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Cognition 107 (2008) 1035–1047

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Brief article

Altered vision near the hands

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Received 30 April 2007; revised 17 September 2007; accepted 18 September 2007

Abstract

The present study explored the manner in which hand position may affect visual processing. We studied three classic visual attention tasks (visual search, inhibition of return, and attentional blink) during which the participants held their hands either near the stimulus display, or far from the display. Remarkably, the hands altered visual processing: people shifted their attention between items more slowly when their hands were near the display. The same results were observed for both visible and invisible hands. This enhancement in vision for objects near the hands reveals a mechanism that could facilitate the detailed evaluation of objects for potential manipulation, or the assessment of potentially dangerous objects for a defensive response.

Keywords: Attention; Visual attention; Vision; Visual search; Action; Reaching; Inhibition of return

1. Introduction

Since the time of Woodworth (1899) researchers have known that visual information can play an important role in guiding movements of the limbs. Only recently have researchers learned that the converse may also be true: the position of the hand

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doi:10.1016/j.cognition.2007.09.006

can sometimes produce a bias in visual attention: Reed, Grubb, and Steele (2006) had subjects hold one of their hands near either the left or right side of a video display upon which a target was presented. Subjects were faster to detect targets on the side closest to their outstretched hand, even though the target location was random. Proximity to the hand has also been shown to affect vision in patients with visual neglect caused by parietal lesions (diPellegrino & Frassinetti, 2000; Schendel & Robertson, 2004), and may augment the capture of attention by a threatening stimulus (Poliakoff, Miles, Li, & Blanchette, 2007).

The presence of a spatial bias in visual attention toward objects near an extended hand suggests that the evaluation of visual stimuli near the hands may be especially important. The bias might be mediated in part by brain areas that code visual space near the body in a hand-centered coordinate system (e.g., Graziano, 2001; Makin, Holmes, & Zohary, 2007). According to this view, objects near the hands may fall into the receptive fields of hand-centered, visually sensitive neurons – invoking neural mechanisms and processing that would not occur if the hands were far away. Given this possibility, hand position may not merely *bias* processing toward or away from one hemifield, but instead the hand might *alter* key aspects of visual processing. Nevertheless, in the work conducted thus far, no one has yet examined whether the processing of stimuli near the hands is fundamentally different from the processing of stimuli far from the hands. We provide initial tests of that possibility here.

In the present study we tested the possibility that proximity to the hands may alter vision. To accomplish that, we examined performance in three classic paradigms that have been used to assess various aspects of visual attention: visual search, inhibition of return, and attentional blink. We had subjects perform each of these tasks under two different postures: one in which they held both of their hands very close to the visual stimuli, and one in which they held their hands on their laps – far from the stimuli. To anticipate the results, we found in each paradigm that subjects were slower to disengage their attention from the visual stimuli when their hands were near the stimuli – revealing a dramatic effect of hand-posture on visual perception.

2. Experiment 1

We first explored the possibility of altered vision near the hands by having subjects search through visual displays for a target letter while their hands were holding the display (*object-proximal* posture; Fig. 1a) and when their hands were on their laps – far from the objects being searched (*object-distal* posture; Fig. 1b). We ran three versions of the visual search experiment. In Experiment 1a subjects used their hands to respond, and in the object-proximal posture they were able to see their hands along the sides of the monitor. In Experiment 1b we repeated the experiment in a new group of subjects but we occluded vision of the hand. In Experiment 1c we had a third group of participants perform the experiment by responding with their feet instead of their hands. If proximity to the hands alters vision then in each situation visual search performance might depend upon the position of the hands relative to the items being searched.

