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Reduced Temporal Fusion in Near-Hand Space

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Abstract
Object-substitution masking (OSM) is thought to reflect a failure of object individuation. That is, a briefly presented target surrounded by four dots is perceptually fused with the four-dot mask when the mask is visible after the target has disappeared, thereby obscuring the visibility of the target. If OSM depends on the inability to temporally segregate objects, then increasing the temporal precision of the visual system should reduce OSM. In the study reported here, we manipulated temporal precision by varying the proximity of participants' hands to visual stimuli, because stimuli in near-hand space have been found to enjoy enhanced attentional processing, and attention is known to speed visual processing. Hand placement was indeed found to affect OSM: Placing participants' hands near the visual stimuli reduced the magnitude of the masking. This finding demonstrates that object individuation can be facilitated by increasing the temporal resolution of vision via increasing the proximity of visual stimuli to the hands.

Keywords
temporal fusion, object-substitution masking, embodied cognition, attention, perihand space, peripersonal space, consciousness, perception

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Although our senses register an almost continuous stream of information, we are able to perceive discrete objects in space and time. This means that the visual system needs to distinguish between stimulation that represents a single object throughout time and stimulation that represents distinct objects. Such inferences about object identity are made using a minimally informative source: the ongoing stimulation hitting the retina. This presents a challenge for the visual system, because even the same object can produce different kinds of stimulation if the object moves, if the observer moves in relation to the object, or if the object is temporarily occluded; it is therefore difficult to differentiate on the basis of stimulation alone what represents distinct physical entities. And yet the mechanisms or heuristic underlying such inferences functions sufficiently well that the existence of this inferential challenge is rarely noticed.

In order to better understand such mechanisms underlying object integration and individuation, it is highly useful to explore the unique conditions under which they are known to fail. For example, when the visual system is exposed to two discrete objects, it might fail to encode them as such and treat them as a single object continuing in time. A paradigm that isolates this scenario is used in tasks measuring what is called *object-substitution masking* (OSM; Di Lollo, Enns, & Rensink, 2000; Enns & Di Lollo, 1997; Goodhew, Pratt, Dux, & Ferber, in press). In OSM tasks, a target object (e.g., a Landolt C) and four dots arranged in an imaginary square surrounding it are briefly presented, after which point the target disappears, leaving the four dots temporally trailing for a given duration. This manipulation—merely delaying the offset of the four dots—substantially interferes with observers' ability to perceive the target, compared with when the

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offset of the four dots and of the target is simultaneous. This impairment, or *masking*, is thought to represent a failure of the visual system to individuate the target and mask as separate objects (Lleras & Moore, 2003; Moore & Lleras, 2005), whereby the visual system instead mistakes all of the stimuli for a single object, which is represented as the mask (at the expense of the target object).

There are several lines of converging evidence that OSM embodies a failure of temporal segregation. Lleras and Moore (2003) demonstrated the critical role of competing object representations in OSM; the researchers found that the physical presence of a mask after target offset is not, by itself, sufficient to produce OSM unless it is conducive to the perception of a continuing mask-object representation. In their experiments, observers were briefly presented with an array that contained eight Cs arranged in a circle; all of the items in the array had four dots around them. The target C was differentiated from the distractors by being a darker shade of grey, and the task was to report the orientation of the target (i.e., location of the gap in the C). There were four conditions: a standard simultaneous-offset (baseline) condition; a standard delayed-mask-offset condition; and two conditions in which the masks and targets disappeared from the screen simultaneously and the masks then reappeared in a new location (all masks moved together out into a larger circumference circle). In one of these last two conditions (short-interstimulus-interval, or ISI, condition), the duration between the offset of the mask and its onset at the new location was amenable to the percept of apparent motion (17–34 ms), whereas in the other condition (long-ISI condition), the mask reappeared after a longer delay (216–233 ms), after which the signal for apparent motion should be eliminated or at least substantially weakened.

Target-identification accuracy in each of these conditions was compared with that in the simultaneous-offset (baseline) condition. It was found that there was significant masking in the standard delayed-offset condition and in the short-ISI condition but not in the long-ISI condition. These results suggest that when the mask is seen as a continuing object, it facilitates object integration, but when the subsequent onset of the mask is perceived as the onset of a new object, it does not (Lleras & Moore, 2003). This illustrates how OSM can reflect temporal fusion of the target and mask object representations, or, in other words, a failure of object individuation.

