering the perception of the lines enough to switch the response should decrease as the distance between the two lines increases. Indeed, the leftmost and rightmost targets were correctly identified 83.6% of the time when the cues would have pushed the perception in the opposite direction. No other two-way interactions, nor the three-way interaction, reached significance (P>0.1).

Replicating the results of Suzuki and Cavanagh (1997), an attentional repulsion effect was found for the perception of the Vernier stimulus. Having found the effect on perception, it can now be determined if the attentional repulsion effect also affects action-based responses.

Experiment 2

This experiment used the same basic methodology as the previous experiment, but instead of a left or right forced choice discrimination response, subjects were instructed to place a cursor (via moving the computer mouse) at the location of the top Vernier line.

Methods

Subjects

Eight undergraduate students from the University of Toronto participated in the experiment in exchange for course credits. All subjects had normal or corrected-to-normal vision and were naïve to the purpose of the experiment. None had participated in the previous experiment. In addition, all subjects gave their informed consent prior to their inclusion in the experiment.

Apparatus and procedure

The basic apparatus and procedures were very similar to those in the previous experiment except that now subjects responded by moving a mouse-controlled cursor to the location where they thought the top line was located. Each trial began with a yellow fixation circle (0.4°, 70.5 cd/m^2) and the subjects were required to move the mouse such that the cursor was positioned in this circle. When this was accomplished, the fixation circle turned white and the same trial sequence used in the first experiment took place. In this experiment, however, subjects were instructed to move the mouse such that they placed the cursor at the location of the top Vernier line. When they were satisfied with the cursor location, they pressed the center mouse button, and the *x,y* coordinates of that cursor position were recorded. As in the first experiment, each subject completed 400 trials. The location of the cues (top left + bottom right and top right + bottom left) and the position of the top Vernier line (−12, −6, 0, +6, +12 pixels) were randomized across each session.

Results and discussion

For the purpose of analysis, the horizontal difference (in number of pixels) between the cursor position and the center of the display was calculated for each of the five top-line positions. Thus, a value of 0 pixels indicates the cursor was placed directly in line with the center of the display, whereas negative pixel values indicate locations to the left of center and positive pixel values indicate locations to the right of center. These data appear in Fig. 3 and were analyzed with a 2 (ISI: 50 or 100 ms) × 2 (cue: top left + bottom right or top right bottom left) × 5 (top Vernier line position: −12, −6, 0, +6, +12 pixels) ANOVA. A main effect of line position was found ($F_{4, 28}$=8.8, P<0.0002) as subjects positioned the cursor at −35.3 for the −12 target, -21.5 for the −6 target, 0.7 for the 0 target, 24.5 for the +6 target, and 32.6 for the +12 target. This indicates that subjects were able to discriminate between the 5 positions, and that they tended to overestimate the peripheral targets. No main effects for ISI (P>0.5) or cue (P>0.13) were found. The lack of a cue main effect was compromised by the large overshooting responses found for the peripheral locations which added additional variance to the analysis. However, post-hoc comparison showed significant (or nearly significant) effects at the −6 (P<0.085), 0 (P<0.05), and +6 (P<0.025) locations.

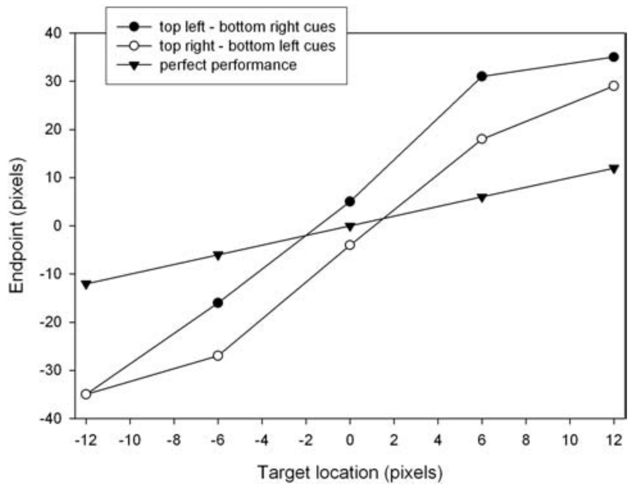

Fig. 3 The mean error, in pixels, of the computer mouse localization responses to the location of the top line of the Vernier stimulus. In addition, a third curve indicating perfect performance on the task is presented

As in the first experiment, only the cue by target interaction was significant ($F_{4,\ 28}$=2.9, P<0.04), with attentional repulsion effects being seen at the −6, 0, and +6 line locations. The difference in cursor locations was 11.4 pixels for the −6 location, 10.5 pixels for the 0 location, and 13.1 for the +6 location. It is worth noting that the size of the repulsion effect was very symmetrical; at the 0 location, the left-top + bottom-right cues produced a right shift of +5.9 pixels, whereas the right-top + left-bottom cues produced a right shift of −4.7 pixels. Averaged together, the two most peripheral locations showed an attentional repulsion effect of only 2.7 pixels. No other two-way interactions, nor the three-way interaction, reached significance (P>0.11).

