

# The visual P2 is attenuated for attended objects near the hands

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Vision is altered when people place their hands near the object they are observing. To investigate the neural processes underlying this effect, we measured electroencephalographic visual-evoked potentials (VEPs) elicited by reversing checkerboards, while participants' hands either surrounded the visual display or rested at their sides. We found the P2 component was attenuated for hand-proximal stimuli, but only when participants attended to the location of the checkerboard. In Experiment 1, participants performed an attention-demanding color-change task that was presented centrally, and the P2 component was attenuated for central, but not peripheral, checkerboards. In Experiment 2, participants performed the attention task in the periphery, and the P2 was attenuated for peripheral, but not central, checkerboards. These results suggest that hand-proximal stimuli benefit from enhanced selective attention at later stages of perceptual processing. The effect only occurs for objects at task-relevant locations, however, even when task-irrelevant locations are physically closer to the hands.

**Keywords:** Attention; VEP; Action.

While researchers have long studied how visual information helps to guide the hand, only recently have they begun to explore the complementary effect: How does hand position guide visual processing? Motivated by prior reports of an attentional bias toward the space around the hands (Reed, Grubb, & Steele, 2006; Schendel & Robertson, 2004), Abrams, Davoli, Du, Knapp, and Paull (2008) recently tested whether visual processing more generally is affected by hand position. In one task, they had participants perform a visual search with their hands either placed near to or far from the stimulus display. Participants searched through the array more slowly when their hands were extended to the display than when placed on their lap, and this effect persisted even when view of the hands was occluded. Performance on attentional blink and

spatial cueing tasks was also affected by hand position: When stimuli were presented close to the hands, participants exhibited a longer-lasting attentional blink and a delayed onset of inhibition of return. In a follow-up study, Davoli and Abrams (2009) showed that simply imagining holding one's hands near the display also produced slowed search rates. From the combined results of these studies (see also Davoli, Du, Montana, Garverick, & Abrams, 2010), Abrams and colleagues concluded that objects near the hands receive enhanced processing, possibly because these objects are candidates for grasping, or because they might be obstacles to be avoided. In either case, they should receive prioritized treatment. We will term this effect, found by Abrams and colleagues, the 'hand position effect.'

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While all of the evidence for enhanced processing near the hands has come from behavioral measures, neurophysiological studies of peripersonal space provide some data demonstrating altered representation of objects near the hand. In particular, bimodal visuotactile neurons that have been reported in non-human primates suggest visual information is represented differently depending on stimulus-to-hand distance (e.g., Graziano, Yap, & Gross, 1994; see Makin, Holmes, & Zohary, 2007, for a related study on human visual processing). It remains unclear, however, how these differences in the way that information is represented within the brain relate to the enhanced processing accounts of the hand position effect that have emerged from behavioral studies. For this reason, we sought to further investigate the underlying neural bases of the hand position effect. Specifically, we measured electroencephalographic recordings of the visual-evoked potentials (VEPs) (for a review, see Tobimatsu & Celesia, 2006) from task-irrelevant stimuli, and examined (1) whether the elicited cortical responses varied with hand position, and (2) whether any such variations were consistent with enhanced attentional processing. VEPs are well suited for this initial neurophysiological investigation of the hand position effect as they can be elicited merely through the presentation of a visual stimulus without requiring an overt response (e.g., Luck, Woodman, & Vogel, 2000). Thus, VEPs provide a direct measure of visual processing that is not confounded by effects acting through the motor system. In addition, the high temporal resolution of VEPs can be used to characterize the time course of the hand position effect. Specifically, VEPs will allow us to assess whether hand position affects early sensory processes (i.e., the P1 and N1 components; Hillyard & Anllo-Vento, 1998; Martínez, et al. 1999), higher-order perceptual processes (P2; Hackley, Woldorff, & Hillyard, 1990; Noldy, Stelmack, & Campbell, 1990), or some combination of the above.