Further evidence for the notion that temporal fusion renders the target inaccessible to awareness arises from the fact that manipulations that encourage the visual system to treat the target and mask as separate objects attenuate or even eliminate masking. For example, having the target and mask move asynchronously or appear in different colors reduces the magnitude of masking (Moore & Lleras, 2005). Similarly, previewing the four-dot mask (i.e., the four dots are presented at all possible stimulus locations, and then, in the subsequent array, the location of the target is indicated with an arrow) reduces OSM, even though the preview is not predictive of the target's location. This is because the prolonged exposure of the four dots alone prior to the appearance of the target facilitates a separate representation of the mask, making it less likely to be bound with the target (Neill, Hutchinson, & Graves, 2002).

In the study reported here, we employed an embodied-cognition manipulation that has been found to have important consequences for the attentional resources devoted to particular stimuli. Visual stimuli in near-hand space appear to enjoy prioritized attentional processing. Specifically, visual targets are more quickly detected (Kao & Goodale, 2009; Reed, Grubb, & Steele, 2006), target discrimination is facilitated (Dufour & Touzalin, 2008; Whiteley, Kennett, Taylor-Clarke, & Haggard, 2004), and attentional dwell time is increased (Abrams, Davoli, Du, Knapp, & Paull, 2008) for stimuli that appear in near-hand space compared with stimuli that appear farther from the hands. These effects do not seem to be dependent on the visual perception of the hands, given that they can be observed even when observers' hands are hidden from view (Abrams et al., 2008). Furthermore, positioning the hands adjacent to the screen on which stimuli appear improves change detection and working memory capacity for the entire display (Tseng & Bridgeman, 2011), which suggests that near-hand space enjoys a wide range of enhanced attentional processing and consolidation.

Critically, this difference in processing is attributed not to some unique visual quality of the hands but instead to the relevance of the near-hand space for action (Reed, Betz, Garza, & Roberts, 2010). That is because, first, similar effects on visual perception are observed for stimuli in the space surrounding handheld tools (Brown, Doole, & Malfait, 2011; Kao & Goodale, 2009; Reed et al., 2010) and even for virtual limbs (Short & Ward, 2009). Second, these effects depend on the observer's ability to control the tool effectively (Brown et al., 2011; Gozli & Brown, 2011). This behavioral evidence for a distinction between near- and far-hand space is supported by neurophysiological work. Specifically, single-cell recording in the primate brain has revealed neurons that are selectively responsive to stimuli in near-hand (or *peripersonal*) space (Ehrsson, Spence, & Passingham, 2004; Graziano & Gross, 1998).

Given the far-reaching effects on the processing of stimuli that appear in close proximity to the hands, we tested whether the same effects would extend to determining whether stimuli are rendered inaccessible to awareness via OSM. As discussed earlier, OSM appears to be due to a failure of temporal resolution that leads to erroneous integration of the target and mask objects and subsequent suppression of target perception. Enhanced attentional processing, which is known to speed the processing and consolidation of visual stimuli (Stelmach & Herdman, 1991), should therefore interfere with integration and thus thwart masking. In the research reported here, we enhanced attentional processing by placing the OSM-task target array in near-hand space.

Although several studies have converged on the notion that stimuli's proximity to the hand affects visuospatial attention, another account has recently been put forward to explain the differential processing in near-hand space. This account draws on the distinction between the two main pathways that support vision: The magnocellular pathway, which has high temporal resolution (fast conduction velocities) and low spatial resolution, is especially sensitive to rapid changes in luminance and predominately innervates the dorsal-cortical processing stream implicated in motion and action, and the parvocellular pathway, which has low temporal resolution (slow conduction velocities), high spatial resolution, and more connections to the ventral-cortical processing stream implicated in form processing and object recognition (Goodale, 2008; Goodale & Milner, 1992; Goodale & Westwood, 2004; Shapley, 1990). Both pathways interact and contribute to perceptual representations but are mutually inhibitory, meaning that increasing the relative contribution of one will decrease the contribution of the other (Bocanegra & Zeelenberg, 2009; Yeshurun, 2004).