The results of the present experiment indicate that the attentional repulsion effect does influence action, as the effect biased the limb movements used to place the cursor (via the computer mouse) at the location of the top Vernier line. It is worth noting that the attentional repulsion effect found at the 0 position (mean of 5.3 pixels, or 0.26°) was approximately the same magnitude of effect reported for perception of the Vernier stimulus by Suzuki and Cavanagh (1997).

Experiment 3

One possible limiting factor from experiment 2 is that the computer mouse localization task is a relatively slow task that probably relies on some representation of the target held in memory. There is evidence that actions to memorized targets may be planned and produced differently than actions to visible targets. For example, Wong and Mack (1981) have found that saccadic eye movements to memorized targets are programmed in perceptual coordinates, whereas saccades to visible target locations are programmed in retinal/spatial coordinates. More directly applicable to the current study, Gentilucci et al. (1996) have reported greater effects of a Müller–Lyer illusion when limb movements are made to memorized target locations than to visible target locations. Thus, the bias shown in the computer mouse task may have occurred because the movements were based on information from the "repulsed" perception of the target location. To provide a stronger test of a dissociation between perception and action in the attentional repulsion effect, the present experiment used the same visual displays as before, but this time the displays were presented on a touch-screen monitor and subjects were instructed to make a pointing limb movement to the location of the top Vernier line.

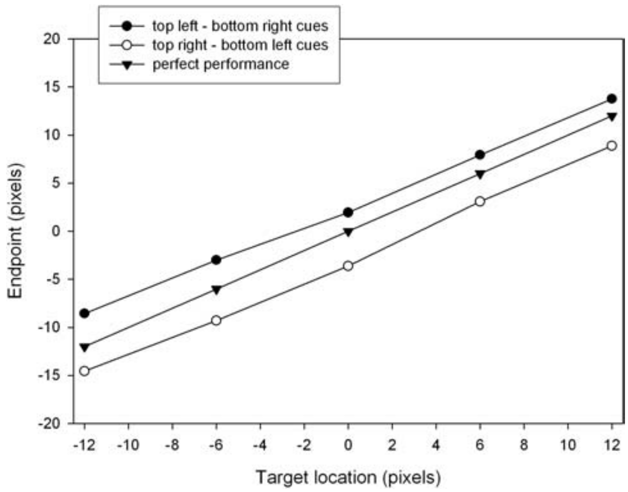

Fig. 4 The mean error, in pixels, of the guided limb localization responses to the location of the top line of the Vernier stimulus. In addition, a third curve indicating perfect performance on the task is presented

Methods

Subjects

Five graduate students and three undergraduates from the University of Toronto participated in the experiment as volunteers. All subjects had normal or corrected-to-normal vision and were naïve to the purpose of the experiment. None had participated in either of the two previous experiments. In addition, all subjects gave their informed consent prior to their inclusion in the experiment.

Apparatus and procedure

The basic apparatus and procedures were similar to the two previous experiments except that now subjects responded by touching with the index finger on their dominant hand the location where they thought the top line was located. Each trial began with a white fixation circle, and the subjects were required to touch within the circle. When this was accomplished, a warning tone was sounded and the same trial sequence used in the first two experiments took place. In this experiment, however, subjects were instructed to touch the location of the top Vernier line. Upon touching the screen, a tone was sounded and the *x*,*y* coordinates of the touch were recorded. As in the previous experiments, each subject completed 400 trials. The location of the cues (top left + bottom right and top right + bottom left) and the position of the top Vernier line (−12, −6, 0, +6, +12) were randomized across each session.

Results and discussion

Similar to the previous experiment, the horizontal difference (in number of pixels) between the cursor position and the center of the display was calculated for each of the 5 top-line positions. These data appear in Fig. 4 and were analyzed with a 2 (ISI: 50 or 100 ms) × 2 (cue: top-left + bottom-right and top-right + bottom-left) × 5 (top Vernier line position: −12, −6, 0, +6, +12 pixels) ANOVA. A main effect of line position was found ($F_{4, 28}$=57.9, P<0.0001), as subjects touched at −11.6 for the −12 target, −6.2 for the −6 target, −0.8 for the 0 target, 5.5 for the +6 target, and 11.3 for the +12 target. This indicates that subjects were able to discriminate between the 5 positions and that their touches were quite accurate. Importantly, a main effect of cue was found ($F_{1, 7}$=8.4, P<0.03), as subjects' pointing responses were biased 2.4 pixels to the right with the top-left + bottom-right cues and 3.1 pixels to the left with the top-right + bottom-left cues. This indicates that there was an attentional repulsion effect across all line positions. No main effect for ISI was found (P=0.25), nor did any of the interactions reach significance (P>0.29). The lack of any interaction effects indicates that the repulsion effect occurred more or less equally at all target locations, and this can be seen in Fig. 4. Therefore, the results of the present experiment further support the notion that the attentional repulsion effect does influence action.