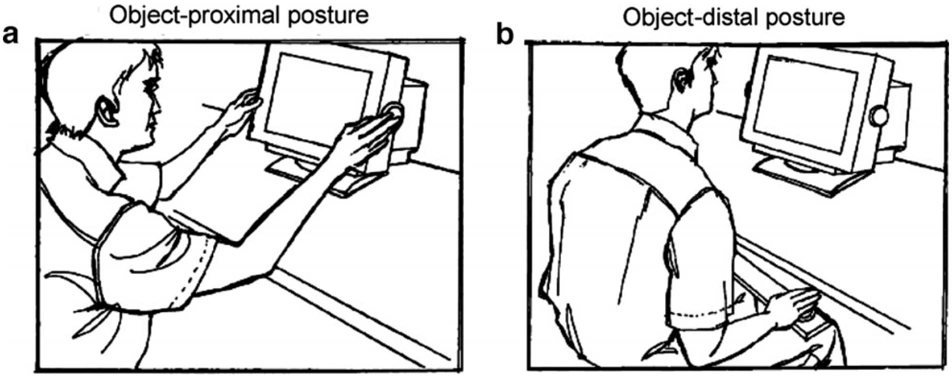

Fig. 1. Hand postures used in the present experiments. In each experiment, each participant viewed stimulus displays in (a) an object-proximal posture in which they placed their hands on buttons on the sides of the CRT monitor, and (b) an object-distal posture in which they rested their hands on identical buttons mounted to a lightweight board that rested on their laps. A cushion (not shown) was used to support the elbows in the object-proximal posture. Under both postures the viewing distance was maintained via chinrest (not shown).

2.1. Method

2.1.1. Subjects

Fifty-two experimentally-naïve college-aged participants each served in one 30-min session. Twenty participants served in Experiments 1a and 1c, 12 served in 1b.

2.1.2. Apparatus

Subjects sat at a table with their heads steadied by a chinrest 42.5 cm from a CRT display. In the object-proximal condition, subjects rested their elbows on a cushion on the table and held each hand on a 6 cm diameter button that was attached to the side of the monitor aligned with the middle of the CRT, as illustrated in Fig. 1a. In the object-distal condition subjects supported a lightweight 50 cm long board on their laps upon which were mounted two buttons identical to those in the object-proximal condition. Subjects rested one hand on each button.

2.1.3. Procedure, Experiment 1a

At the beginning of each trial a black fixation cross (1.5° × 1.5°) appeared at the center of a white display presented on an 18-inch CRT. After 500 ms, a search array appeared consisting of four or eight letters, each 3.0° high and 1.5° wide, displayed in randomly selected locations (but not closer than 0.75° to other letters) inside an active area 21° high × 33° wide. Each array contained one target letter, either an *H* or an *S*, and subjects were to indicate which target was present by pressing one of two response buttons as quickly as possible using their hands. Distracter letters were randomly selected *E*s and *U*s. Subjects received feedback messages if their response had a latency less than 100 ms (“Too fast!”), greater than 1500 ms (“Too slow!”), or if they pressed an incorrect key (“Wrong key pressed!”). There was a 2-s intertrial interval.

2.1.4. Procedure, Experiment 1b

Experiment 1b was identical to Experiment 1a except that cardboard shields were added to each side of the monitor in order to prevent the subjects from viewing their hands in the object-proximal posture. (The hands were always invisible in the object-distal posture.)

2.1.5. Procedure, Experiment 1c

Experiment 1c was identical to Experiment 1a except that subjects responded by pressing one of two pedals with their feet. All other aspects of the experiment were identical to Experiment 1a, including the positioning of the hands on buttons throughout the experiment in object-proximal and object-distal postures.

2.1.6. Design

Subjects completed each half of the experimental session under one of the two hand postures, with posture order counterbalanced across subjects. Each session began with 10 practice trials, followed by two test blocks of 64 trials each in each hand-posture condition. Within each block, targets under each display-size were equally likely to be an *H* or *S*.

2.2. Results and discussion

Mean reaction times to identify the target for each hand-posture and search array size are shown in Fig. 2 separately for each of the three experiments. In each experiment, as the number of non-target elements in the display increased so did the time needed to find the target (analysis of variance (ANOVA) revealed a main effect of display-size, $F(1,19) = 73.9$, $p < 0.001$ for Experiment 1a; $F(1,11) = 33.5$, $p < 0.001$ for Experiment 1b; $F(1,19) = 30.4$, $p < 0.001$ for Experiment 1c). This is a common finding that reflects the serial nature of the search. Importantly, the search rate (indexed by the slope of the line segments in Fig. 2) was slower when the hands were near the display in each of the three experiments (ANOVA revealed a display-size × hand-posture interaction, $F(1,19) = 6.57$, $p < 0.05$ for Experiment 1a; $F(1,11) = 5.84$, $p < 0.05$ for Experiment 1b; $F(1,19) = 5.95$, $p < 0.05$ for Experiment 1c).[1] Because the search rate reflects shifts of attention between items during the search (Treisman & Gelade, 1980; Wolfe,