In the present study, we elicited VEPs by reversing checkerboard patterns that were presented either centrally (one small checkerboard at central fixation) or peripherally (two large checkerboards, one in each visual field). Participants either held on to the display (hands-up) or placed their hands on the table (hands-down), and dividers were used to block the participant's view of their hands—as a result, the visual environment was identical for the two postures (see Figure 1). To engage participants' attention, we had them perform a centrally presented color-change task. Thus, although checkerboards were always task irrelevant, they either appeared at the location of the attention task (central checkerboard) or not (peripheral checkerboards), providing preliminary

data on the attentional specificity of the hand-position effect. The primary question, however, is how does hand position alter the VEP?

## EXPERIMENT 1

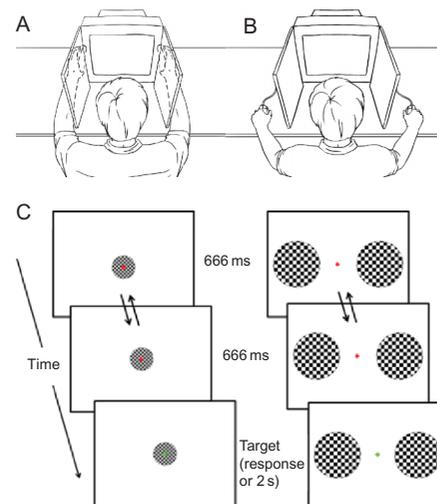
### Methods

#### *Participants*

Participants were 26 University of Toronto undergraduate students. One participant was excluded for excessive slow-wave activity, and a second for improper recording at a channel of interest. Four more participants were excluded for excessive blinks and eye movements (greater than 33% of trials). Of the remaining 20 participants (mean age = 20.9; 8 women), all were right-handed and had normal or corrected-to-normal vision.

#### *Apparatus*

Participants sat in a dimly lit room in front of a 21-inch CRT monitor (1600 × 1200 resolution, 60-Hz refresh rate), with a viewing distance of 30 cm. Two foam boards were positioned vertically at the sides of the monitor to prevent participants from seeing their hands.



**Figure 1.** Hand postures in (A) the hands-up condition and (B) the hands-down condition. (C) Stimuli and trial sequence for the center and peripheral checkerboard conditions in Experiment 1. Checkerboards reversed every 666 ms. Target trials occurred every 7–15 s (11–22 reversals), at which point the fixation cross changed color. In Experiment 2, the target stimulus for the color-change task was changed to a larger square and moved to the center of the peripheral checkerboard.

EEG was recorded using a BioSemi ActiveTwo (Cortech Solutions, Wilmington, NC, USA) with 64 scalp electrodes in standard 10-20 placement. In addition, electrodes were placed at each mastoid, 1 cm from the external canthus of each eye, and 2.5 cm above and below the right eye. Continuous data were recorded at a 512-Hz sampling rate. Ethical approval was received from the Research Ethics Board at the University of Toronto.

### *Design and procedure*

Participants completed the experiment twice, once in a hands-up condition and once in a hands-down condition (order counterbalanced across participants). In the hands-up condition, participants rested their elbows on cushions and placed each hand on a computer mouse that was mounted to the side of the monitor and aligned with the middle of the screen (Figure 1A). In the hands-down condition, participants held the mice with hands on the table (Figure 1B).

During each run of the experiment, participants viewed a block of center-checkerboard reversals and a block of peripheral-checkerboard reversals (see Figure 1C). The centrally presented checkerboard was circular and subtended  $7.6^\circ$  of visual angle, with checks that subtended  $0.6^\circ$ . The peripherally presented checkerboards were doubled in size and placed  $12^\circ$  to the left and right of fixation. The size of the peripheral stimuli was increased to compensate for the decreased cortical representation of the peripheral visual field, so that the area of primary visual cortex activated by central and peripheral stimuli would be approximately equal (Baseler, Sutter, Klein, & Carney, 1994). All checkerboard patterns reversed at a frequency of 1.5 Hz.

Participants were asked to respond when the centrally presented red fixation cross changed color (“click left mouse for blue, right mouse for green”). Target events (i.e., color changes) occurred every 7–15 s, synchronized with a checkerboard reversal. Checkerboard reversals that coincided with target events were not used in measuring the VEP. Upon a color change, the checkerboards stopped reversing. Once a response was made, the reversals resumed and the fixation cross changed back to red. If the response was incorrect or slow ( $>2$  s), an error tone sounded (4000 Hz for 50 ms).

