

# Trade-offs in visual processing for stimuli near the hands

Richard A. Abrams · Blaire J. Weidler

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**Abstract** It is known that stimuli near the hands receive preferential processing. In the present study, we explored changes in early vision near the hands. Participants were more sensitive to low-spatial-frequency information and less sensitive to high-spatial-frequency information for stimuli presented close to the hands. This pattern suggests enhanced processing in the magnocellular visual pathway for such stimuli, and impaired processing in the parvocellular pathway. Consistent with that possibility, we found that the effects of hand proximity in several tasks were eliminated by illumination with red diffuse light—a manipulation known to impair magnocellular processing. These results help clarify how the hands affect vision.

**Keywords** Embodied perception · Visual perception

Researchers have recently reported changes in the performance of a number of tasks that depend on the proximity of the hands to the stimuli being evaluated. For example, Abrams, Davoli, Du, Knapp, and Paull (2008) found that participants searched more slowly through arrays of stimuli that were near to, as opposed to far from, their hands. Reed, Grubb, and Steele (2006) found prioritized attentional allocation near an outstretched hand. And Weidler and Abrams (2013) showed that participants more fully engaged cognitive control mechanisms when task stimuli were near their hands. Objects near the hands are thought to receive preferential visual processing because such objects are important—they might be candidates for action, or they could be dangerous

obstacles that should be avoided (Abrams et al., 2008). Thus, the effects are thought to reflect the important ways in which the capabilities or vulnerabilities of our bodies can affect perceptual and cognitive processes (see Brockmole, Davoli, Abrams, & Witt, 2013, for a review).

The range of tasks that is affected by the proximity of the hands is broad. For example, in addition to the results mentioned earlier, proximity to the hands has been shown to affect semantic processing (Davoli, Du, Montana, Garverick, & Abrams, 2010), visual working memory (Tseng & Bridgeman, 2011), and figure–ground segregation (Cosman & Vecera, 2010). Proximity to the hands affected the P2 component of visual evoked potentials (Qian, Al-Aidroos, West, Abrams, & Pratt, 2012), and slowed the rate of learning complex images (Davoli, Brockmole, & Goujon, 2012) and rates of switching between global and local decisions at brief delays (Davoli, Brockmole, Du, & Abrams, 2012). Yet, despite the burgeoning interest in the effects of hand proximity on vision, very little is known about the precise nature of the visual perceptual changes that underlie the effects.

Our goal in the present study was to more precisely identify the changes in visual processing that occur near the hands. In particular, several lines of evidence have suggested that vision near the hands might be biased in favor of processing along the magnocellular visual pathway. The magnocellular pathway is one of two parallel visual pathways that originate in distinct types of retinal ganglion cells. The M retinal ganglion cells of the magnocellular pathway are characterized by their fast response and high sensitivity to motion (Callaway, 1998). These cells project to the dorsal visual processing stream, which is heavily involved in planning and preparing movements. The other pathway, the parvocellular pathway, originates in P retinal ganglion cells that have higher spatial acuity, but slower responses relative to the M cells (Callaway, 1998). This channel projects to the ventral visual stream, which is involved in object recognition.

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R. A. Abrams · B. J. Weidler  
Washington University, St. Louis, MO, USA

R. A. Abrams (✉)  
Department of Psychology, Washington University, St. Louis,  
MO 63130, USA  
e-mail: rabrams@wustl.edu

One reason to expect greater involvement of the magnocellular pathway for stimuli near the hands stems from the defensive advantage that would be afforded by heightened sensitivity around the hands and the body. In particular, Graziano and Cooke (2006) have identified multimodal neurons in several brain areas that are sensitive not only to tactile stimulation on the skin, but also to visual stimulation near the body. They have provided evidence that these neurons play an important role in defense by forming a margin of safety around the body. Others have argued that known properties of these multimodal neurons correspond closely to the visual changes that have been observed near the hands (Reed et al., 2006). Importantly for the present purposes, the multimodal neurons that have been found are most densely concentrated in the ventral intraparietal (VIP) area and an area in the precentral gyrus. The ventral intraparietal area is on the magnocellular pathway, and VIP is known to project to the precentral gyrus (Lewis & Van Essen, 2000), suggesting that objects near the hands may receive preferential processing from magnocellular mechanisms.