It has been suggested that many of the tasks that enjoy an advantage in near-hand space, such as detection of luminance and motion onsets (Kao & Goodale, 2009; Reed et al., 2006), fall within the purview of the magnocellular pathway. The one task that has been found to suffer a disadvantage in near-hand space is the extraction of semantic content (i.e., reading; Davoli, Du, Montana, Gaverick, & Abrams, 2010). This possibility was anticipated by Previc (1998), who proposed a connection between the magnocellular pathway and information processing in the near-hand space. A recent study provided a direct test of this hypothesis and found enhanced temporal discrimination but a disruption of spatial discrimination in near-hand space (Gozli, West, & Pratt, 2012). It should be noted that the hypothesis of greater contribution of the magnocellular pathway than of the parvocellular pathway in the near-hand space (Gozli et al., 2012; Previc, 1998) remains speculative, pending further physiological investigations. However, if near-hand space does indeed receive stronger input from the magnocellular pathway than from the parvocellular pathway, then, given the superior temporal precision of the magnocellular pathway, this account would predict enhanced object individuation of the target and mask objects, and thus reduced OSM.

We tested the central role of temporal fusion of the target and mask objects in OSM by placing the OSM array in near-hand space. Both the attentional and magnocellular-pathway accounts predict superior temporal precision of visual processing in near-hand space. This temporal precision should encourage the visual system to create distinct object identities for the target and mask in OSM, thus protecting the target from masking.

Experiment 1

The purpose of Experiment 1 was to examine whether placing stimuli in near-hand space could facilitate target-mask object segregation, thus protecting the target from masking. To achieve this purpose, we coupled a manipulation of hand position (hands near stimuli vs. hands far from stimuli) with an OSM task. We predicted that masking magnitude (i.e., target-identification accuracy for the simultaneous-offset condition minus target-identification accuracy for the delayed-mask-offset condition) would be reduced in the hands-near, relative to the hands-far, condition because of the increased temporal precision of processing in this condition.

Method

Participants. Twelve undergraduate psychology students (7 female, 5 male; mean age = 18.67 years, *SD* = 1.23) were recruited from the University of Toronto and participated in return for course credit. All participants provided written informed consent.

Stimuli and apparatus. The experiment was conducted using a computer with a CRT monitor operating at a refresh rate of 85 Hz. Participants were tested in individual rooms, seated in front of the computer with their chins in a headrest. Viewing distance was held constant at 44 cm. The computer was attached to a standard keyboard that rested on the desk in front of the screen and to two computer mice, one attached to either side of the screen (see Fig. 1). The vertical separation between the keyboard and the bottom of the screen was 23 cm, and the horizontal distance between the keyboard in its typical position and the front-most part of the screen was approximately 34 cm. In contrast, the distance between each of the mice and the screen was 3.5 cm (the mice were separated from the screen by only the width of the screen's frame). Each mouse was positioned approximately 3 cm below the horizontal midpoint of the screen.

Procedure. Each trial began with the presentation of a white fixation cross on a black background for 1,000 ms,