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[1] An analysis of the errors in each of our experiments shows that the reaction time pattern did not arise from a tradeoff between speed and accuracy. In particular, in Experiment 1a the error rate overall was 4.9%, with subjects making slightly more errors under the object-distal posture (5.9%) compared to the object-proximal posture (3.8%; $F(1,19) = 7.8$, $p < 0.05$). But error rate did not depend at all on display-size, nor did hand-posture interact with display-size (*F*s(1,19) < 1). In Experiment 1b the overall error rate was 6.9%, with no significant effects of hand-posture ($F(1,11) = 4.2$, $p > .05$), display-size ($F(1,11) < 1$) nor an interaction ($F(1,11) < 1$). In Experiment 1c the overall error rate was 4.8%. Errors did not depend on hand-posture ($F(1,19) < 1$), but subjects did commit more errors for larger display-sizes (5.8% vs. 3.8%; $F(1,19) = 8.4$, $p < 0.01$). Importantly, the effects of display-size did not interact with those of posture ($F(1,19) = 2.4$, n.s.).

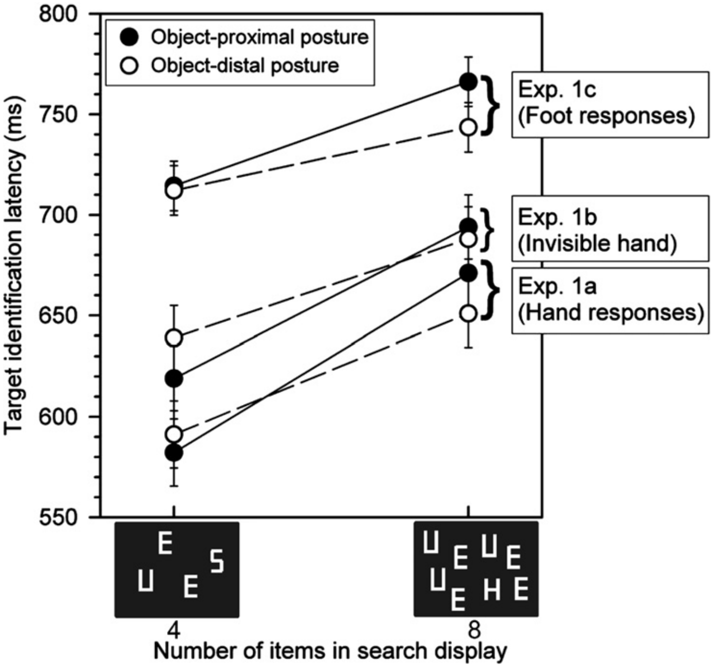

Fig. 2. Visual search results. Subjects identified the single target letter (either an *H* or an *S*) in a display that contained either three or seven non-target letters. Sample displays are shown below the abscissa. Plotted data show the mean reaction time for subjects to identify the target as a function of the total number of target and non-target items in the display, separately for object-proximal and object-distal postures. Hand movement latencies are shown from Experiments 1a and 1b; foot movement latencies from Experiment 1c. Error bars represent the within-subject 95% confidence intervals.

1998), our results reveal a surprising alteration of vision for stimuli near the hands. Processing of such stimuli is prolonged, presumably to ensure a thorough visual analysis. Importantly, the enhanced processing does not require vision of the hands, because the effect occurred even when the hands were not visible. Additionally, because the effect also occurred when all responses were by foot, it appears that mere proximity of the hands to the search display is the critical factor that produced the alteration in vision, and not the requirement to produce motor responses near the display. Finally, it is worth noting that our results could not reflect the sort of hemifield bias caused by proximity to a single hand that has been reported by others (e.g., Reed et al., 2006). This is because in our experiment, in the object-proximal posture, subjects held one hand on each side of the display – precluding any bias to one side or the other. Instead, our results reflect a true alteration in visual processing near the hands.

