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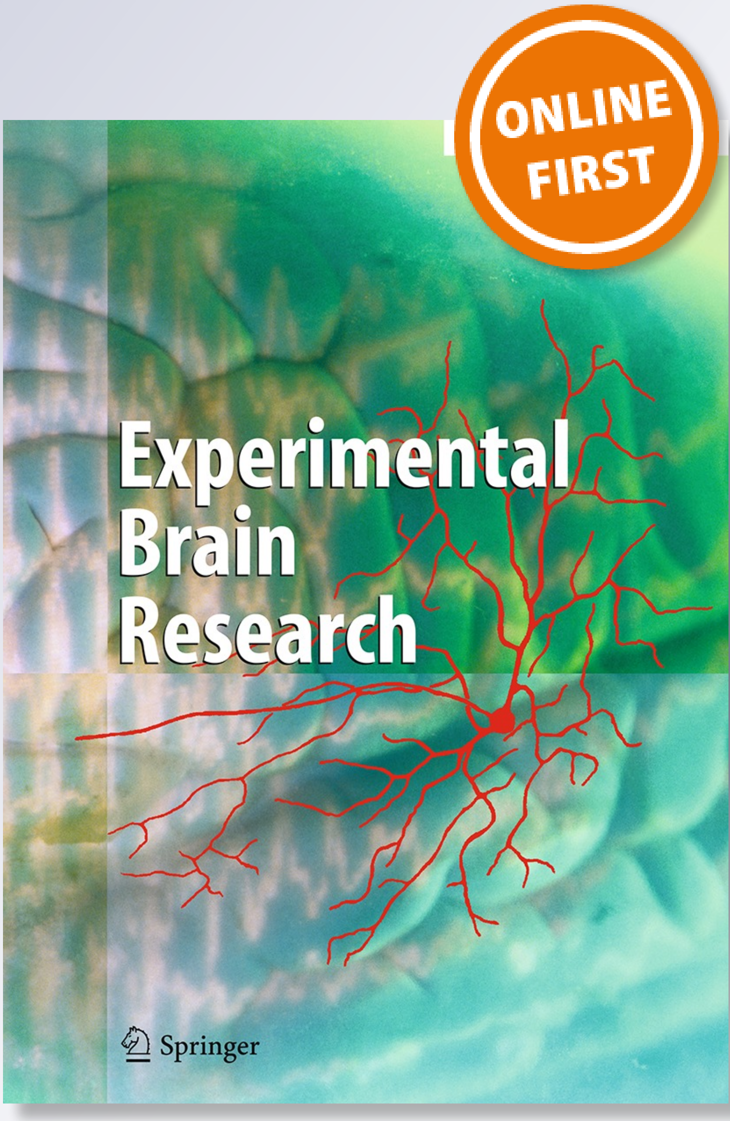

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RESEARCH ARTICLE

Hand position influences perceptual grouping

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Abstract Over the past decade, evidence has accumulated that performance in attention, perception, and memory-related tasks are influenced by the distance between the hands and the stimuli (i.e., placing the observer's hands near or far from the stimuli). To account for existing findings, it has recently been proposed that processing of stimuli near the hands is dominated by the magnocellular visual pathway. The present study tests an implication of this hypothesis, whether perceptual grouping is reduced in hands-proximal space. Consistent with previous work on the object-based capture of attention, a benefit for the visual object in the hands-distal condition was observed in the present study. Interestingly, the object-based benefit did not emerge in the hands-proximal condition, suggesting perceptual grouping is impaired near the hands. This change in perceptual grouping processes provides further support for the hypothesis that visual processing near the hands is subject to increased magnocellular processing.