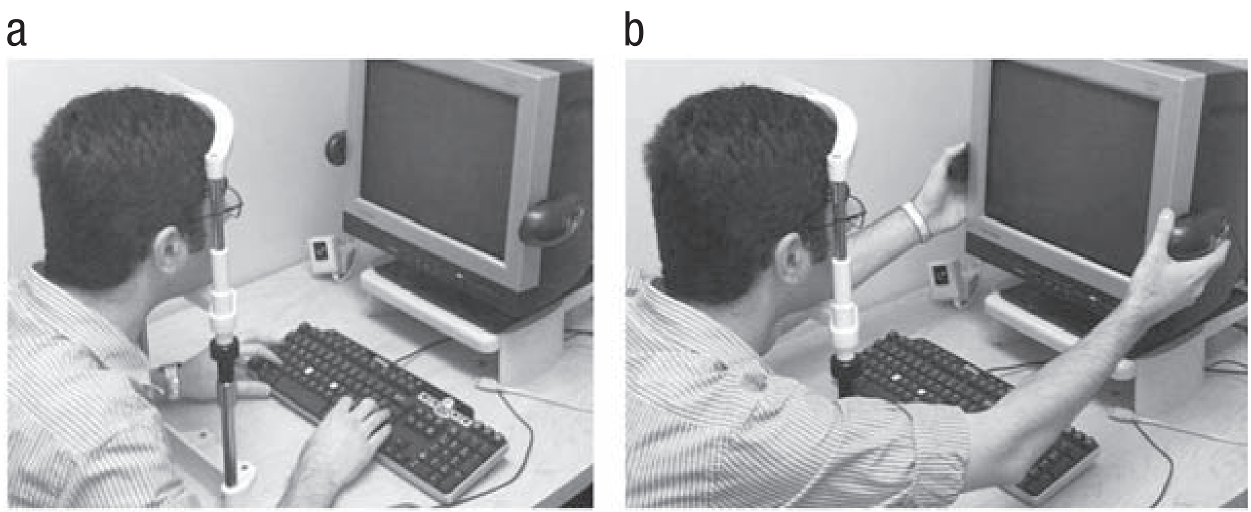

Fig. 1. Photographic illustration of the experimental setup. The two pictures show how participants' hands were positioned in the (a) hands-far condition and (b) hands-near condition.

followed by the presentation of a blank screen for 506 ms. Next, the target array appeared for 82 ms. This array consisted of eight white Cs (one target and seven distractors), which were arranged in a rectangle around a central fixation cross (the center-to-fixation separation of the Cs was 4° of visual angle) on a black background (see Fig. 2). Each C, which subtended 2°, had an opening (0.52°) on either its left side or its right side. The target object was signaled by four dots surrounding it (each dot = 0.2° × 0.2°) and arranged in a notional square centered on the target object. On a given trial, the target could appear in any of the eight possible locations around the central fixation cross, with the distractors occupying the other seven locations. The four-dot mask would either disappear from the screen at the same time as the other items in the target array (simultaneous-offset condition) or temporally trail for 200 ms (delayed-mask-offset condition). The screen was then blank until a response was made.

Participants' task was to identify whether the gap in the target C was on the left or the right of the object. In the hands-near condition, participants made responses by clicking buttons on the computer mice that were attached to either side of the computer screen. To avoid ambiguity, each mouse had one button removed so that there was only one button per mouse. Participants were instructed to click the mouse attached to left of the screen when they perceived the gap in the target C to be on the left and to click the mouse attached to the right of the screen when they perceived the gap to be on the right. In the hands-far block, participants made their responses by pressing the "Z" key on the keyboard when the gap was on the left of the object and the question-mark/slash key when the gap was on the right of the object. All participants completed the two blocks (hands near vs. hands far), each of which consisted of 20 practice trials and 140 test trials.[1] Order of block completion was counterbalanced across participants. Target location within the target array and mask duration (simultaneous offset vs. delayed mask offset) were randomized on each trial and equiprobable.

Design. The experiment was a 2 (hands near vs. hands far) × 2 (simultaneous offset vs. delayed mask offset) repeated-measures design.

Results and discussion

A 2 (hands near vs. hands far) × 2 (simultaneous offset vs. delayed mask offset) repeated-measures analysis of variance (ANOVA) revealed no main effect of hand position ($F < 1$); a main effect of mask duration on target-identification accuracy, $F(1, 11) = 104.46$, $p < .001$, $\eta_p^2 = .905$; and an interaction between hand position and mask duration, $F(1, 11) = 8.81$, $p = .013$, $\eta_p^2 = .445$. In order to further understand this interaction, we compared the magnitude of masking (calculated as accuracy in the simultaneous-offset condition minus accuracy in the delayed-mask-offset condition) for the hands-near and hands-far conditions (see Fig. 3). Results revealed that masking was reduced in the hands-near condition compared with the hands-far condition, which suggests that enhancing the temporal precision of the visual system by placing the hands near visual stimuli increased the likelihood that the target and mask were encoded as distinct objects, thus reducing OSM.