3. Experiment 2

The changes in vision that we have reported could have been caused by either delayed *engagement* of attention to items during the search, or delayed *disengagement* of attention after inspection of each item during the search. It is possible to adjudicate between these alternatives by utilizing an attentional procedure that taps into both engagement and disengagement mechanisms. The technique involves presenting an uninformative peripheral visual cue and subsequently measuring the effects of the cue on reaction times to detect a target at relatively short or long delays. Reaction times at short delays reflect the effects of attentional engagement at the cued location and typically reveal an advantage when the target appears at the location that had been cued. In contrast, reaction times at long cue–target delays reveal the effects of disengaging from the cued location.[2] Under those conditions subjects are typically slower to respond to targets at the cued location, presumably because they have disengaged from the cue during the additional delay and consequently are inhibited in returning their attention there when the target eventually appears. The latter, inhibitory effect is known as inhibition of return (IOR) (Posner, Rafal, Choate, & Vaughan, 1985). IOR is believed to aid in the efficient scanning of a scene, such as when foraging for food (Klein, 1988; Klein & MacInnes, 1999; Tipper, Weaver, Jerreat, & Burak, 1994). Here we used an IOR paradigm to attempt to separately measure the effects of hand-posture on attentional engagement and disengagement processes.

On each trial of the experiment one of two locations was cued by an uninformative flash. Subjects responded via button-press to a subsequent target presented either 300 or 950 ms later at one of the two locations under object-proximal and object-distal postures. If hand-posture affects attentional engagement then effects of posture would be expected at the 300-ms delay. However, if posture affects attentional disengagement, then posture effects might be apparent only at the 950-ms delay.

3.1. Method

3.1.1. Subjects and apparatus

Twelve naïve participants served in the present experiment. The apparatus was the same as that used earlier.

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[2] To be more precise we should note that reaction times to targets appearing in uncued locations at short cue–target delays may in part reflect exogenously-driven disengagement from the cued location, whereas responses at long cue–target intervals reflect voluntary, endogenous disengagement from the cue. The latter case is most similar to the endogenous disengagement necessary to move from item to item during visual search (as studied in Experiments 1a, 1b, and 1c).

3.1.2. Procedure

The procedure was that of a typical inhibition of return paradigm and is illustrated in Fig. 3a. Each trial began with a fixation display that contained three one-degree unfilled squares: one at the center of the display and two centered eight degrees to the left and right of center. After a 500-ms delay, one of the peripheral squares was cued by flickering it for 300 ms. On *300-ms cue–target interval* trials the target (a plus-sign) was presented immediately after the cue in one of the periph-