If the purpose of closely monitoring the space around the body (and hands) is a defensive one, it would be advantageous if a person could respond rapidly to objects that are within the margin of safety, by either moving so as to avoid them or reaching out to grasp them. And even when one's safety is not being threatened, accurate guidance and control of hand movements would be facilitated by enhancements in vision near the hands. Considerable evidence has suggested that the dorsal visual pathway is heavily involved in the processing that is needed to guide and control hand movements (Goodale & Milner, 1992). Because the dorsal pathway receives its predominant input from the magnocellular channel (Livingstone & Hubel, 1987; Maunsell, Nealey, & DePriest, 1990), greater involvement of magnocellular mechanisms would be expected for evaluating stimuli near the hands. Such reasoning was recently put forth by Gozli, West, and Pratt (2012), and they reported results consistent with those possibilities: They found improvements in temporal sensitivity for stimuli near the hands at the expense of a deficit in spatial acuity, consistent with the known temporal advantage of magnocellular mechanisms.

Effective interaction with objects near the hands would be facilitated by more rapid or accurate segregation of such objects from the background. Indeed, Cosman and Vecera (2010) reported that proximity to the hands influences figure-ground assignment, with elements near an extended hand being more likely to be judged as figure. The reported bias could be mediated by enhanced magnocellular processing (Gozli et al., 2012), because the magnocellular channel is known to be sensitive to luminance differences that are thought to underlie figure-ground segregation (Livingstone & Hubel, 1988).

Finally, one additional reason for suspecting greater involvement of magnocellular mechanisms in the evaluation of stimuli near the hands centers on the emotional significance of such stimuli. Objects near the body are potentially threatening and must be closely monitored in order to maintain safety. Thus, visual mechanisms that are suited for the rapid assessment of threat might be engaged by such objects. It is known that emotionally evocative stimuli enjoy preferential processing in vision (e.g., Fox, Russo, & Dutton, 2002; Öhman, Flykt, & Esteves, 2001; Phelps, Ling, & Carrasco, 2006). Importantly, emotion affects vision by activating the amygdala, and because the amygdala receives input and projects to the visual cortex primarily via magnocellular connections (Amaral, Behnia, & Kelly, 2003), emotional stimuli produce a bias in processing on the magnocellular pathway (Bocanegra & Zeelenberg, 2009, 2011). Thus, if the mechanisms that prioritize objects near the hands are the same as those that prioritize emotionally significant stimuli, the visual changes for objects near the hands would be expected to reflect greater involvement of magnocellular mechanisms.

Our goal in the present study was to determine whether indeed objects near the hands receive biased processing by magnocellular visual mechanisms. As we noted earlier, already some evidence is consistent with that possibility (Gozli et al., 2012). To learn more, we exploited two known properties of the magnocellular mechanisms. In particular, the magnocellular channel is known to have greater sensitivity to relatively low-spatial-frequency stimuli, as compared to the parvocellular pathway (Callaway, 1998). Hence, in Experiment 1 we measured sensitivity to a range of spatial frequencies for stimuli that were both near to and far from the hands. As expected, we found enhanced sensitivity to low spatial frequencies near the hands. Additionally, the magnocellular channel is known to be suppressed by illumination with diffuse red light. This conclusion is based in part on single-cell recordings made by Wiesel and Hubel (1966) in the lateral geniculate nucleus, in which distinct layers are known to receive input selectively from either M or P retinal ganglion cells. Hence, any phenomenon suspected to be mediated by magnocellular processing should be attenuated in red light. In Experiments 2 and 3, we showed that changes in vision near the hands are indeed suppressed in red light—confirming the involvement of magnocellular mechanisms in the effects.

## Experiment 1

In this experiment, participants discriminated the orientation of briefly presented Gabor patches that varied in spatial frequency. Participants performed the task with the hands both near to and far from the stimuli. We had participants hold both hands either near to or far from the display, because previous studies have shown much stronger effects of hand proximity

when both hands are near the stimuli than when only one hand is outstretched (Tseng & Bridgeman, 2011). If objects near the hands are subjected to enhanced processing along the magnocellular pathway, we would expect improved discrimination of low-spatial-frequency stimuli near the hands, consistent with the properties of magnocellular mechanisms. Furthermore, several researchers have reported trade-offs between magnocellular and parvocellular mechanisms: Conditions that lead to enhancement of magnocellular processing also lead to impairment of the parvocellular channel (e.g., Bocanegra & Zeelenberg, 2009; Breitmeyer & Breier, 1994; Burr, Concetta Morrone, & Ross, 1994). Thus, in the present experiment our focus was specifically on trade-offs in the processing of low- and high-spatial-frequency information near the hands.