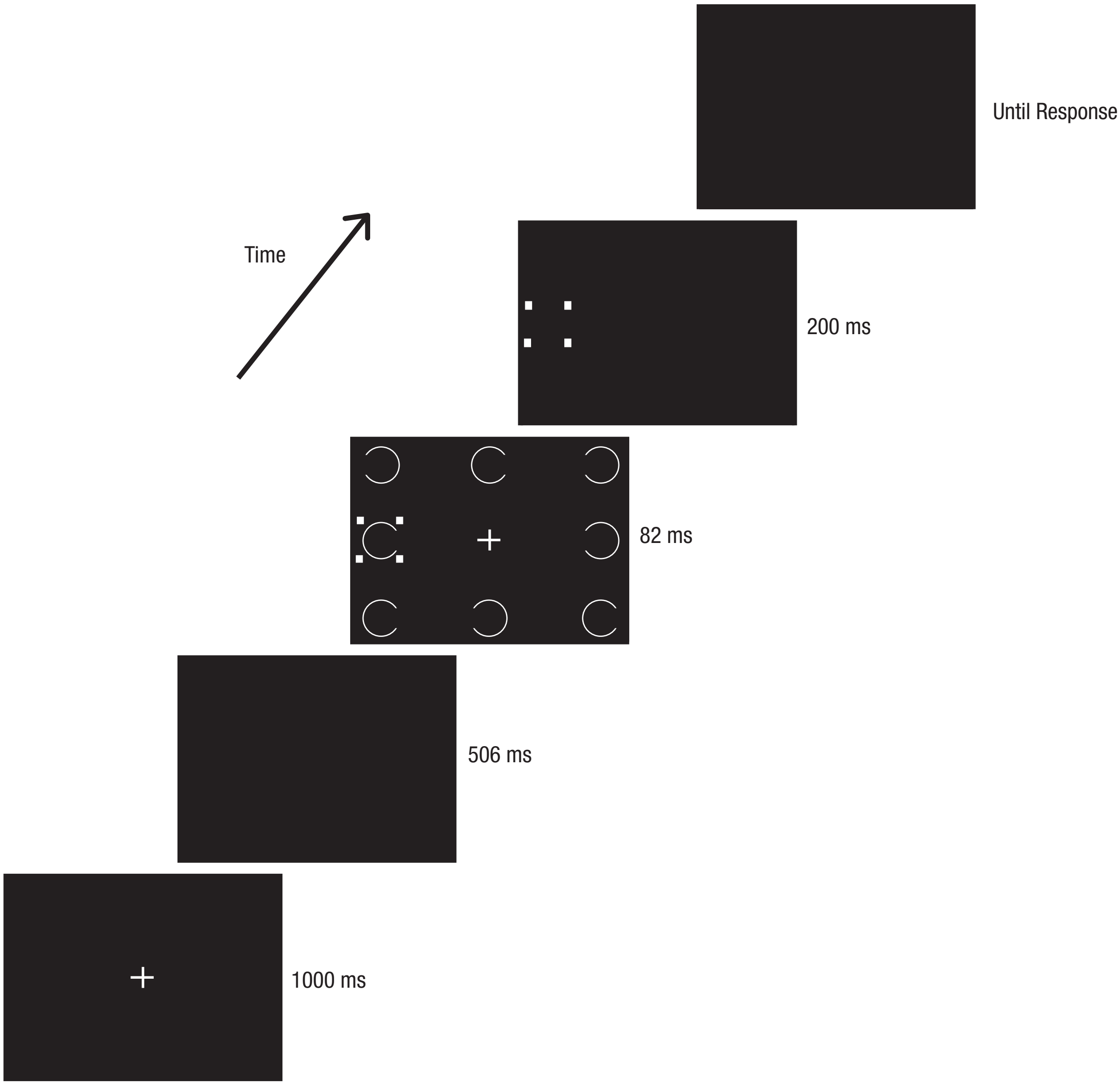

Fig. 2. Schematic illustration of the trial structure for the delayed-mask-offset condition in Experiments 1 and 2. Each trial began with the presentation of a white fixation cross, followed by a blank screen. An array of eight Cs, each with a gap on its left or right side, was then presented for 82 ms. The target object was signaled by the presence of a four-dot mask surrounding it (the onset of the mask was simultaneous with that of the target). The target and distractors then disappeared, but the mask trailed for 200 ms following the offset of the target array. (In the simultaneous-offset control condition, the array and mask disappeared simultaneously, and a blank screen was shown for 200 ms in place of the trailing mask.) The screen then went blank until participants responded. Participants' task was to identify whether the gap in the target C was on its left or right side.