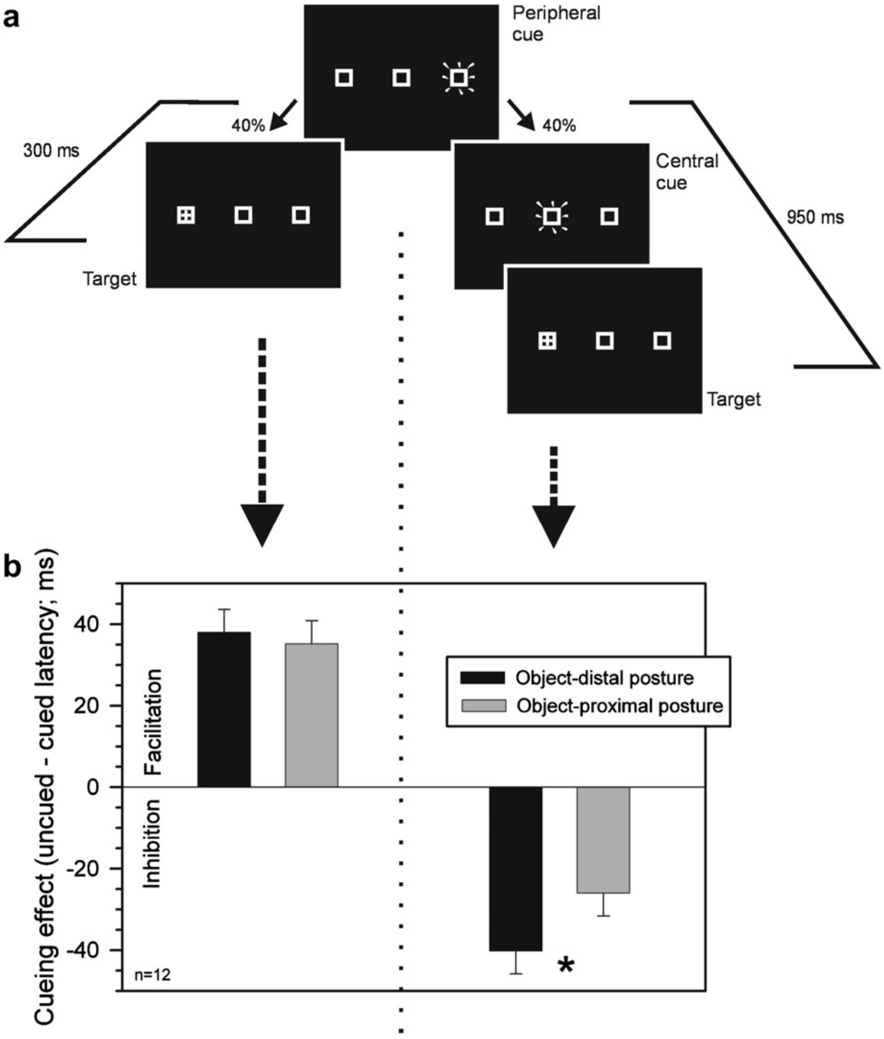

Fig. 3. Attentional cueing and inhibition of return. (a) Sequence of events on trials with 300 ms (left) or 950 ms (right) cue–target interval in Experiment 2. (b) Differences in latency to detect targets appearing at the location of the cue, compared to the opposite location. Error bars show the standard error of the mean within-subject cueing difference * = $p < 0.05$.

eral boxes. On *950-ms cue–target interval* trials, the target was separated from the peripheral cue by an additional 650-ms delay (this interval consisted of a 150-ms delay, a flickering of the central square for 300 ms, and an additional 200-ms delay). Subjects were instructed to respond by pressing either the left or right response button to indicate the location of the target.

3.1.3. Design

Subjects completed six blocks of 40 trials each under both object-proximal and object-distal postures. Within each block the trials were evenly divided among 300- and 950-ms cue–target intervals. In each block, four trials at each cue–target interval were catch trials and did not include a target. Subjects were to refrain from responding on such trials. Of the remaining trials, at each cue–target interval each combination of cue location and target location was equally likely. The various trial types were presented in random order. Hand-posture order was counterbalanced across subjects.

3.2. Results and discussion

Reaction times are shown in Fig. 3b. Reaction times at the 300-ms cue–target interval revealed the typical advantage at the cued location thought to reflect the capture of attention by the cue (Posner, Nissen, & Ogden, 1978), and that reaction time advantage did not depend on hand-posture (ANOVA revealed an effect of cue location, $F(1,11) = 9.37$, $p < 0.05$, but no effect of hand-posture, $F(1,11) < 1$). The absence of a posture effect at the short cue–target interval shows that hand position did not affect the ability of subjects to engage attention at the cued location. Reaction times at the 950-ms cue–target interval revealed the typical inhibitory disadvantage for the cued location (IOR; $F(1,11) = 21.7$, $p < 0.005$). IOR depends critically on the *disengagement* of attention from the cued location during the interval between the cue and the target (Castel, Chasteen, Scialfa, & Pratt, 2003; Klein, 2000). Importantly, the magnitude of the IOR was reduced when the hands were holding the display ($F(1,11) = 5.89$, $p < 0.05$ for the cuing by hand interaction), suggesting delayed or disrupted disengagement of attention from the cued object and, as a consequence, preferential processing of the cued object when the stimuli were near the hands.[3] Delayed attentional disengagement is also consistent with the results of the visual search experiments (Experiments 1a, 1b, and 1c). In that case, during serial search attention must be disengaged from one item prior to engagement on the next. Thus delayed disengagement would result in a steeper search slope, as we observed.