Keywords Hands-proximal vision · Near-hand vision · Object perception · Perceptual grouping

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Introduction

In recent years, there has been increasing interest in interactions between the perception and action systems because, rather than operating in isolation, the two systems have been shown to be highly intertwined both inside the laboratory (Gallivan et al. 2014; Hommel et al. 2001) and outside the laboratory (Taylor et al. 2011; Witt et al. 2012). These studies show that previous action experience with stimuli can influence how those stimuli are later perceived, acted upon, and neurally represented. Recent studies have gone on to show that previous action experience is not necessary to show perception and action interactions, but a mere change in posture can influence perception. Particularly, if their hands are near the display, participants seem to process the visual stimuli differently, compared to when they place their hands away from the display (e.g., Abrams et al. 2008; Reed et al. 2006). It has recently been proposed that these hands-proximal/hands-distal influences on visual processing occur because the contributions of the magnocellular (M) and parvocellular (P) pathways to the visual task are modulated by relative position of the hands to the stimuli. The main tenet of the modulated visual pathways (MVP) account is that the M-pathway, the primary input for the action-oriented dorsal visual stream, is dominant over the P-pathway in processing stimuli in hands-proximal space, whereas the P-pathway, the primary input for the perception-oriented ventral visual stream, is dominant in processing stimuli in hands-distal space (Gozli et al. 2012). In the current study, two experiments are reported examining a prediction of the MVP account: Perceptual grouping, which relies on the P-pathway, should be impaired when hands are placed near the screen, close to the stimuli. Before outlining the present studies, we briefly review of the emerging literature on hands-proximal vision.

In the first study which examined how viewing stimuli in hands-proximal space altered visual processes, performances in three visual attention-based tasks (visual search, attentional blink, and attentional cueing) were examined with either both hands near or far from the display (Abrams et al. 2008). It was found that hand position modulated attentional processing such that having the hands near the stimuli was associated with: (a) more time spent on each item in a visual search task; (b) a longer delay between the first and second targets was necessary for observers to become aware of the second target in an attentional blink task; and (c) the magnitude of inhibition of return was reduced in an attentional cueing task. From these results, Abrams et al. suggested that attention may take longer to disengage from stimuli in hands-proximal space than in hands-distal space.

Following the original study by Abrams et al. (2008), a number of studies further investigated the effects of placing hands near compared to far from a display on visual processes using a wide range of paradigms. These studies, focussing on visual cognitive processes, have demonstrated slowed switching between global/local scopes of attention (Davoli et al. 2012), higher cost of a salient distractor (Vatterott and Vecera 2013), better target identification in a flanker task (Davoli and Brockmole 2012), improved change detection (Tseng and Bridgeman 2011), improved stimulus specific learning (Davoli et al. 2012), and biased figure–ground segmentation (Cosman and Vecera 2010) near the hands. From these studies, the notion emerged that viewing stimuli near the hands may lead to more in-depth processing for such stimuli. There is, however, one notable exception to the findings supporting a depth of processing hypothesis—a trade-off was found between spatial and semantic processing near the hands such that hands-proximal semantic information was more difficult to extract (Davoli et al. 2010).

Very recently, a spate of studies has also shown that hand position can also alter fundamental visual processes. In proposing a mechanism for changes in vision near the hands, Gozli et al. (2012) developed the basis for the MVP account of hands-proximal vision changes (see Taylor et al. 2015, for a review). Specifically, they hypothesized biased processing toward the action-oriented M-pathway when viewing stimuli in hands-proximal space and toward the perception-oriented P-pathway when viewing stimuli in hands-distal space. To test this hypothesis, spatial and temporal acuity were measured in the hands-proximal and hands-distal conditions. The M- and P-pathways functionally and structurally diverge at the retina with different ganglion cells exhibiting differential sensitivity to temporal and spatial aspects of stimuli in single-cell recordings (Livingstone and Hubel 1988). In particular, higher temporal acuity is found in the M-pathway relative to the P-pathway, while higher spatial acuity is found in the P-pathway relative to the M-pathway. Importantly, it has been observed that increased activity in one pathway inhibits activity in the other (Yeshurun 2004). Because of the trade-offs between the M- and P-pathways, Gozli and colleagues predicted that, if hand position modulates which visual pathway is more dominant in processing, higher temporal acuity should be seen in the hands-proximal condition compared to the hands-distal condition and the opposite pattern should be seen for spatial acuity. Both predictions were confirmed in a temporal-gap detection task (better performance in the hands-proximal condition) and a spatial-gap detection task (better performance in the hands-distal condition). These effects are consistent with an increased contribution of the M-pathway, and inhibition of the P-pathway, when the hands are placed near the stimuli relative to when they are far from the stimuli.