An interesting aspect of the results from Experiment 1 was that there was a trend toward greater target-identification accuracy when the offset of the mask and of the target was simultaneous in the hands-far condition compared with the hands-near condition. Considered from the perspective of the magnocellular-pathway hypothesis, this pattern likely reflects the fact that while the increased magnocellular-pathway contribution makes the target less susceptible to masking by increasing the temporal resolution, it also decreases the contribution of the parvocellular pathway, which is necessary for fine-grained spatial discrimination, such as identifying the location of a small gap. We tested this assumption in Experiment 2 by increasing the size of the stimuli in the target array, including the size of the gap in the target. This increase in stimulus size should increase observers' ability to recognize stimuli effectively, on the basis of the type of information that is conveyed via the

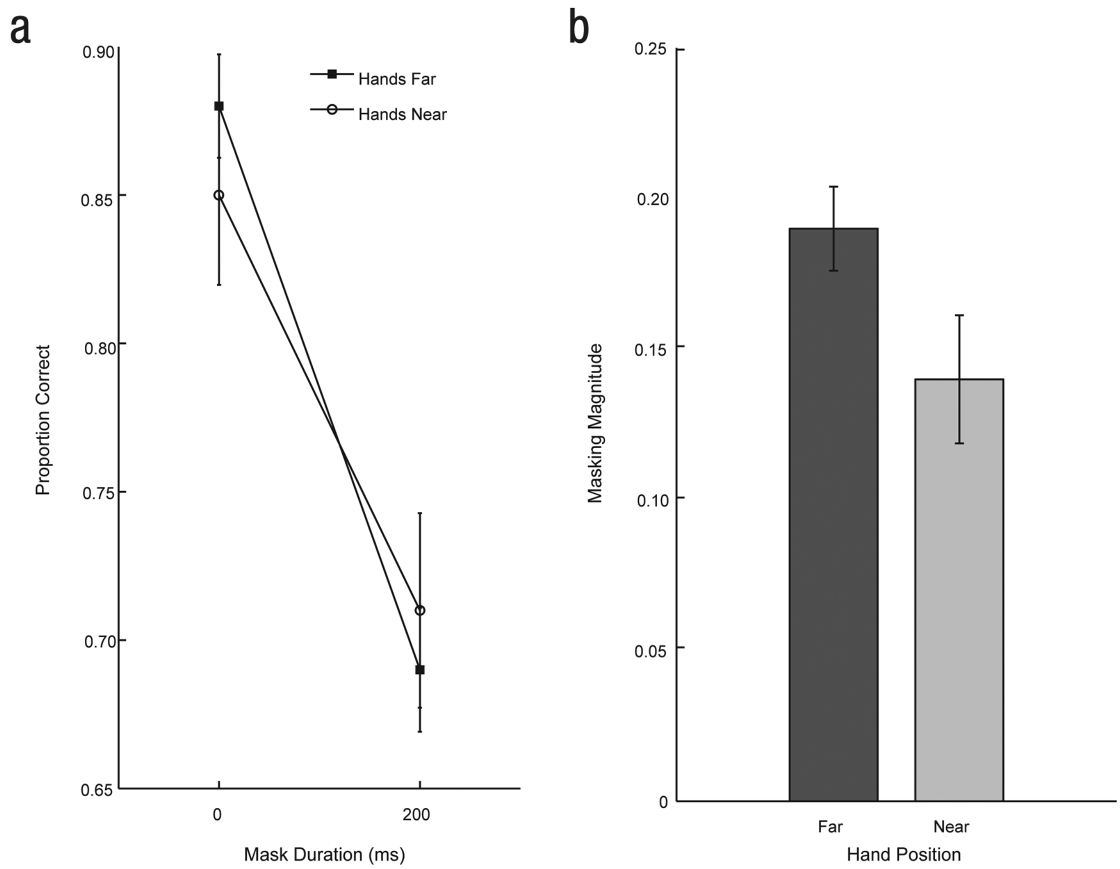

Fig. 3. Results from Experiment 1. The graph in (a) shows target-identification accuracy as a function of mask duration (0 ms = simultaneous-offset condition; 200 ms = delayed-mask-offset condition) and hand position. The graph in (b) shows masking magnitude (accuracy in the simultaneous-offset condition minus accuracy in the delayed-mask-offset condition) for each hand position. Error bars represent standard errors of the mean.

magnocellular pathway, and eliminate any effect of hand position on simultaneous-offset trials while retaining the effect on delayed-offset trials.