One aspect of the present experiment leaves open the possibility of undetected differences in the initial engagement of attention at the cued location under the two hand postures. In particular, although we found that equivalent amounts of facilitation were achieved at a 300-ms cue–target interval in the object-proximal and object-distal conditions, it is possible that the benefit of the cue accrued at different rates in

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[3] Error rates were 2.9% overall. At both the long and short cue–target intervals, errors were independent of posture, of cueing condition, and there were no interactive effects (Fs$(1,11) > 2.4$, ps > 0.15).

the two hand-posture conditions – ultimately (i.e., by 300 ms) achieving the same level in each. To examine that possibility, we conducted an experiment similar to the present one that tested cue–target intervals that were shorter than 300 ms. The experiment revealed remarkably similar patterns of cuing benefits in both hand-posture conditions, bolstering the conclusion offered.[4]

4. Experiment 3

The experiments reported thus far examined effects of the hand on engagement and disengagement of visual attention in space. In Experiment 3 we studied the effects of hand-posture on the deployment of attention over time. In the experiment subjects were asked to detect two targets in a stream of rapidly presented alphanumeric characters (Fig. 4). A typical finding in such a situation is that people are impaired in identifying the second target when it appears within a few hundred milliseconds of the first (Duncan, Ward, & Shapiro, 1994). The deficit in detection is referred to as the attentional blink (AB; Raymond, Shapiro, & Arnell, 1992) and is presumed to reflect in part the time needed to disengage attention from the processing of the first target in order to process the second (Duncan et al., 1994; Raymond et al., 1992; Shaprio, Arnell, & Raymond, 1997). If hand-posture affects attentional disengagement over time (in addition to the spatial effects that we have reported) then we might expect an altered attentional blink for stimuli that are near the hands. The specific changes expected are somewhat different from those that were observed in the visual search task. In contrast to visual search, subjects do not control the timing of “movements” of attention from one item to the next in the AB par-

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[4] The additional experiment that we conducted was similar to Experiment 2. Here we briefly cued one of two peripheral boxes by brightening it for 50 ms. We then presented a target equally often in either the cued or the uncued box at cue–target intervals of 100, 200, and 300 ms. Twelve naïve subjects responded with a keypress when the target was detected under both object-distal and object-proximal postures. Postures were tested in a counterbalanced order while all other factors were randomly mixed. The results, which support our earlier conclusions, are shown in the table. Subjects were faster to detect targets at the cued location ($F(1,11) = 6.5$, $p < 0.05$) and at longer cue–target intervals ($F(2,22) = 30.2$, $p < 0.001$). The cuing benefit decreased with increasing cue–target interval, resulting in an interaction between those factors ($F(2,22) = 5.5$, $p < 0.05$). Most importantly, results under the two hand postures were remarkably similar: there was no main effect of hand position, nor was hand position involved in any interaction (all Fs < 1). These results bolster our conclusion that hand-posture does not affect engagement of attention at a cued location, but instead posture affects disengagement.

	Object-distal posture			Object-proximal posture		
	100 ms	200 ms	300 ms	100 ms	200 ms	300 ms
Uncued	379.5	350.4	338.8	379.4	347.7	333.0
Cued	349.5	323.7	328.0	345.0	330.7	323.4
Difference	30.0	26.7	10.8	34.4	17.0	9.6

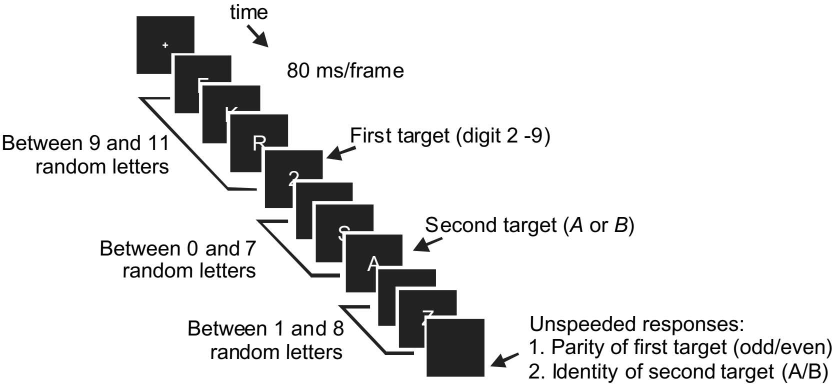

Fig. 4. Measurement of attentional deployment over time. The attentional blink paradigm used in Experiment 3. Subjects were asked to identify two targets in the stream of characters presented rapidly at fixation. The first target was the sole digit; the second was the letter *A* or *B*. The two targets were separated in time by from zero to seven filler characters.