Although the pattern of responses to the 0 target were similar between experiments 2 and 3, the large overshoot seen in mouse movements were not found with the pointing responses. This is probably due to the nature of the two movements. With the pointing responses, subjects were moving the limb toward the touch screen and using the touch screen surface to help brake the movement. With most of the force not being directed in the *x*-axis (in terms of the start and target locations on the screen), and having a hard surface to brake against, there was little overshoot to the peripheral targets. This was unlike the mouse movements, in which virtually all the force was directed along the *x*-axis and there was no border or surface to brake the movement. As subjects were no doubt timing the pressing of the mouse button to the arrival of the mouse cursor on the target, the nature of the mouse movement is most likely responsible for the pattern of overshooting seen in the previous experiment.

General discussion

The present study had a twofold purpose. The first purpose was to replicate the attentional repulsion effect in Vernier discrimination task, as originally reported by Suzuki and Cavanagh (1997). This was accomplished in experiment 1, as the brief peripheral cues caused the top line of the Vernier stimulus to be perceived in the opposite direction of the top cue. The second purpose was to determine whether the peripheral cues would produce an attentional repulsion effect when localization responses were made to the location of the top line of the Vernier stimulus. Although there is considerable research showing there is a differentiation between effects on object-perception and perception-for-action, this did not occur in experiments 2 or 3. Rather, attentional repulsion effects were found with both computer mouse and guided limb localization tasks.

To explain why brief peripheral cues produce an attentional repulsion effect, Suzuki and Cavanagh (1997) propose that the repulsion effect represents the cost of orienting attention in order to enhance perception at a peripheral location. They assume that position-coding neural units have spatially localized receptive fields (RFs), and they note that cells in areas V1, V2, and V3 that preserve retinotopy could serve this purpose. They further assume that the perceived position of the Vernier stimulus is represented by the centroid of the response distribution of these position-coding units. Because of this, the position of the Vernier would be coded in retinal space. In the absence of the peripheral cues, the centroid is at the attended location and the Vernier stimulus would be coded by the overlapping RFs of the position-coding units. However, in the presence of the peripheral cues, attention is oriented to the cue location, and this results in a shift of the centroid of the distribution in the opposite direction. Suzuki and Cavanagh provide three specific, and equally plausible, mechanisms for how such a shift in the response distribution could occur with a peripheral cue (surround suppression, RF recruitment, and RF shrinking). They were unable, however, to determine which of the three mechanisms was the exact cause of the shift in RFs.

Although the present study does not discuss how the shift in RFs is accomplished, the results provide insight into where the attentional repulsion effect is instantiated in the visual processing stream. As noted above, Suzuki and Cavanagh (1997) suggest that the effect originates in primary visual cortex. This is consistent with the notion that the attentional repulsion effect affects both perception and action, because it is instantiated before the visual pathways split into ventral and dorsal components. Indeed, there are examples of other spatial effects being carried down both visual pathways. One such example comes from Dyde and Milner (2002), when they compared perceptions and actions to the simultaneous tilt illusion (which originates in V1 and then effects all subsequent processing) and the “rod-and-frame” illusion (which relies on ventral stream processing). They found that only perception was influenced by the “rod-and-frame” illusion, but that the simultaneous tilt illusion affected both perception and action. Thus, it is plausible that the locus of the attentional repulsion effect also occurs before the two visual pathways split.

Unfortunately, we were unable to measure response times in the three experiments. Such information would be valuable because it would help determine, to some degree, how much the movements were based on perceptual representations. In other words, it would be useful to know whether the attentional repulsion was affecting the action system or rather that the guided limb responses were sufficiently slow that they relied on the distorted perceptual representation produced by the cues. This issue was highlighted by Gentilucci et al. (1996), as they found that the effect of a Müller–Lyer illusion on pointing responses was small when the illusion stimulus was removed at the onset of the movement and much greater when it was removed 5 s before the onset of the movement. Thus, as the movement relied more on the perceptual representation of the target, the effect of the illusion on action became greater.

To gain some idea of the basic responses times (RTs + MTs) needed in the experiments, we collected data from four subjects that made localization responses to central Vernier targets either with choice key presses (454 ms), mouse movements (882 ms), or pointing movements (911 ms). A couple of things are worth noting. First, the key presses were by far the fastest, largely because they did not have a MT component. Second, with the guided movements, the overall responses times were both relatively fast and very similar between the mouse and pointing responses. Given that these conditions were essentially the same as Gentilucci et al.’s 0 s-delay condition, it seems likely that the attentional repulsion effect directly affects the action system and therefore occurs relatively early in visual processing, before the ventral and dorsal pathways separate. Thus, the evidence from the three experiments in this study indicates that brief peripheral cues affect not only our perception of objects in space but also the actions we make toward those objects.

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