Experiment 2

Method

The materials and procedures in Experiment 2 were identical to those in Experiment 1, with the following exceptions. The center-to-center separation of the Cs in the target array was now 7° of visual angle; the Cs' center-to-fixation separation was 6°, and each C subtended 3°. The size of the gap in the C was increased to 2.36°, which better corresponds to the range of spatial frequencies to which human magnocellular cells are responsive (Leonova, Pokorny, & Smith, 2003). Correspondingly, the size of the dots comprising the mask was increased to 0.8° × 0.8°. Twelve new participants (8 female, 4 male; mean age = 18.54 years, *SD* = 0.52) completed this experiment. Eleven of the participants were undergraduates at the University of Toronto, and one was one of the authors of this report (D. G. G.). The undergraduate students provided written informed consent and were given course credit in return for their participation.

Results and discussion

A 2 (hands near vs. hands far) × 2 (simultaneous offset vs. delayed mask offset) repeated-measures ANOVA revealed no main effect of hand position, $F(1, 11) = 1.07$, $p = .324$, $\eta_p^2 = .088$; a main effect of mask duration on target-identification accuracy, $F(1, 11) = 31.66$, $p < .001$, $\eta_p^2 = .742$; and an interaction between hand position and mask duration, $F(1, 11) = 6.04$, $p = .032$, $\eta_p^2 = .354$. It is important to note that the data from D. G. G. did not deviate from those of the other participants and that this interaction was still significant when data from him were excluded ($p = .031$, $\eta_p^2 = .387$).

In order to illustrate the nature of this interaction, we computed the magnitude of masking (accuracy in the simultaneous-offset condition minus accuracy in the delayed-mask-offset condition) for the hands-near and hands-far conditions (see Fig. 4). Results showed that OSM was reduced in the hands-near condition compared with the hands-far condition. This finding is consistent with our findings from Experiment 1 in that it suggests that increasing the temporal precision of the visual system prevents the fusion of the target and mask that characterizes OSM.

General Discussion

Across two experiments, we found that OSM was attenuated when visual stimuli appeared near the hands compared with when they appeared far from the hands. A substantive body of literature suggests that increased attentional resources are devoted to visual stimuli in near-hand space (Abrams et al., 2008; Reed et al., 2010; Reed et al., 2006; Tseng & Bridgeman, 2011; Whiteley et al., 2004), which facilitates the speed of their perception. Given that OSM at its core reflects a failure to segregate the target and mask as distinct objects (Lleras & Moore, 2003; Moore & Lleras, 2005; Neill et al., 2002), this boost in perceptual processing speed facilitates object individuation, thus reducing masking.

This attentional account dovetails nicely with the critical role of attention in OSM. That is, OSM is observed only when attentional resources are occupied either by accompanying distractor stimuli or by another cognitively engaging task, such as mental arithmetic (Dux, Visser, Goodhew, & Lipp, 2010). Thus, masking may be the product of insufficient available attentional resources to encode the target and mask as separate objects. This finding represents an important advancement in our understanding of the perception of stimuli in near-hand space. Not only does positioning objects in near-hand space increase accuracy and response speed