adigm – the timing is determined by the presentation rate of the stream of characters. Thus, with the hands near the display, subjects might be less fully disengaged from the first target at the time the second target is presented – reducing second-target accuracy – but they would have no way to delay inspection of the second target. As a result, any deficit in disengaging attention from items in the stream might be expected to manifest itself as a reduction in accuracy – not a change in the time course of the effect.

4.1. Method

4.1.1. Subjects and apparatus

Twenty-four naïve participants served in the present experiment. The apparatus was the same as that used earlier.

4.1.2. Procedure

The procedure was that of a typical attentional blink paradigm (Fig. 4). After display of a fixation cross, each trial consisted of a stream of 19–21 80 ms frames, each containing a single grey alphanumeric character (1.6° wide × 1.75° high) on the black screen at fixation. The first target was a digit (2–9) which appeared in the 10th, 11th or 12th frame. A second target, either an *A* or a *B*, appeared between one and eight frames after the first. All non-target elements in the stream were randomly selected letters (not including *A*, *B*, or *I*). The stream ended nine frames after the first target. After the stream ended, subjects were to report the parity of the first target (odd or even), and then to indicate the identity of the second target (*A* or *B*). Responses were unspeeded.

4.1.3. Design

Subjects served in two blocks of 128 trials each under each hand-posture condition. Each block contained 16 trials at each of the 8 inter-target intervals. The various trial types were presented in random order. Hand-posture order was counterbalanced across subjects.

4.2. Results and discussion

The accuracy with which subjects identified the second target is shown in Fig. 5 as a function of the interval between the two targets, separately for each hand-posture. We found a substantial attentional blink, with second-target identification accuracy reduced at intermediate intervals between the two targets (ANOVA revealed a main effect of inter-target interval, $F(7, 161) = 8.3$, $p < 0.001$). Importantly, the deficit was greater when the hands were near the display (main effect of hand-posture, $F(1, 23) = 4.97$, $p < 0.05$). The increased attentional blink in the object-proximal condition is consistent with an impaired ability of subjects to disengage their attention from the first target when their hands were near the stimuli. As a result, reduced attentional resources were available for the processing of the second target. Additionally, hand proximity did not affect the ability of subjects to identify the first target (first-target accuracy was 94% overall and did not depend on hand-posture, $F(1, 23) < 1$). Thus, the engagement of attention (on the first target) was unaffected by hand-posture, consistent with the results from the earlier experiments. Instead, the effects of hand proximity occurred within a few hundred milliseconds after attention had been engaged by the first target, when rapid disengagement is necessary in order to process the second target.

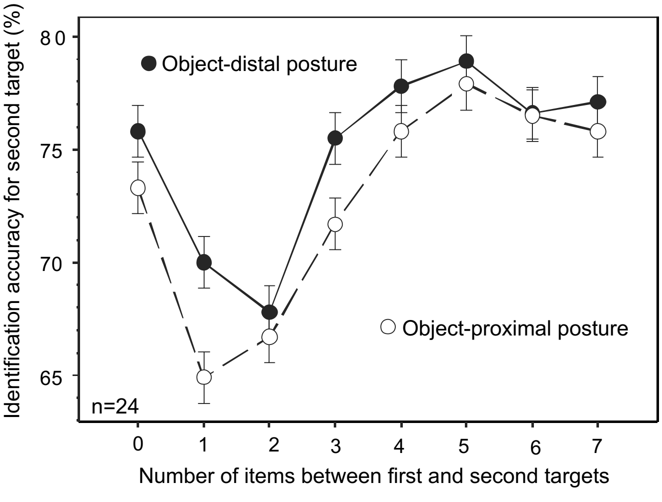

Fig. 5. Results from attentional blink experiment. Accuracy of second-target identification given correct identification of the parity (odd/even) of the first target from Experiment 3. Error bars show the within-subject 95% confidence intervals.