## Method

**Participants** Eleven undergraduates each participated in one 30-min session in exchange for course credit. One participant was replaced due to an excessive number of errors (>40 %), resulting in usable data from ten participants. The participants were naïve with respect to the hypotheses under investigation and had not previously served in any experiments in which hand proximity had been manipulated.

**Apparatus and procedure** Participants viewed the CRT display binocularly from a distance of 35 cm (fixed by a chinrest). The two postures used in all of the experiments are shown in Fig. 1. In the *hands-near* blocks, participants placed their hands on 6-cm-diameter buttons attached to each side of the monitor, with their elbows resting on foam cushions. In *hands-far* blocks, participants placed their hands on the same two buttons resting on a board on their lap. The sequence of events on each trial is shown in Fig. 2. All of the stimuli were presented on a gray background. Each trial began with the presentation of a white fixation spot, followed 1 s later by the presentation of a Gabor patch 4° to the left or right of fixation for 50 ms. The Gabor patch consisted of a sine-wave grating with a spatial frequency of either 2.1 or 4.2 cycles per degree (cpd), contained within a 2°-diameter Gaussian envelope. The grating was either vertical or tilted 4° to the left or right of vertical—the participant's task was to indicate whether the grating was vertical or tilted, and to press the correct one of the two keys to indicate their judgment. Participants had 2 s after patch onset to produce their unspeeded response. The next trial began at the end of the 2-s response interval.

**Design** After 16 practice trials, participants served in two blocks of 64 trials in one hand posture, followed by two blocks in the other posture. Within each block, equal numbers were presented of each combination of spatial frequency (2.1 or 4.2 cpd), presentation side (left or right), and orientation

(tilted or vertical). Half of the tilted gratings for each presentation side and spatial frequency were tilted clockwise; the others were tilted counterclockwise. Posture order was counterbalanced across participants.

## Results and discussion

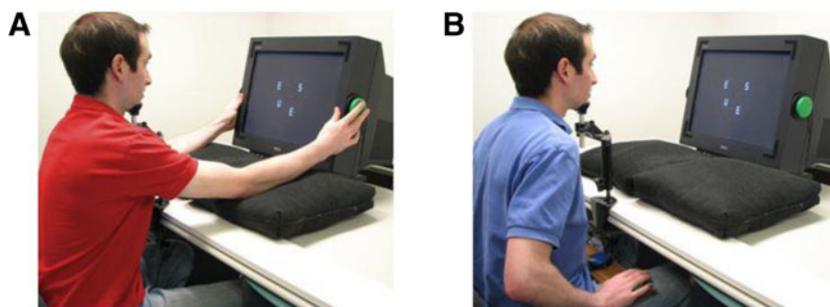
Sensitivity to the tilt in the gratings was measured by calculating  $A'$ . We considered the presence of tilt to be the signal, so a response was scored as a hit if the grating was tilted and the participant indicated that it was tilted. (We used  $A'$  because a few cells had zero false alarms, for which  $d'$  is undefined. Computation of modified  $d'$ 's yielded the same results.) Mean sensitivity is shown in Fig. 3, separately for each hand posture and spatial frequency. As can be seen, we observed no main effect of hand posture, nor a main effect of spatial frequency,  $F_s(1, 9) < 1$ , but hand posture did interact with spatial frequency: Sensitivity to low spatial frequencies was better near the hands, whereas sensitivity to high spatial frequencies was better away from the hands,  $F(1, 9) = 8.4, p = .018, \eta_p^2 = .48$ .

We also analyzed the median response times to rule-out the possibility of a speed–accuracy trade-off. The mean reaction times (RTs) were 1,664 and 1,662 ms with hands far for the low and high spatial frequencies, respectively, and 1,686 ms (LSF) and 1,675 ms (HSF) with the hands near. The analysis revealed no main effect of posture,  $F(1, 9) = 2.0, p = .196$ , or of spatial frequency,  $F(1, 9) < 1$ , nor an interaction,  $F(1, 9) = 1.5, p = .249$ .

