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Attention Affects Visual Perceptual Processing Near the Hand

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Abstract

Specialized, bimodal neural systems integrate visual and tactile information in the space near the hand. Here, we show that visuo-tactile representations allow attention to influence early perceptual processing, namely, figure-ground assignment. Regions that were reached toward were more likely than other regions to be assigned as foreground figures, and hand position competed with image-based information to bias figure-ground assignment. Our findings suggest that hand position allows attention to influence visual perceptual processing and that visual processes typically viewed as unimodal can be influenced by bimodal visuo-tactile representations.

Keywords

attention, figure-ground, proprioception, bimodal cells, action, cross-modal

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The objects of goal-directed action are often located near the body, within peripersonal space. As a result, primates possess specialized neural systems to support the processing of objects located within arm's reach. Neurophysiological studies have demonstrated that there are populations of bimodal visuo-tactile neurons that respond exclusively to tactile and visual stimulation in perihand space (di Pelligrino, Ladavas, & Farne, 1997; Graziano & Gross, 1993). One hypothesis regarding these bimodal neurons is that they are responsible for integrating information in visual and tactile space, supporting the control of reaching and grasping and the visual processing of objects near the hand (Ladavas, di Pellegrino, Farne, & Zeloni, 1998). It is possible that the presence of such bimodal representations influences unimodal visual representations and biases or strengthens visual processing of objects near the hand.

Recent studies have demonstrated that bimodal representations can influence the allocation of visual attention. For example, hand position modulates visual neglect following parietal lobe damage: Placing a patient's hand in the neglected visual field reduces neglect (di Pelligrino & Frassinetti, 2000). Further, in neurologically normal observers, target objects appearing in perihand space are detected faster and scrutinized longer than those appearing farther from the hand (Abrams, Davoli, Du, Knapp, & Paull, 2008; Reed, Betz, Garza, & Roberts, 2010; Reed, Grubb, & Steele, 2006).

Although hand position can influence attention, the precise effects of this influence are unclear. In the experiments reported here, we investigated the consequences of placing the hand near or on an object: Does hand position simply direct attention toward perihand space, or does hand position allow attention to alter perceptual processing in that space? These alternatives focus on the nature of the attentional effects produced by proprioceptively guided attention. A prioritization account predicts that proprioception influences attention by assigning a processing order—a processing priority—to objects near the hand, such that objects near the hand are processed before other objects, but the perception of objects near the hand is unaffected. In contrast, a perceptual-modification account predicts that proprioception allows attention to alter the perception of objects in perihand space, such that objects near or touching the hand are perceived differently than objects elsewhere. Such perceptual differences would allow objects near or touching the hand to be detected and recognized faster than other objects.

To distinguish these accounts, we examined the influence of hand position on an early perceptual process, figure-ground assignment. Figure-ground assignment is typically described as a unimodal perceptual process that operates early in vision, and that can occur preattentively (Julesz, 1984; Kimchi & Peterson, 2008). If hand position prioritizes attention but does not affect perceptual processing, then figure-ground processes

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should be unaltered by hand position because figure-ground status should be determined before attention and proprioception have their influence. However, if hand position modifies perception, then objects near the hand should be more likely than other objects to be perceived as foreground figures.

We examined whether the placement of participants' hands within one region of a two-region figure-ground display would influence the assignment of figural status to that region. In Experiment 1, which used ambiguous two-region figure-ground displays, participants were more likely to perceive a given region as the figure if they had placed their hand in that region than if they had not. In Experiment 2, we demonstrated that hand position could override bottom-up perceptual cues to figure-ground assignment, a result suggesting that bimodal representations modify perceptual processing near the hand and act as a potent cue to figure-ground assignment.