Participants viewed 350 checkerboard reversals for each of the four conditions created by crossing the two-level factors of Hand Position (up versus down) and Stimulus Position (central versus peripheral), resulting in a total of 1400 trials. The order of both hand position and stimulus type was counterbalanced across participants. Seven participants completed a version of this study in which they also performed an intervening task between the

center and peripheral conditions. The pattern of the effects reported below did not vary between these participants and those who performed the conditions consecutively.

### *EEG processing and analysis*

The raw EEG data were converted into EEProbe format (Version 3.3.118), using PolyRex (ANT Software BV, Enschede, The Netherlands; Kayser, 2003). Individual data sets were re-referenced to the average of the two mastoids, resampled at 250 Hz, and then filtered with a high-pass frequency of 0.16 Hz and a low-pass frequency of 30 Hz. Trials were defined as the  $-200$  to  $400$  ms epoch surrounding each checkerboard reversal (excluding reversals that coincided with a fixation-point color change). Trials with artifacts were rejected on the basis of the horizontal electrooculogram (HEOG)—the voltage difference between electrodes placed lateral to the external canthi—and vertical electrooculogram (VEOG)—the voltage difference between electrodes placed above and below the right eye. Trials were rejected if the HEOG exceeded a threshold of  $-40$   $\mu\text{V}$  or  $40$   $\mu\text{V}$  or the VEOG exceeded  $80$   $\mu\text{V}$ . Participants were excluded from the analysis if the HEOG and VEOG thresholds were exceeded in more than 33% of their trials. The VEP was then calculated as the average waveform for each condition. Temporally, differences in the VEP were assessed for three separate time ranges that correspond with the latencies of the P1 (80–120 ms), N1 (120–160 ms), and P2 (160–260 ms) components. Spatially, VEPs were calculated as the average voltage over posterior central, occipital, and parietal electrode sites (Oz, O1, O2, POz, PO3, PO4, Pz, P1, P2, and CPz).