The present results are precisely what would be expected if objects near the hands benefit from biased processing on the magnocellular pathway because magnocellular mechanisms are sensitive to lower spatial frequencies relative to parvocellular mechanisms. Additionally, whereas proximity to the hands improved sensitivity to low spatial frequency stimuli, we also found impaired processing of higher frequency stimuli. The pattern of results is very similar to that reported by Bocanegra and Zeelenberg (2009), who also measured spatial frequency sensitivity while manipulating activation of the magnocellular pathway. They attributed the trade-off between high- and low-spatial-frequency processing to cross-inhibition between magnocellular and parvocellular channels. Also, in their experiment, the perceptual changes were produced by the presentation of emotionally evocative stimuli. Given the similar pattern of results, the present findings are consistent with the suggestion that visual changes near the hands occur in part because of the emotional significance of objects near the hands.

## Experiment 2

Considerable evidence, both behavioral (Bedwell, Brown, & Orem, 2008; Breitmeyer & Breier, 1994; Livingstone &

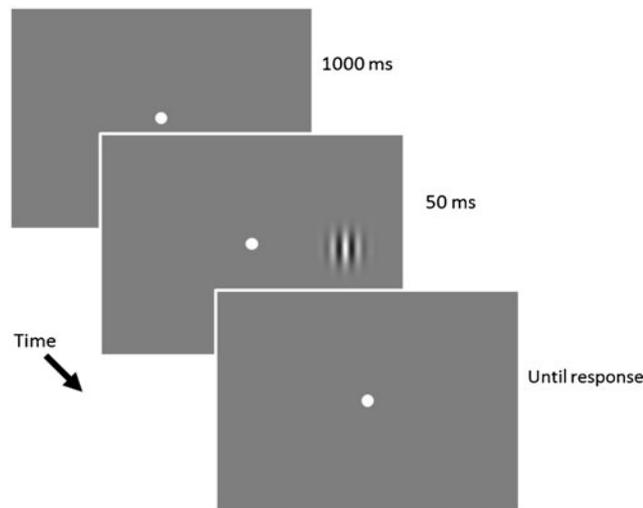


**Fig. 1** The hands-near (a) and hands-far (b) postures used in the present experiments

Hubel, 1988; West, Anderson, Bedwell, & Pratt, 2010) and neurophysiological (Bedwell, Miller, Brown, & Yanasak, 2006; de Monasterio, 1978; Wiesel & Hubel, 1966), has indicated that activity in the magnocellular channel is suppressed by exposure to diffuse red light. For example, West et al. (2010) presented either low or high spatial frequency Gabor patches and assessed the perceived time of onset of one relative to the other. LSF patches were perceived to appear before simultaneously presented HSF patches—consistent with the faster responses of the magnocellular pathway relative to the parvocellular pathway. Importantly, the temporal advantage for LSF stimuli was eliminated under illumination by diffuse red light, presumably because such light suppressed activity in the magnocellular pathway. If the effect of hand posture reported in Experiment 1 was due to enhanced activation of magnocellular mechanisms near the hands, the changes in spatial frequency sensitivity near the hands should be reduced in the presence of diffuse red light. We tested that prediction here by repeating Experiment 1, but in the presence of red illumination.

**Method**

*Participants* Twenty undergraduates each participated in one 30-min session for course credit. Two participants were



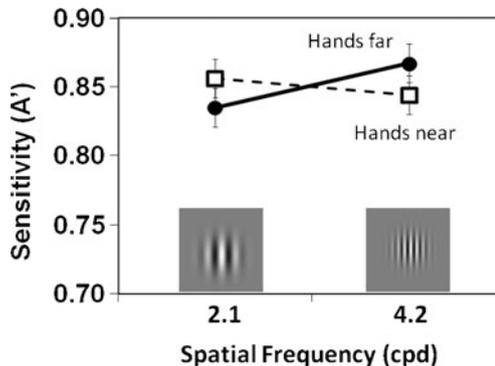
**Fig. 2** Sequence of events during a trial of Experiment 1

eliminated due to excessive error rates (>40 %), resulting in usable data from 18 participants. The participants were naïve with respect to the hypotheses under investigation and had not served in Experiment 1 or in other experiments in which hand proximity was manipulated.

*Apparatus, procedure, and design* The experiment was identical to Experiment 1, except that the stimuli were presented on a red background here as opposed to the gray background used in Experiment 1. The screen background remained red throughout the entire experiment.