Experiments 1a and 1b

In Experiment 1, participants performed a visual short-term memory task in which they viewed ambiguous two-region figure-ground displays and reported which of two probe regions appeared in the initial displays (Fig. 1a). This implicit measure of figure-ground assignment avoids potential response biases that can be present in phenomenological explicit report measures (see Driver & Baylis, 1996). In Experiment 1a, either the participants' hand or a wooden dowel was present in one region of each figure-ground display. This manipulation (which was implemented between participants to circumvent possible carryover effects between the hand and dowel conditions) allowed us to compare the effects of the hand with those of a visual anchor (the dowel). To conduct a stronger test of the influence of hand position, in Experiment 1b, we directly pitted hand position against a visual anchor both within participants and within each trial. If reaching toward and touching a region increases its likelihood of being perceived as figure, then we would expect reaction times (RTs) to be faster for recalling regions that contained the hand than for recalling other regions.

Method

Participants. Participants were 36 University of Iowa undergraduates (24 in Experiment 1a and 12 in Experiment 1b). All participated for course credit and reported normal or corrected-to-normal vision.

Stimuli and procedure. Stimuli were presented on a Mac Mini computer with a 17-in. CRT monitor, using MATLAB and the Psychophysics Toolbox (Brainard, 1997). The figure-ground displays measured 8° × 8°, and each was separated into two colored regions (one red, one green) by an irregular contour (Fig. 1a). Each color was equally likely to appear to the left or to the right of fixation. On each edge of the figure-ground display was a small, 3.0° × 3.0° "tab." In Experiment 1a, one of the participant's hands (right or left) or a wooden dowel (1.5 cm in diameter) was positioned at the beginning of each block of trials so that it would be inside the tab (approximately 7° from fixation) of either the left or the right region of all the figure-ground displays in that block (i.e., region was

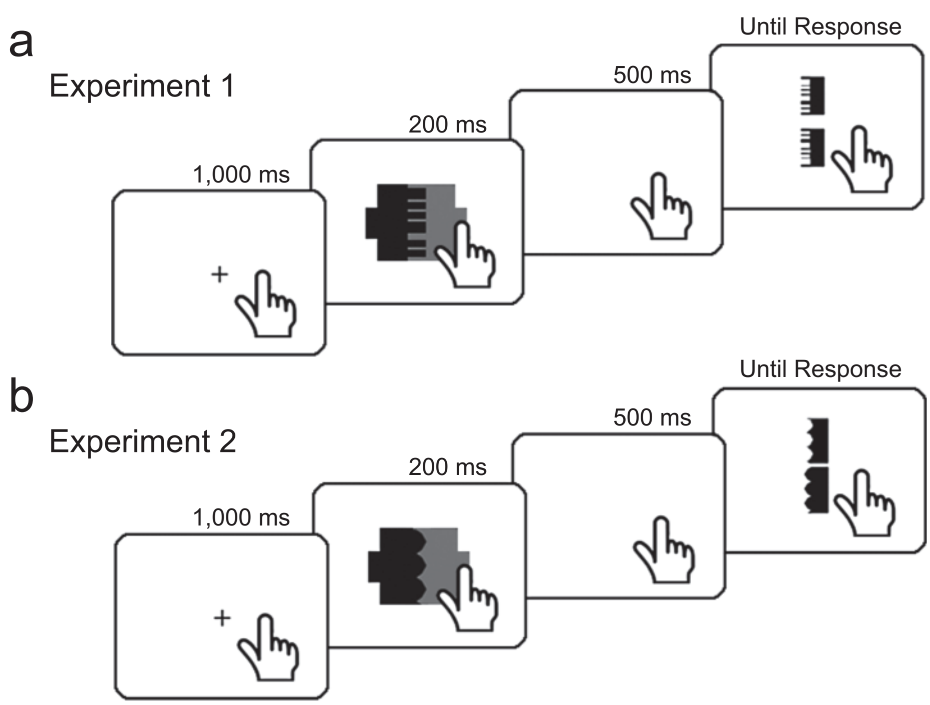

Fig. 1. Schematic diagram of the trial sequence for (a) the hand condition of Experiment 1a and (b) Experiment 2.

held constant within each block). At the start of each block of Experiment 1b, one of the participant's hands and the wooden dowel were placed so that hand and dowel directly opposed one another, with the hand inside one region of the displays and the wooden dowel in the other.