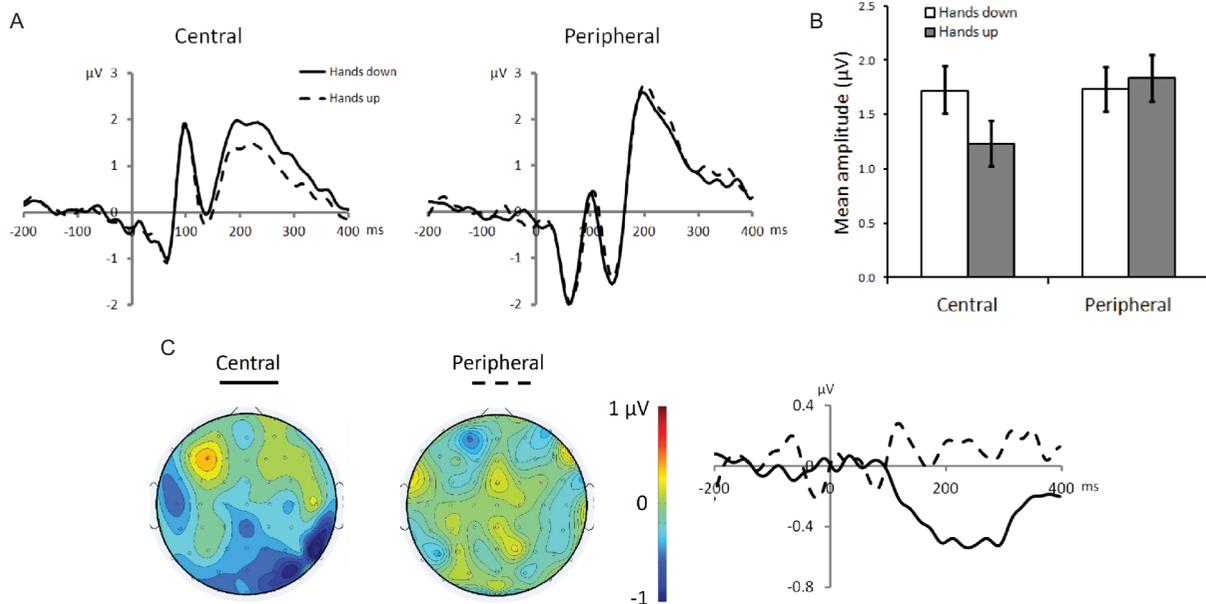
## **Results and discussion**

### *Behavioral results*

All participants completed the target fixation task with an accuracy of at least 90% ( $M = 96.0$ ,  $SD = 2.5$ ). Behavioral responses were not analyzed further.

### *ERP results*

The VEPs elicited by centrally and peripherally presented checkerboards are plotted as a function of hand position in Figure 2A. Visual inspection of this figure reveals an effect of hand position on the centrally elicited VEP that emerges about 150 ms post-reversal, and is sustained across the duration of the P2 component. This effect is absent in the VEP elicited by peripheral checkerboards.



**Figure 2.** Experiment 1 results. (A) VEPs elicited by centrally and peripherally presented checkerboard inversions, as a function of hand position. Plots are the mean voltage collapsed across electrodes Oz, O1, O2, POz, PO3, PO4, Pz, P1, P2, and CPz. (B) Mean amplitude of the P2 component (160 to 260 ms). Placing the hands near the visual display attenuated the amplitude of the P2 generated by central inversions, and had no effect on the peripherally generated P2. Error bars are 1 *SEM* with between-subject error removed (Cousineau, 2005). (C) Scalp plots (left) at 185 ms post inversion and time course (right) of the effect of hand position, calculated as hands-up minus hands-down. Hand position affected the amplitude of the P2 component generated by central stimuli, resulting in smaller amplitude potentials at posterior electrodes when participants' hands were placed close to the visual display. For clarity, the plotted ERP time course has been filtered with a low-pass frequency of 15 Hz.

Three separate 2 (Hand Position)  $\times$  2 (Stimulus Position) within-subject ANOVAs were used to test for statistical differences in mean voltage for the P1, N1, and P2 components. The P1 analysis revealed a main effect of Stimulus Position,  $F(1, 19) = 8.12$ ,  $MSE = 37.51$ ,  $p = .01$ , indicating a significantly larger P1 amplitude for centrally presented stimuli than peripherally presented stimuli. Of primary interest, however, there was no main effect of Hand Position and no interaction between Hand Position and Stimulus Position, both  $F_s < 1$ . Similar results were observed across the N1 time range: a significant main effect of Stimulus Position,  $F(1, 19) = 11.17$ ,  $MSE = 29.05$ ,  $p = .003$ , but no significant effect of Hand Position,  $F < 1$ , and no interaction,  $F(1, 19) = 3.25$ ,  $MSE = 1.18$ ,  $p = .09$ .

In contrast to the P1 and N1 analyses, mean voltage was affected by Hand Position across the P2 time range, as revealed by a Hand Position  $\times$  Stimulus Position interaction,  $F(1, 19) = 4.97$ ,  $MSE = 1.69$ ,  $p = .04$  (see Figure 2B). The main effect of Stimulus Position for the P2 analysis was not significant,  $F < 1$ , nor was the main effect of Hand Position,  $F(1, 19) = 2.09$ ,  $MSE = 0.72$ ,  $p = .16$ . Two paired-samples *t*-tests were used to assess the interaction, revealing a significant effect of Hand Position for central stimuli,  $t(19) = 3.05$ ,  $p = .007$ , and no effect for peripheral stimuli,

$t(19) < 1$ . As depicted in Figure 2C, when participants placed their hands next to the visual display, the potentials generated by central stimuli were attenuated over posterior-occipital electrodes across the duration of the P2 component.

It is interesting that hand position altered VEPs for central, but not peripheral, stimuli. Because participants performed a central attention-demanding task throughout the session, it may be that hand position only affects the processing of stimuli that fall within the focus of spatial attention. There are additional differences, however, between the central and peripheral conditions. Central stimuli, but not peripheral stimuli, were overtly fixated. Moreover, stimulus-to-hand distance varied across the hands-up conditions, although, counterintuitively, our effect occurred for the stimulus location furthest from the hands. To address these issues, a second experiment was conducted.