Since the Gozli et al. (2012) study, a line of research has been reported testing the MVP account for hands-proximal changes in visual processing including experiments using object-substitution masking (OSM), object identification, and feature binding paradigms. In OSM, reduced masking magnitudes were observed near the hands, presumably due to an increased ability to segregate the target from the mask because of increased temporal acuity near the hands (Goodhew et al. 2013). In an object identification task, the advantage of low spatial frequency information over high spatial frequency information is magnified in the near-hand space (Chan et al. 2013). These differences are consistent with physiological evidence that the M-pathway preferentially processes low spatial frequency information. In addition, discriminating orientation of low-frequency Gabor stimuli was better in hands-proximal space (this was not observed for high-frequency Gabors), and the effect was attenuated with red diffuse light which inhibits the M-pathway (Abrams and Weidler 2014). Consistent with evidence showing the P-pathway's importance in representing objects with multiple features (Barense et al. 2007) and P-pathway inhibition near the hands, feature binding is impaired in hands-proximal space (Goodhew et al. 2014b; Gozli et al. 2014; Kelly and Brockmole 2014). These later findings are presumably due to inhibited P-pathway processing that is essential for feature binding. Additionally, a recent study replicated the original temporal acuity benefit for near-hand stimuli (Bush and Vecera 2014). Taken together, there is a growing base of evidence supporting the view that hands-proximal space is preferentially processed by the M-pathway.

The finding that proximal hand position impairs feature binding with objects (Goodhew et al. 2014; Gozli et al.

2014; Kelly and Brockmole 2014) is the starting point for the current study. Specifically, our study was designed to determine whether the perception of objects due to the gestalt principle of "good continuation," in which displays of lines can produce the percept of a single object, will be impaired when the hands are near to the stimuli. In addition to the prior-mentioned studies showing impaired object processing near the hands, there is also evidence suggesting that gestalt grouping is a P-pathway dominant process (Doniger et al. 2000; Ganel and Goodale 2003; Han et al. 2002). Thus, the MVP account predicts that gestalt grouping will be impaired in hands-proximal space because the P-pathway should be inhibited. To measure gestalt grouping processes, the present study employed a paradigm similar to one developed by Kimchi et al. (2007). These authors presented groups of lines that would form both a gestalt object and a non-object (i.e., an array of lines). They found that targets appearing within such objects were responded more rapidly than those within the non-objects, presumably because such objects capture attention. Using a variation of this paradigm, it was predicted that the object-based cueing effect caused by the gestalt grouped object capturing attention should be reduced or eliminated in the hands-proximal condition.

Experiment 1

Methods

Participants

Seventeen undergraduates attending University of Toronto participated in the experiment and were compensated with course credit. All participants provided informed consent and reported normal or corrected-to-normal vision.

Materials and apparatus

Stimuli were generated and presented using the Psychophysics Toolbox libraries (Brainard 1997; Pelli 1997; version 3.0.8) for MATLAB (MathWorks, Natick, MA) on a CRT monitor with a screen resolution of 1080 × 768 and a refresh rate of 85 Hz. A modified computer mouse was attached to each side of the monitor for collecting data in the hands-proximal condition. Viewing distance was kept constant at 45 cm using a chin and forehead rest for the duration of the experiment.

Stimuli were presented in white on a black background and consisted of an array of seven curved lines each of which was a 70° arc of a circle whose diameter subtended 4° of visual angle (see Fig. 1). One curved line was placed at the center with its convex/concave portions along the horizontal meridian. The remaining six lines were placed on each side of the center line, three on each side. On one side, the lines were oriented such that, along with the center line, the four lines create a circular object, while the other three lines appeared in mirrored positions on the opposite portion of the display and reversed so that the concave side faced outward. After a delay of 106–306 ms, the target line changed color to red or green.