In each experiment, a trial began with a fixation point for 1,000 ms (see Fig. 1a). Next, a figure-ground display appeared for 200 ms. After a 500-ms delay, two black probe shapes measuring 8° × 4° appeared 1.2° above and below fixation. The task was to determine which of these two regions had appeared in the preceding figure-ground display. The correct probe item was equally likely to appear above or below fixation and was equally likely to match the region that did or did not contain the dowel or hand on a given trial. The probe display remained on the screen until the participant responded.

In Experiment 1a, whether the participant's hand or a dowel was placed in the displays was manipulated between subjects, with 12 participants in the hand condition and 12 in the dowel condition. In the hand condition, participants reached toward the screen and placed their finger on either the left or the right side of the monitor, with the finger touching the monitor and the palm facing toward fixation. In the dowel condition, the experimenter placed a wooden dowel into one of the two regions to act as a visual anchor. Hand or dowel position was blocked, with position alternating across blocks (i.e., right, left, right, left) and starting position counterbalanced across participants. For example, for the duration of a given block, participants in the hand condition would hold their left hand toward the left side of the monitor, so that their finger was inside the tab of the left region of the displays, and use their right hand to make button-press responses on a keyboard. In the following block of trials, this position was switched so that they held their right hand toward the right side of the monitor, within the tab of the right region of the displays, and responded using their left hand. The procedure in the dowel condition was identical, except that a dowel (rather than the participant's hand) was placed within the displays; participants responded with one hand and kept the other hand in their lap. As in the hand condition, the position of the dowel (right or left region) and the response hand were alternated on a block-by-block basis. In each block of Experiment 1b, participants placed one hand on one side of the computer monitor, and the dowel was placed on the other side.

We informed participants that hand or dowel location would not predict which of the two regions would be probed, and we asked them to maintain central fixation on the contour separating the two regions of the display. Eye position was monitored using an Applied Science Laboratories (Bedford, MA) eye tracker, and we excluded trials (< 6%) in which the eyes deviated more than 1.5° from fixation. We asked participants to respond as quickly and accurately as possible; participants completed 12 blocks of 16 trials for each hand or dowel position (left or right), for a total of 384 trials per subject in each experiment.

Results and discussion

The results of Experiment 1a are shown in Figure 2a. We performed a 2 × 2 mixed analysis of variance (ANOVA) with visual anchor type (hand vs. dowel) as a between-subjects factor and probed region (anchor present vs. absent) as a within-subjects factor. There was a significant interaction between anchor type and probed region, $F(1, 22) = 5.9$, $p < .05$. Planned comparisons indicated that the interaction was driven by significantly faster RTs in the hand condition when the probe matched the region containing the participant's hand than when it did not, $t(11) = 2.7$, $p < .03$; there was no such difference in the dowel condition, $t(11) < 1$, $p > .50$. Neither main effect was significant (Fs < 1.8, ps < .22). The accuracy data revealed no significant main effects or interactions (Fs < 1, ps > .73).