## EXPERIMENT 2

To determine whether the focus of attention was why hand position only affected central VEPs and not peripheral VEPs in Experiment 1, Experiment 2 used the same central and peripheral checkerboards, but moved the color change detection task to a peripheral location.

Thus, in this experiment, the focus of attention is in the periphery rather than the central location. If the hand position effect is restricted to stimuli that fall within the focus of spatial attention, then we should observe a P2 attenuation for peripheral, but not central, checkerboards.

## Methods

### *Apparatus and participants*

Using the same apparatus as Experiment 1, we collected data from 22 undergraduate students at the University of Toronto. Two participants were excluded due to excessive slow-wave artifacts, and three for excessive blink and eye movements (greater than 33%). Of the remaining 17 participants (mean age = 18.6; 5 women), all were right-handed and had normal or corrected-to-normal vision.

### *Design, procedure, and EEG analysis*

Experiment 2 used a peripheral, rather than central, color-change task. The target was changed to a large square ( $2.4^\circ$  of visual angle) to ensure that participants could perform color discriminations without moving their eyes from a central, gray fixation point. To maintain comparability with Experiment 1, we continued to present peripheral checkerboards in both visual fields, but targets only appeared in one of the locations (counterbalanced across experiment halves) so that attention was focused in a single location, as in Experiment 1, rather than divided across multiple locations. To ensure that participants actively attended the peripheral target for color changes, the task was made more difficult by decreasing the time window for response to 800 ms. The left and right target conditions were collapsed into a single condition for analysis. VEPs were assessed as the average voltage over electrode sites: Oz, O1, O2, POz, PO3, PO4, Pz, P1, P2, P3, P4, and CPz. Participants viewed 700 reversals for each of four conditions created by crossing hand position and stimulus location, resulting in a total of 2800 trials. In all other respects, Experiments 1 and 2 were identical.

## Results and discussion

### *Behavioral results*

All participants completed the color-change task with an accuracy of at least 70% ( $M = 88.3$ ,  $SD = 8.8$ ). Behavioral responses were not analyzed further.