5. General discussion

In the present article we have shown that people appear to be slow to disengage their attention in both space (Experiments 1a, 1b, 1c, and 2) and time (Experiment 3) when the objects being examined are near their hands. What purpose might be served by such effects of hand proximity on vision? One possibility stems from the fact that objects that are near the hands are likely candidates for physical manipulation, such as when a tool is to be wielded or a food to be eaten. In those circumstances, extended analyses of objects near the hand may facilitate the production of accurate movements. Apparently, a plan for movement is not even necessary – mere proximity of the stimuli to the hands was sufficient to affect vision. Indeed, in many cases movement is needed not to interact with objects near the hands, but instead to avoid them because they are potential obstacles (Graziano & Cooke, 2006). In that situation, inhibited disengagement of attention from nearby objects could facilitate a more thorough assessment of their potential danger and avoidance of a collision.

References

Castel, A. D., Chasteen, A. C., Scialfa, C. T., & Pratt, J. (2003). Adult age difference in the time course of inhibition of return. *Journal of Gerontology: Psychological Sciences, 58B*, 256–259.

diPellegrino, G., & Frassinetti, F. (2000). Direct evidence from parietal extinction of enhancement of visual attention near a visible hand. *Current Biology, 10*, 1475–1477.

Duncan, J., Ward, R., & Shapiro, K. (1994). Direct measurement of attentional dwell time in human vision. *Nature, 369*, 313–315.

Graziano, M. (2001). Is reaching eye-centered, body-centered, hand-centered, or a combination? *Reviews in the Neurosciences, 12*, 175–185.

Graziano, M., & Cooke, D. (2006). Parieto-frontal interactions, personal space, and defensive behavior. *Neuropsychologia, 44*, 845–859.

Klein, R. (1988). Inhibitory tagging system facilitates visual search. *Nature, 334*, 430–431.

Klein, R. M. (2000). Inhibition of return. *Trends in Cognitive Sciences, 4*, 138–147.

Klein, R. M., & MacInnes, W. J. (1999). Inhibition of return is a foraging facilitator in visual search. *Psychological Science, 10*, 346–352.

Makin, T. R., Holmes, N. P., & Zohary, E. (2007). Is that near my hand? Multisensory representation of peripersonal space in human intraparietal sulcus. *Journal of Neuroscience, 27*, 731–740.

Poliakoff, E., Miles, E., Li, X., & Blanchette, I. (2007). The effect of visual threat on spatial attention to touch. *Cognition, 102*, 405–414.

Posner, M. I., Nissen, M. J., & Ogden, W. C. (1978). Attended and unattended processing modes: The role of set for spatial location. In H. L. Pick & I. J. Saltzman (Eds.), *Modes of perceiving and processing information*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Posner, M. I., Rafal, R. D., Choate, L. S., & Vaughan, J. (1985). Inhibition of return: Neural basis and function. *Cognitive Neuropsychology, 2*, 211–228.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception & Performance, 18*, 849–860.

Reed, C. L., Grubb, J. D., & Steele, C. (2006). Hands up: Attentional prioritization of space near the hand. *Journal of Experimental Psychology: Human Perception & Performance, 32*, 166–177.

Schendel, K., & Robertson, L. C. (2004). Reaching out to see: Arm position can attenuate human visual loss. *Journal of Cognitive Neuroscience, 16*, 935–943.

Shaprio, K. L., Arnell, K. M., & Raymond, J. E. (1997). The attentional blink. *Trends in Cognitive Sciences, 1*, 291–296.

Tipper, S. P., Weaver, B., Jerreat, L. M., & Burak, A. L. (1994). Object-based and environment-based inhibition of return of visual attention. *Journal of Experimental Psychology: Human Perception & Performance, 20*, 478–499.

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*, 97–136.

Wolfe, J. (1998). What can one million trials tell us about visual search? *Psychological Science, 9*, 33–39.

Woodworth, R. S. (1899). The accuracy of voluntary movement. *Psychological Review, 3* (2, Whole No.13).