Procedure

The experiment was completed in two blocks. In one block, participants responded with both hands on a keyboard on the desk in front of them (hands-distal), and in the other condition, they responded with both hands on computer mice attached to the monitor (hands-proximal) to ensure the entire display was in the hands' action space or none of it was. Each trial began with a central fixation cross. After 1000 ms, an array of white lines appeared. Following a variable delay (106, 200, or 306 ms), one line changed color to

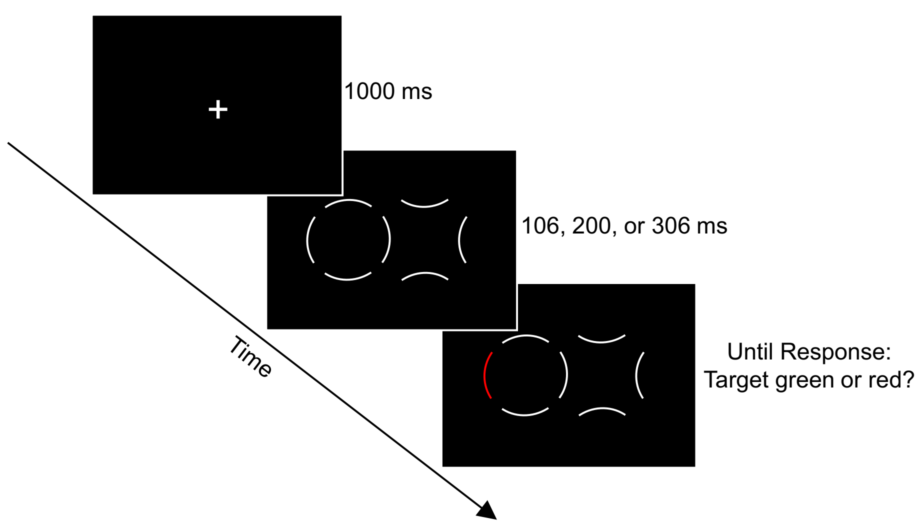

Fig. 1 Experiment 1 stimuli and trial time course

Table 1 Mean RT and PE by experiment and condition

Experiment	Hand posture	CTOA	Target Type				Cueing effect	
			Object		Non-object			
			RT	PE	RT	PE	RT	Accuracy
Experiment 1	Hands-distal	100	485	5.4	494	4.2	9*	−1.2
		200	474	4.7	477	5.0	2	0.3
		300	475	5.6	474	4.4	−1	−1.2
	Hands-proximal	100	475	4.2	472	4.6	−3	0.4
		200	458	5.2	463	4.6	6	−0.6
		300	459	5.5	462	4.4	3	−1.1
Experiment 2	Hands-distal	100	508	1.9	509	3.2	0	1.3*
	Hands-proximal	100	509	2.4	512	2.8	2	0.3

* Statistical differences from zero ($p < .05$)

red or green.[1] Any line except for the center line could be the target. A color discrimination task was used to ensure that both hands were equally active throughout the experiment. Participants were instructed to respond as quickly as possible, without sacrificing accuracy. A left-handed response was required if the target was green, and a right-handed response if the target was red. In the hands-distal condition, left- and right-handed responses were made with the "Z" and "/" keys, respectively. In the hands-proximal condition, left and right responses were made by clicking the corresponding computer mice attached to the sides of the monitor.

Design

Each participant completed both the hands-distal and hands-proximal blocks, but the order in which they completed the blocks alternated across participants such that eight participants completed the hands-distal task first and the other nine completed the hands-proximal task first. Across the experiment, each combination of target location, display type (gestalt object in the left or right visual field), cue–target onset asynchrony (CTOA), and target color was presented an equal number of times in randomized order. Each combination of factors was repeated 5 times for a total of 360 trials per block such that participants completed a total 720 trials in the testing session.

[1] It is worth noting that the use of red stimuli in the current experiment will not inhibit M-pathway activity. Indeed several previous studies that reported increased M-pathway contribution used displays that could include a red stimulus (e.g., Goodhew et al. 2014; Gozli et al. 2014; Kelly and Brockmole 2014). It is only when the light source is diffuse (i.e., the entire background of the monitor) that the M-pathway is inhibited by red light. In the single-cell recording studies that initially demonstrated the effect, when light sources were focused enough such that they did not cover the surround portion of the receptive fields, no inhibition was found (Wiesel and Hubel 1966).