### *ERP results*

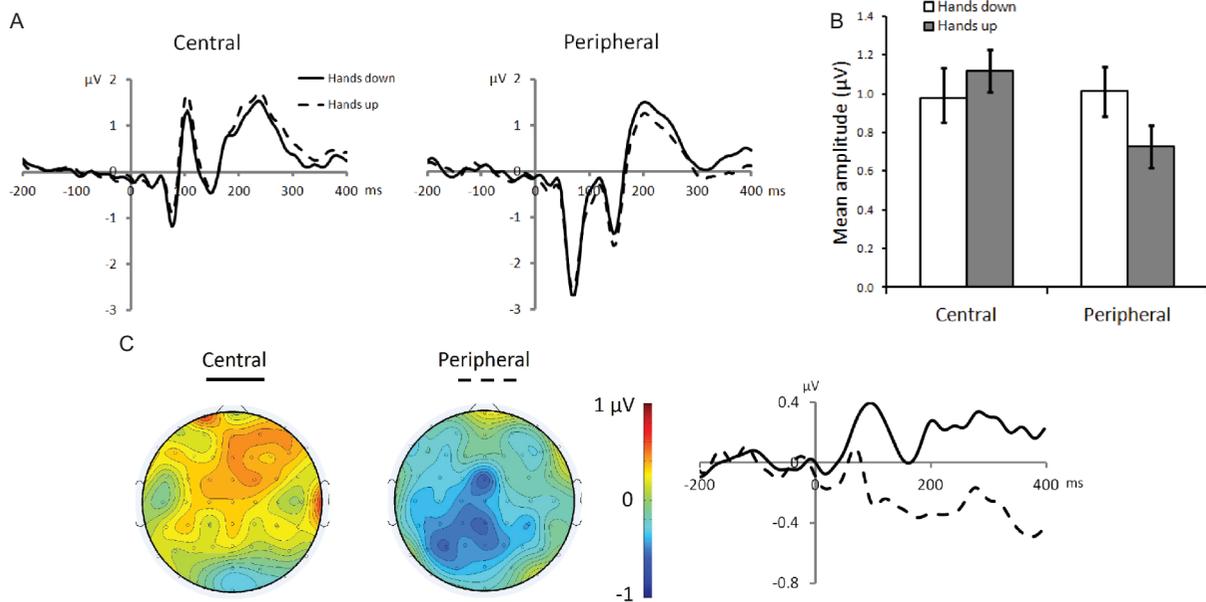
The P1 and N1 results were similar to those from Experiment 1. The P1 analysis revealed a main effect of Stimulus Position,  $F(1, 16) = 6.86$ ,  $MSE = 34.0.1$ ,  $p = .02$ , indicating a larger P1 amplitude for central stimuli than peripheral stimuli. However, there was no main effect of Hand Position and no interaction between Hand Position and Stimulus Position, both  $F_s < 1$ . Similar results were observed across the N1 time range: a significant main effect of Stimulus Position,  $F(1, 16) = 15.21$ ,  $MSE = 11.23$ ,  $p < .001$ , but no significant effect of Hand Position,  $F < 1$ , and no interaction,  $F(1, 16) = 2.27$ ,  $MSE = 0.49$ ,  $p = .15$ . As with Experiment 1, the P2 analysis revealed a Hand Position  $\times$  Stimulus Position interaction,  $F(1, 16) = 5.19$ ,  $MSE = 0.77$ ,  $p = .04$  (see Figure 3A and B), with non-significant main effects, both  $F_s < 1$ . Of importance, however, the interaction was reversed, with a significant effect of Hand Position for peripheral stimuli,  $t(16) = 3.05$ ,  $p = .008$ , and no effect for central stimuli,  $t(16) < 1$ . The effect occurred at posterior-occipital regions over the course of the P2 component (Figure 3C).

In the peripheral condition of Experiment 2, spatial attention was lateralized: Subjects alternated attention to each visual field across separate blocks. To further investigate the P2 Hand Position effect, we assessed whether it was similarly lateralized by performing a 2 (Hand Position)  $\times$  2 (Hemisphere: ipsilateral vs. contralateral to the location of attention) ANOVA. Hemisphere did not interact with Hand Position,  $F(1, 16) = 0.66$ ,  $MSE = 0.02$ ,  $p = .43$ ; taken together with the scalp plot in Figure 3C, the P2 attenuation appears to be greatest over central electrodes, even though subjects attended to peripheral spatial locations.

The results of Experiment 2 clarify why, in Experiment 1, hand position only affected VEPs elicited by central checkerboards and not peripheral checkerboards. Specifically, the results of Experiment 1 could have been due to differences in (1) covert attention (i.e., the location of the target task), (2) overt attention (i.e., the location of fixation), and (3) stimulus-to-hand distance in the hands-up condition. Because we manipulated the location of covert attention while holding fixation and stimulus-to-hand distance constant, the results of Experiment 2 reveal that the effect of hand position on VEPs only occurs for stimuli that appear in the focus of spatial attention.

## GENERAL DISCUSSION

In the present study, we investigated whether hand position affects the processing of visual stimuli as



**Figure 3.** Experiment 2 results. (A) VEPs elicited by central and peripheral checkerboards, as a function of hand position. Plots are the mean voltage collapsed across electrodes Oz, O1, O2, POz, PO3, PO4, Pz, P1, P2, P3, P4, and CPz. (B) Mean amplitude of the P2 (160–260 ms). In contrast to Experiment 1, placing the hands near the visual display attenuated the P2 amplitude for peripheral stimuli, and had no effect on P2 generated by central stimuli. Error bars are 1 *SEM* with between-subject error removed. (C) Scalp plots (left) at 185 ms post-inversion and time course (right) of the effect of hand position, calculated as hands-up minus hands-down. The plotted ERP time course was filtered with a low-pass frequency of 15 Hz.

measured by the VEP. The results of this investigation reveal that when one's hands are close to the visual display, the VEP is attenuated over parieto-occipital electrode sites, with the effect emerging most strongly during the time range of the P2 component. Of importance, this effect was qualified by an interaction with the location of attention: When participants performed a central attention task, the P2 was attenuated for central but not peripheral checkerboards (Experiment 1), and when participants performed a peripheral attention task, the P2 was attenuated for peripheral but not central checkerboards (Experiment 2). These results demonstrate that hand proximity alone is insufficient to elicit the P2 effect. Rather, the hand position effect appears to depend both on where the hands are positioned (surrounding versus not surrounding the stimulus) and whether or not the stimulus appears in a behaviorally relevant spatial location.