**Results and discussion**

Mean sensitivity is shown in Fig. 4 as a function of hand posture and spatial frequency. We found no main effect of posture,  $F(1, 17) < 1$ , or spatial frequency,  $F(1, 17) = 2.4$ , n.s., nor an interaction,  $F(1, 17) < 1$ . The absence of an interaction between posture and spatial frequency was not due to a lack of statistical power, because the present experiment was identical to Experiment 1, but with nearly twice as many participants. Thus, the diffuse red illumination eliminated the enhanced sensitivity to low spatial frequencies near the hands. Because magnocellular channel activity is suppressed by such illumination, the results suggest that the changes in vision produced



**Fig. 3** Mean sensitivities from Experiment 1 as a function of spatial frequency, separately for the two hand postures. The dashed line is from the hands-near condition. Error bars show the within-subjects standard errors

by hand proximity are caused by enhanced magnocellular processing.

As in Experiment 1, we also analyzed the median response times to rule-out the possibility of a speed–accuracy trade-off. The mean RTs were 1,717 and 1,718 ms with the hands far for low and high spatial frequencies, respectively, and 1,682 and 1,680 ms for hands near. We observed a main effect of posture,  $F(1, 17) = 12.5, p = .003, \eta_p^2 = .42$ , with hands-near responses being faster than hands-far responses. But no effect of spatial frequency emerged, nor any interaction,  $F_s < 1$ .

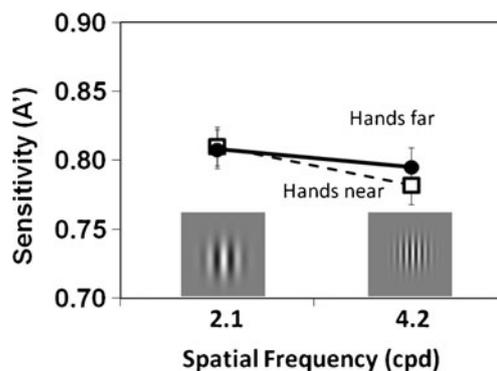
### Experiment 3

If enhanced processing in the magnocellular pathway is responsible for the changes that have been reported in vision near the hands, such changes would be expected to be reduced in the presence of red illumination for changes other than spatial frequency sensitivity. For example, researchers have reported reduced rates of visual search for stimuli near the hands (Abrams et al., 2008; Davoli & Abrams, 2009). If the changes in visual search rate are produced in part by changes in activity along the magnocellular pathway, then such changes should be attenuated under red illumination. We tested that possibility here by comparing visual search near and far from the hands, in the presence of either green or red illumination.

#### Method

**Participants** Twenty-four undergraduates each served in one 1-h session in exchange for course credit. The participants were naïve with respect to the hypotheses under investigation and none had served previously. Participants all had normal or corrected-to-normal vision.

**Apparatus and procedure** The apparatus was the same as that used in the earlier experiments. The procedure is illustrated in Fig. 5. At the beginning of each trial, a white fixation cross ( $1.5^\circ \times 1.5^\circ$ ) appeared at the center of the display on either a red or a green background. After 500 ms, a search array appeared consisting of four or eight letters, each  $3.0^\circ$  high and  $1.5^\circ$  wide, displayed in randomly selected locations (but no closer than  $0.75^\circ$  to any other letter) inside an active area  $21^\circ$  high  $\times$   $33^\circ$  wide. Each array contained one target letter, either an H or an S, and participants were to indicate which target was present by pressing one of two response buttons as quickly as possible using their hands. The distractor letters were randomly selected Es and Us. The participants received feedback messages if their response had a latency less than 100 ms (“Too fast!”) or greater than 1,500 ms (“Too slow!”), or if they pressed the incorrect key (“Wrong key pressed!”). We used a 2-s intertrial interval.

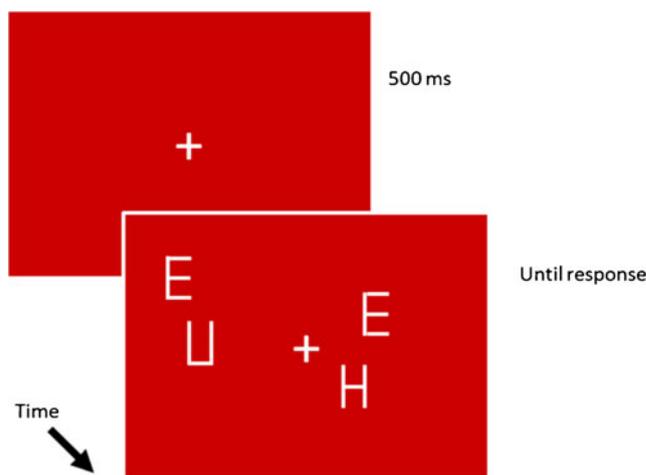


**Fig. 4** Mean sensitivities from Experiment 2, under diffuse red illumination, as a function of spatial frequency, shown separately for the two hand postures. Error bars show the within-subjects standard errors