Results and discussion

Trials with incorrect responses, RTs faster than 100 ms, and RTs slower than 1000 ms were excluded as response errors, anticipatory responses, and attentional lapses, respectively. The mean and standard deviation of the remaining RTs were calculated, and all trials with RTs more than two standard deviations above the mean were excluded. Overall, mean accuracy was 95 % (SD = 3.8 %) with no individuals performing below 89 %. An object-based cueing effect score was calculated by subtracting RTs to targets appearing within objects from those to targets appearing outside the object (see Table 1; Fig. 2a).

A repeated-measures, 2 (hand position) × 3 (CTOA) ANOVA was conducted with the object-based effect score as the dependent measure. Neither the main effect of hand position nor CTOA was significant, $F\text{s} < 1$. Importantly, the two factors interacted, $F(2,32) = 3.46$, $p < .05$, $\eta_p^2 = .178$. Single sample t tests were conducted testing whether there was a greater than zero object-based cueing effect at each of the CTOAs within each hand position. The object-based cueing effect differed reliably from zero only at the 106 ms CTOA within the hands-distal condition, $t(16) = 2.165$, $p < .05$, $d = 0.52$, indicating faster responses (9 ms) to targets appearing within objects rather than outside objects at the 106 ms CTOA, replicating previous object-based cueing effects (Kimchi et al. 2007).

Finally, a two-way, repeated-measures ANOVA with differences in percent error (PE) as the dependent variable was conducted (see Table 1; Fig. 2b). No effects were significant indicating that the RT results were not due to a speed–accuracy trade-off.

Overall, the results from this experiment indicate that while targets appearing in a gestalt-formed object were responded to more rapidly than those outside of the object in the hands-distal condition, no such benefit was found in the hands-proximal condition. This finding is consistent

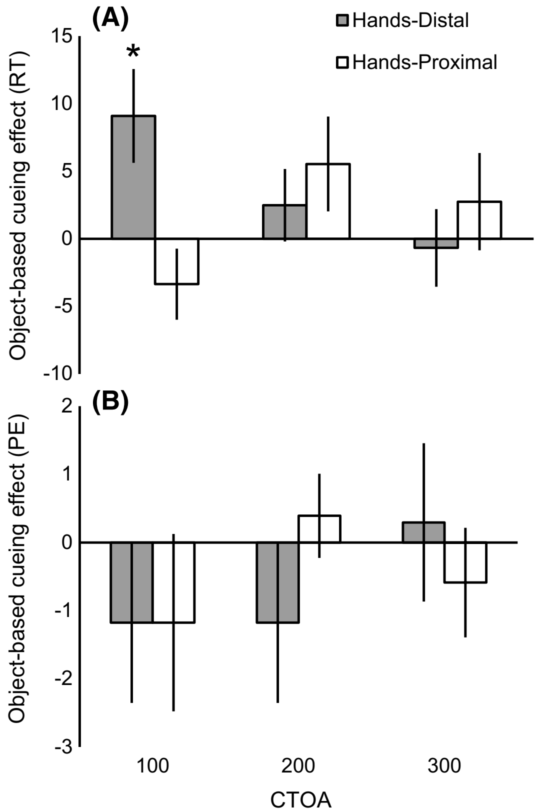

Fig. 2 Object-based cueing effect in RT (**a**) and PE (**b**) by CTOA and hand position. *Asterisks* represent statistical differences from zero ($p < .05$). *Error bars* represent within-subject *SEs*

with the prediction from the MVP account; gestalt grouping is a P-pathway process, and because no object is formed, object-based benefits should be absent in the hands-proximal condition.

One finding of note, however, is that responses were significantly faster in the hands-proximal condition than the hands-distal condition (15 ms), $t(16) = 2.297$, $p < .05$. This difference might raise some concerns about whether the main theoretically relevant finding is due to a ceiling effect in RTs. That is, because hands-proximity led to faster responses across the conditions, there was no room for the object–effect to come out. To test this hypothesis, the variance was calculated within each hand position for each participant, and then, means of these values were compared. If performance was at ceiling in the hands-proximal condition, less variance should be found. Contrary to this, the variances were equal across the two hand positions, $F(16) = .502$, $p > .05$, suggesting that the lack of object-based cueing was not due to a ceiling effect.