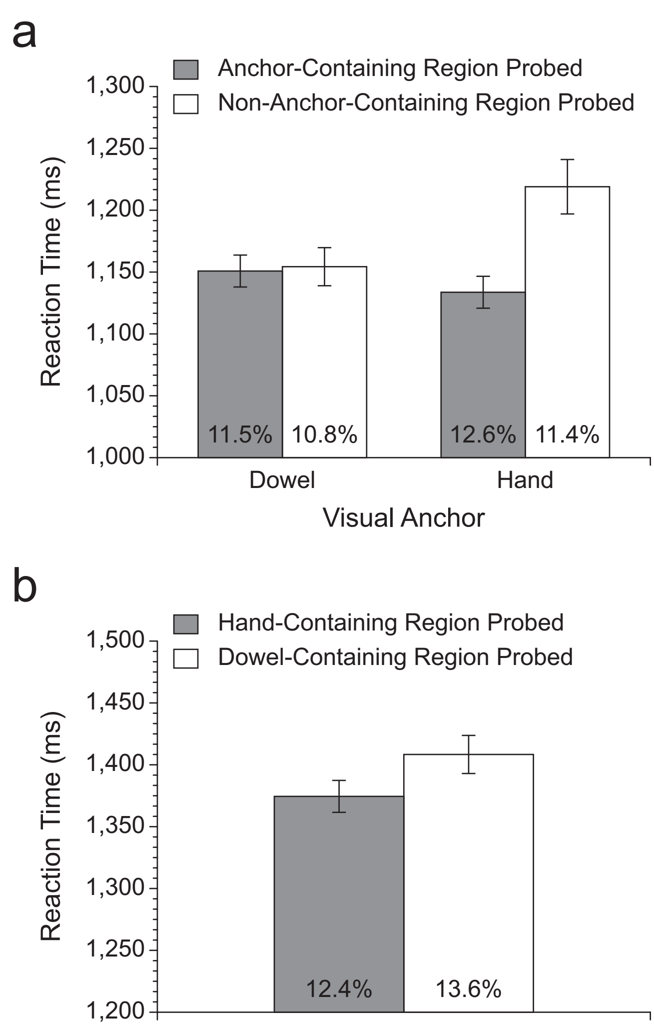

Fig. 2. Mean reaction times to probe items in (a) Experiment 1a and (b) Experiment 1b as a function of the region probed. In Experiment 1a, a single visual anchor, either the participant's hand or a dowel, was present in one region of each figure-ground display; in Experiment 1b, the participant's hand was placed in one region of each display, and the dowel was placed in the other region. Error bars represent 95% confidence intervals (Loftus & Masson, 1994), and the numbers at the bases of the bars are the error rates.

The results of Experiment 1b are shown in Figure 2b, and they corroborate those of Experiment 1a: Participants' RTs were significantly faster when the region containing their hand was probed than when the region containing the dowel was probed, $t(11) = 2.8$, $p < .02$. There was no difference in accuracy between the two probed regions, $t(11) = 1.1$, $p < .31$.

These results indicate that when observers are presented with a figurally ambiguous display, hand position influences which region is perceived as figure. This suggests that hand position—and presumably the bimodal representations of space near the hand—allows attention to contribute to figure-ground assignment. However, it is unclear whether such bimodal representations affect the outputs of an early perceptual process or act solely at some later stage of processing (e.g., visual short-term memory). Because the displays used in Experiment 1 had ambiguous figure-ground assignment, it is possible that early, perceptual mechanisms of figure-ground assignment failed because there were no image-based cues to determine the likely figural region. Consequently, hand position might not have influenced early figure-ground processes, but instead might have been used to disambiguate the displays at a later point (e.g., after both regions had been entered into visual memory).

To determine the locus of the observed hand-position effects, in Experiment 2 we employed a task identical to that used in Experiment 1, but with stimuli that directly tapped visual segregation processes themselves. The displays contained a strong image-based cue for figure-ground assignment, namely, convexity (Kanizsa & Gerbino, 1976; Pomerantz & Kubovy, 1986); convex regions are more likely than concave regions to be perceived as figure. By using displays containing image-based cues, our task reflected the outputs of figure-ground processes and not solely the effects of other, postperceptual processes (Driver & Baylis, 1996).

If bimodal representations influence early perceptual processes, then hand position should directly influence the effectiveness of image-based convexity cues in driving figure-ground assignment. Specifically, when a convex figure and a concave ground are both present in a scene, a hand located within the concave "ground" region should cause that region to more effectively compete for figural status with the convex "figure" region, reducing the RT benefit when a memory probe matches the convex region. In contrast, if hand position simply prioritizes the allocation of attention, we would expect convex regions to receive a processing benefit irrespective of hand position, because figure-ground status would be determined before hand position could have an influence.

Experiment 2

Method

Participants. Participants were 12 University of Iowa undergraduates who volunteered for course credit; all reported normal or corrected-to-normal vision.

Stimuli and procedure. The figure-ground displays contained a convexity cue known to influence figure-ground assignment. For example, in the display illustrated in Figure 1b, the left region is more convex than the right region according to Hoffman and Singh's (1997) part-salience analysis. Specifically, given the local geometry around the shared contour, the left region, compared with the right region, contains a greater number of salient, convex parts that influence figure-ground assignment. As in Experiment 1, on each edge of the figure-ground display was a small 3.0° × 3.0° tab.