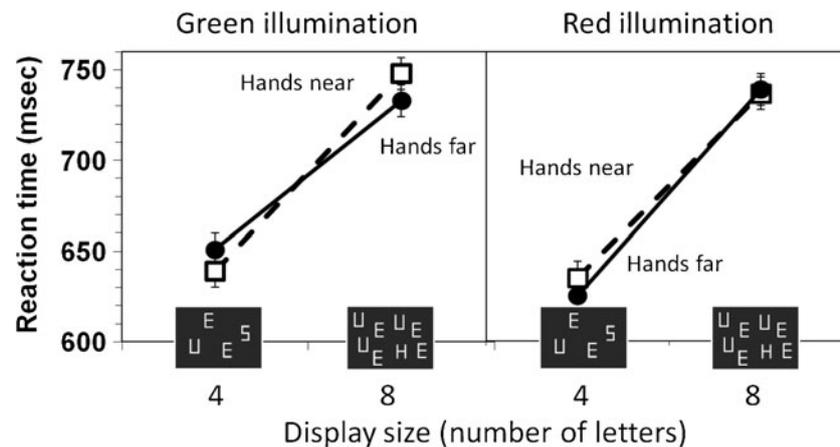
**Design** Each participant performed ten practice trials followed by four 80-trial test blocks. Within each block, half of the trials were presented at each display size (four or eight letters to be searched), and within each display size the target was equally likely to be an S or an H. The screen background color alternated across blocks. The hand posture was held constant for the first two blocks, and then was switched for the last two. The initial screen color and hand posture were counterbalanced across participants, as was the assignment of response keys to target letters.

#### Results and discussion

Mean RTs are shown in Fig. 6. RTs were longer when more items were present in the display,  $F(1, 23) = 173.0, p < .001, \eta_p^2 = .88$ , but we observed no main effect of background color,  $F(1, 23) = 1.7, n.s.$ , or hand posture,  $F(1, 23) < 1$ . Importantly, however, we did find a three-way interaction between posture, display size, and background color,  $F(1,$



**Fig. 5** Sequence of events during a trial of Experiment 3. The background of the display was either green or red, depending on the trial block



**Fig. 6** Mean reaction times from Experiment 3 as a function of display size, shown separately for the two hand postures and the two illuminations. Error bars show the within-subjects standard errors

23) = 6.0,  $p = .023$ ,  $\eta_p^2 = .21$ : With a green background, the search rate was slower when the hands were near the display rather than far away, but with a red background, the proximity of the hands did not affect the search rate.

To confirm our interpretation of the three-way interaction, we conducted separate ANOVAs for each background color. For both the red and green backgrounds, display size had a main effect [red,  $F(1, 23) = 135.1$ ,  $p < .001$ ,  $\eta_p^2 = .85$ ; green,  $F(1, 23) = 115.1$ ,  $p < .001$ ,  $\eta_p^2 = .83$ ], and hand posture had no overall effect,  $F_s(1, 23) < 1$ . Critically, with a green background we found the typical interaction between posture and display size, revealing slower search rates when the hands were near the display,  $F(1, 23) = 4.7$ ,  $p = .041$ ,  $\eta_p^2 = .17$ , but with a red background no suggestion of an interaction emerged,  $F(1, 23) < 1$ .

The proportions of correct trials in each condition are shown in Table 1. Accuracy did not depend on color or posture,  $F_s(1, 23) < 1$ , but participants were more accurate with the smaller display size,  $F(1, 23) = 11.4$ ,  $p < .005$ ,  $\eta_p^2 = .33$ . The differences in accuracy as a function of display size were somewhat smaller with a red background, resulting in a Color  $\times$  Display Size interaction,  $F(1, 23) = 4.3$ ,  $p = .050$ ,  $\eta_p^2 = .16$ . Importantly, posture was not involved in any interaction (nor did it have a main effect, as already noted).