Because we were uncertain as to exactly when any object-based benefits might arise in the hands-distal condition, we used three CTOAs in Experiment 1. The data revealed that, with this particular set of stimuli and procedures, the object-based effect only appeared at the shortest (106 ms) CTOA when the hands were on the keyboard and far from the stimuli. With the timing of the maximum object-based effect identified, a second experiment was conducted to attempt a replication of these findings using this single time interval.

Experiment 2

In this experiment, we aimed to replicate and confirm the main finding of Experiment 1. Because the difference between the two hand positions was only observed with CTOA of 106 ms, we conducted a simplified version of the experiment, on a second group of participants using only the CTOA value of 106 ms. Following the first experiment, we predicted to observe grouping in the hands-distal, but not in the hands-proximal condition.

Methods

Participants

Twenty undergraduates from University of Toronto participated in exchange for course credit. All participants provided informed consent and reported normal or corrected-to-normal vision.

Stimulus and apparatus

The stimuli and apparatus used in Experiment 2 were identical to those used in Experiment 1.

Procedure

The procedure of Experiment 2 replicated Experiment 1 with the following exceptions. Rather than three CTOAs, only the 106 ms CTOA was used in Experiment 2. Additionally, to maintain some degree of temporal uncertainty within each trial, the fixation cross remained for a random interval between 506 and 1506 ms. All other aspects of Experiment 2 were exactly as Experiment 1.

Design

The hands-proximal and hands-distal blocks were counterbalanced across participants. Each combination of variables, target location, display type, and target color, was randomly presented 10 times each for a total of 240 trials per block (a total of 480 trials across the experiment).

Results and discussion

Response time data were trimmed using the same method as Experiment 1, and difference scores between object and non-object target type conditions were again used as the dependent variable for the analysis. For the means of the RT and PE measures, see Table 1 and Fig. 3a, b. Because the direction of the anticipated effects was known from Experiment 1, one-sided *t* tests were used for each of the following one-sample *t* tests. In terms of RT, no difference was found between the hands-distal and hands-proximal conditions, $t(19) = .739$, $p > .05$, $d = .18$. The object-based cueing effect also did not differ from zero in either the hands-distal, $t(19) = .240$, $p > .05$, $d = .05$, or proximal conditions, $t(19) = .883$, $p > .05$, $d = .20$. In terms of PE, however, a larger object-based effect was found in the hands-distal condition than in the hands-proximal condition, $t(19) = 1.762$, $p < .05$, $d = .59$. The object-based cueing effect in the hands-distal condition was significantly greater than zero, $t(19) = 4.540$, $p < .001$, $d = .91$, while the object-based cueing effect in the hands-proximal effect was not, $t = .812$, $d = .18$.

Although no effect of hand position in RT was found in Experiment 2, hand position did have a significant effect on PE. Specifically, an object-based cueing effect was found in the hands-distal condition (fewer errors when the target was part of an object), but not in the hands-proximal condition (no difference in errors when the target was not part of an object). This finding is again consistent with the hypothesized impaired perceptual grouping due to P-pathway inhibition processing hands-proximal space. Even though the foreperiod was randomized between 506 and 1506 ms, there was a constant delay between the onset of the cue and the onset of the target (always 106 ms). Thus, it is possible that participants adopted a rhythm in their responses that was anchored to the cue onset (i.e., preparing to respond once the cue was presented), eliminating the RT effects and shifting the influence to accuracy. The fact that the grouping effect only appeared in PE data is consistent with this strategy.

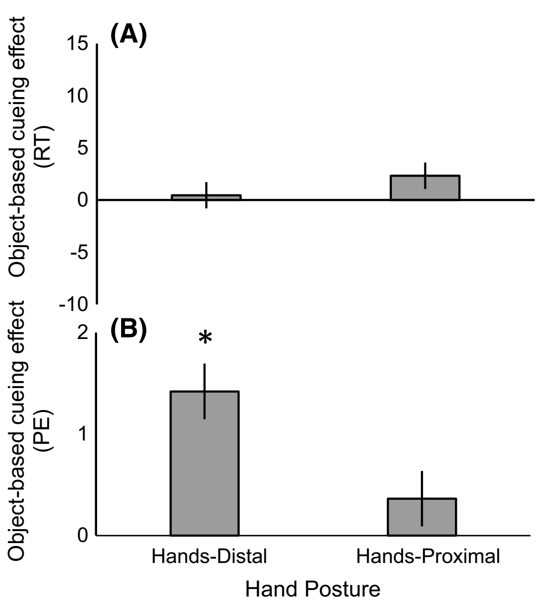

Fig. 3 Object-based cueing effect by hand posture in **a** RT and **b** PE. *Asterisks* represent statistical differences from zero ($p < .05$). *Error bars* represent within-subject *SEs*