The procedure was identical to that in Experiment 1, except that the visual anchor was always the participant's hand (see Fig. 1b). At the start of each block, one of the participant's hands (right or left) was positioned so that it would be located inside the tab (approximately 7° from fixation) of either the concave or the convex region of all the figure-ground displays in that block. Participants completed 12 blocks of 16 trials for each hand position (convex or concave region), for a total of 384 trials.

Results and discussion

The results of Experiment 2 are shown in Figure 3. A 2 × 2 repeated measures ANOVA with hand-containing region (convex vs. concave) and region probed (convex vs. concave) as factors revealed a significant main effect of region probed, $F(1, 11) = 14.9$, $p < .01$, with participants responding faster overall to convex probes. The main effect of hand-containing region was not significant, $F(1, 11) = 3.2$, $p > .10$. Critically, we observed a significant interaction between hand-containing region and region probed, $F(1, 11) = 4.9$, $p < .05$. The RT difference between convex and concave probes was not significant when the hand was placed in the concave region of the display, $t(11) = 1.1$, $p > .05$, which indicates that the concave region was better able to compete for figural status when a

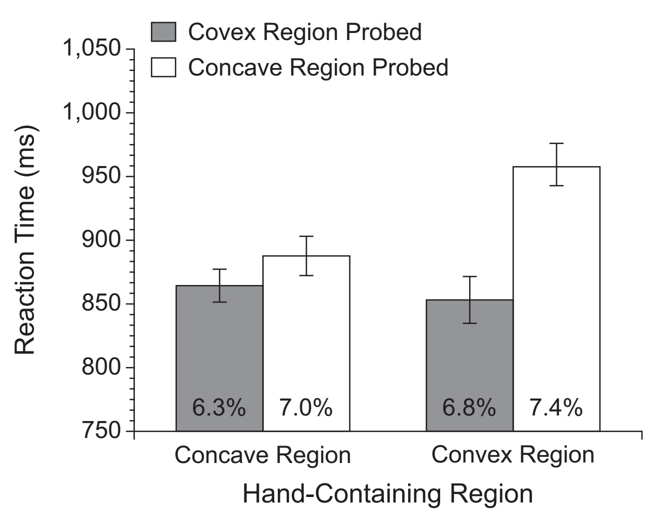

Fig. 3. Mean reaction times to probe items in Experiment 2 as a function of the region probed and the region in which the participant's hand had been placed. Error bars represent 95% confidence intervals (Loftus & Masson, 1994), and the numbers at the bases of the bars are the error rates.

participant's hand was located within it. Analyses revealed no significant main effects or interactions in the accuracy data (Fs < 1, ps > .65). The results of Experiment 2 demonstrate that hand position allows attention to influence perception, namely, figure-ground assignment.

General Discussion

Our results suggest that bimodal neural representations can alter perceptual processes, supporting a perceptual-modification account in which bimodal representations allow attention to interact with visual perceptual representations. Our findings also indicate that hand position acts as a cue to figure-ground assignment, biasing the assignment of figural status to regions near the hand on the basis of bimodal visuo-tactile inputs. These findings are novel because they provide the first evidence that in addition to prioritizing visual attention (Reed et al., 2006), hand position allows attention to alter figure-ground processes, which are thought to rely on unimodal visual processing. This novel behavioral evidence is in line with neurophysiological studies showing that bimodal representations of peripersonal space can influence activity in brain areas involved in the unimodal processing of visual information (Macaluso, Frith, & Driver, 2000) or attenuate visual-field loss in hemianopia (Schendel & Robertson, 2004).

The finding that visual perceptual processing is altered by proprioceptively guided attention is important given that items located near the hand are often objects of action that warrant increased perceptual scrutiny. Such an interaction between bimodal and unimodal information may increase the efficiency with which people are able to carry out goal-directed actions such as grasping. For example, in a case in which the perceptual segregation of objects would be demanding if based solely on image-based cues (e.g., grabbing a book from a cluttered table), bimodal representations might supplement the unimodal representation of objects near the hand in order to efficiently segregate them from their backgrounds. Our results raise the possibility that other aspects of early perceptual processing are altered in the space near the hand and shed light on the nature of bimodal visuo-tactile interactions.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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