Despite observing significant modulations of the P2 amplitude in both experiments, we did not observe any reliable modulations of the earlier P1 and N1 components. The absence of an effect of hand position on the P1 and N1 components suggests that the hand position effect does not result from a narrowing of the focus of visuospatial attention. It has been demonstrated behaviorally that target detection is enhanced (i.e., speeded) for stimuli that appear near a single outstretched hand, suggesting that visual processing is prioritized near a single extended hand (Reed et al., 2006). Thus, one

explanation for the changes that occur when *two* hands are placed around a display is that nearness to the hands causes visuospatial attention to become more focused within the circumscribed area, even before any stimuli have been presented. Such a focusing of attention might, for example, allow participants in the present study more quickly and accurately to notice changes in the fixation point color (and checkerboard reversals). The results of the present study are not, however, compatible with this interpretation, as the focusing of visual spatial attention typically produces P1/N1 enhancements (Hillyard & Anllo-Vento, 1998; Martínez et al., 1999). The hand position effect in the present study did not emerge until later, at the time of the P2 component, suggesting that the attentional enhancement occurs once hand-proximal stimuli have reached later stages of processing.

The observed P2 modulation is compatible with the changes in visual processing reported by Abrams et al. (2008) and Davoli et al. (2010). The P2 is an endogenous component, influenced mainly by internal variables rather than characteristics of the sensory stimulus (McDonough, Warren, & Don, 1992). While modulations of the P2 have been associated with numerous higher perceptual and cognitive processes, such as feature detection (Luck & Hillyard, 1994), memory encoding (Dunn, Dunn, Languis, & Andrews, 1998), and working memory (Lefebvre, Marchand, Eskes, & Connolly, 2005), it is the modulation by selective attention (Hackley et al., 1990; Noldy et al., 1990) that most

resembles the hand position effect in the present study. Importantly, visual stimuli that are selectively attended show the same P2 attenuation as that observed in the hands-up condition of the present study (Hackley et al., 1990). It is plausible, then, that the hand position effect reflects the greater allocation of attentional resources at late stages of visual perception for hand proximal stimuli. This interpretation of the P2 hand position effect as a late attentional enhancement is consistent with the conclusion that stimuli near the hands receive improved spatial processing (Davoli et al., 2010), which may involve the delayed disengagement of attention from hand proximal stimuli (Abrams et al., 2008).

The conclusion that attention mediates the hand effect places constraints on the possible mechanisms through which this effect might operate. This conclusion is particularly relevant to one of the stronger candidate mechanisms: bimodal visual-tactile neurons (Graziano et al., 1994). These visual-tactile neurons, identified so far in monkeys, have receptive fields anchored to the hands, in that they respond most strongly to hand-proximal stimuli. Naturally, this population of neurons is an attractive candidate for explaining the hand position effect reported in the present and past studies (Abrams et al., 2008; Davoli & Abrams, 2009). Bimodal neurons could be recruited in a bottom-up manner (i.e., depending on stimulus-to-hand proximity) and facilitate a more detailed and thorough visual analysis of objects near the hand. While these bimodal neurons may play some role in changing visual processing near the hands, our results suggest that top-down attentional resources also contribute to the hand position effect. The importance of top-down factors in determining the hand position effect is further supported by the prior demonstration that hand-position effects do not require physical changes in stimulus-hand proximity, but can be elicited simply through imagined changes in proximity (Davoli & Abrams, 2009). The involvement of top-down attentional control may be useful, as it enables us to select only the most task-relevant stimuli near our hands for enhanced processing.

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