General discussion

In two experiments, we investigated whether or not perceptual grouping processes were impaired in hands-proximal space. In the hands-distal conditions, targets appearing within a gestalt figure were responded to reliably faster (Experiment 1) and more accurately (Experiment 2) relative to targets appearing outside the gestalt at 106 ms CTOA. In the hands-proximal condition, however, whether or not the target appeared within the gestalt figure had no effect on RTs or accuracy. Thus, the data indicate that gestalt grouping processes are indeed disrupted when viewing stimuli in hands-proximal space.

Because the object was a non-predictive cue of target location, our hands-distal finding replicates previous work showing that gestalt-formed objects can exogenously cue attention (Kimchi et al. 2007). It is worth noting that, similar to our findings in Experiment 1, Kimchi et al. found their largest object-based benefit at their shortest CTOA. They also found small effects at CTOAs up to 500 ms, whereas we did not. Note, however, that participants in their study were required to: (a) read a word (e.g., "above") on every trial and (b) attend to an asterisk that, together with the word, defined the target location. Thus, being required to read words (which involves grouping letters into a unit), as well as using the informative cues to locate each target, may have encouraged forming a representation of the spatial layout that preserved the benefit of the gestalt figure. By contrast, our visual target was defined as a temporally unique color singleton, and no other kinds of gestalt (e.g., words) or informative cue was used. Perhaps for this reason, our findings resemble the typical time course of stimulus-driven attentional capture whereby facilitation at cued locations tends to dissipate with CTOAs over ~150 ms (e.g., McAuliffe and Pratt 2005; Posner and Cohen 1984; Theeuwes et al. 2000). Therefore, we believe that the benefit of the gestalt figure in the present study reflected a purely stimulus-driven bias, and as such, it was short-lived.

Given neurological evidence that perceptual closure is supported by P-pathway processes (Doniger et al. 2000;

Han et al. 2002), the presence of the cuing effects in the hands-distal condition suggests that the P-pathway is active and working efficiently when the hands were far from the stimuli. In contrast, the absence of object-based cueing effects in the hands-proximal condition suggests that P-pathway processing is degraded or inhibited when viewing stimuli in hands-proximal space. That is, the current data suggest that P-pathway processing is inhibited when processing stimuli in hands-proximal space weakening gestalt grouping processes such that the gestalt-formed object did not capture attention. Furthermore, these data are consistent with recent findings of other P-pathway perceptual processes being impaired near the hands (Goodhew et al. 2014b; Gozli et al. 2014; Kelly and Brockmole 2014).

Although the MVP account can accommodate the current findings, given the studies suggesting changes in attentional allocation near the hands (e.g., Abrams et al. 2008), it is prudent to ask whether an alternative account can explain the current results. For example, an attentional account would suggest that hands-proximal stimuli undergo deeper processing resulting in delayed disengagement from items which initially capture attention. Thus, in the current experiment, if gestalt grouping processes were unaffected by the hands manipulation (as attentional accounts have no reason to suggest they would be affected), one would still predict the gestalt-formed object would capture attention and produce an object-based cueing in hands-proximal space, but that the effect would be found across extended CTOAs relative to the hands-distal condition because of delayed attentional disengagement from the object. Thus, the data from the present study provide some additional, though by no means conclusive, evidence against a strict attentional account. In addition, it is possible that the attention and MVP explanations are not necessarily mutually exclusive, but in fact different levels of description of the same phenomenon.

In conclusion, the present findings of reduced gestalt within hands-proximal space support the MVP theory of hands-proximal changes in visual processing. Moreover, in conjunction with the existing literature, the present findings add to the emerging picture that hand position can influence visual object perception, by modulating gestalt grouping, object consistency, object files, and rapid gist identification.

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