In the present experiment, when the screen background was green, participants searched more slowly through visual displays that were close to their hands

than through those that were far away. This slowing of search rates near the hands is the same pattern that has been reported previously (with a gray background; Abrams et al., 2008; Davoli & Abrams, 2009). However, when the screen background was red, the proximity of the hands to the display did not affect search at all. Because red illumination suppresses magnocellular mechanisms, the present results suggest that the change in search produced by hand proximity is mediated by such mechanisms, and hence was reduced when they were suppressed.

Why might enhanced magnocellular processing slow visual search rates? One possibility, suggested by Gozli et al. (2012), stems from the presumed trade-off between magnocellular and parvocellular processing (such as that reported by Bocanegra & Zeelenberg, 2009, and observed in Exp. 1). Parvocellular mechanisms may be necessary for efficient evaluation of the detailed high-spatial-frequency information contained in the visual search stimuli. If enhanced magnocellular processing leads to reduced parvocellular processing, the reduced parvocellular processing might impair detailed evaluation of the stimuli, thus leading to slower search rates.

One other aspect of the results is noteworthy. In particular, with a display size of 4, RTs were slightly faster when the hands were near the display rather than far—but that only happened with a green background, not a red one. Indeed, this is the same pattern that has been reported several times previously (Abrams et al., 2008, Exps. 1a and 1b; Davoli & Abrams, 2009). One explanation for this pattern is that it reflects a small (but not significant) reduction in the baseline RT when the hands are near the display. It is possible that this speed-up is in fact caused by the enhanced reliance on the magnocellular pathway, which is faster than the parvocellular pathway, near the hands. The fact that the RT reduction was not observed with a red background is not surprising, since the red illumination suppresses magnocellular processing. Hence, this pattern provides further evidence consistent with the

**Table 1** Proportions correct in each condition of Experiment 3

	Green Background		Red Background	
	Display Size 4	Display Size 8	Display Size 4	Display Size 8
Hands near	.963	.926	.946	.938
Hands far	.966	.928	.969	.935

conclusion that the effects of hand proximity are mediated by magnocellular mechanisms.

## General discussion

In the present study, we examined the nature of the changes that take place in vision near the hands. Several lines of reasoning predict that objects near the hands might benefit from enhanced processing along the magnocellular visual pathway. Such a bias might bolster the margin of safety around the body and facilitate accurate detection of and interaction with objects, threatening or otherwise. Consistent with that prediction, we found an advantage near the hands for discriminating low-spatial-frequency stimuli in Experiment 1. That advantage was eliminated in Experiment 2, in which the stimuli were presented under diffuse red illumination—a condition that is known to suppress magnocellular mechanisms. In Experiment 3, we showed the typical finding of reduced visual search rates near the hands—but only under green, not red, illumination. Taken together, these results confirm the presence of enhanced processing along the magnocellular pathway for objects near the hands.

Enhanced magnocellular processing for objects near the hands could have several potential beneficial effects. One advantage is a defensive one—if the space around the body (and near the hands) is being monitored for dangerous objects or threatening conditions, more rapid assessment of any such threats would be advantageous. Enhanced involvement of the magnocellular pathway could allow one to benefit from the faster responses of that channel. Another advantage is a practical one. Objects near the body are often intended to be grasped or manipulated. Biased processing along the magnocellular pathway would enhance activity in dorsal stream mechanisms that are crucial for the accurate control of action.

It is possible to speculate about two potential mechanisms that might underlie the observations that we have reported. First, as others have suggested (e.g., Reed et al., 2006), bimodal visual–tactile neurons are ideally suited to play a role in enhancing vision near the hands. These neurons have visual receptive fields that move along with the hand, and hence would confer some processing advantage to near-hand objects that are in their receptive fields. Another mechanism that might underlie hand proximity effects on vision is activation of the amygdala. The amygdala is known to primarily receive magnocellular input (Amaral et al., 2003), and behavioral results consistent with enhanced magnocellular processing have been shown to occur in response to emotionally evocative stimuli (Bocanegra & Zeelenberg, 2009, 2011). Because of the defensive importance of assessing the potential dangers posed by nearby objects (Graziano & Cooke, 2006), it is not unreasonable to regard such objects as emotional stimuli. If that occurred, enhanced processing of potential dangers would

be facilitated. Although this is speculative, such an occurrence would have the effect of biasing the magnocellular channel to the processing of nearby objects—consistent with the results that we have reported.

Although more work will be needed to determine the precise underlying neural mechanisms and the complete nature of the behavioral changes, it appears clear that objects near the hands enjoy enhanced processing along the magnocellular visual pathway.

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