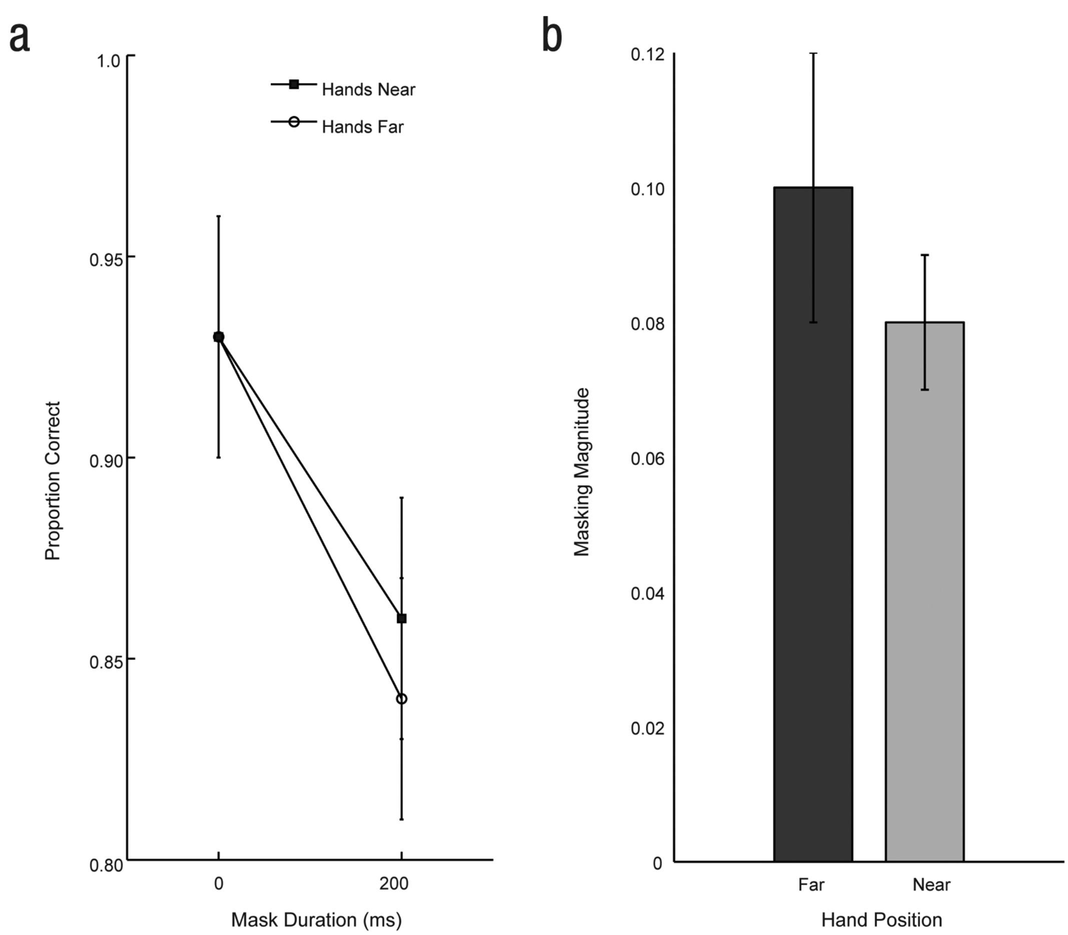

Fig. 4. Results from Experiment 2. The graph in (a) shows target-identification accuracy as a function of mask duration (0 ms = simultaneous-offset condition; 200 ms = delayed-mask-offset condition) and hand position. The graph in (b) shows masking magnitude (accuracy in the simultaneous-offset condition minus accuracy in the delayed-mask-offset condition) for each hand position. Error bars represent standard errors of the mean.

in attentional tasks, it can also help to protect against an otherwise potent effect of a mask on the visibility of a target stimulus.

One finding that requires further discussion is that of Abrams et al. (2008), whereby an increased attentional-blink deficit was found for objects in near-hand space. That is, when participants had to identify two targets in a centrally presented rapid-serial-visual-presentation (RSVP) stream, the well-documented deficit in identifying the second target (T2) that extends for several hundred milliseconds after processing of the first target (T1; Dux & Marois, 2009; Raymond, Shapiro, & Arnell, 1992) was actually prolonged for stimuli in near-hand space. Given that the attentional blink reflects a failure of temporal attention, this finding might at first glance appear at odds with our evidence for reduced temporal fusion in near-hand space. However, closer consideration reveals that this finding is actually consistent with such an account: It has been found that the attentional blink is increased whenever processing time for T1 is increased (Jolicoeur, 1998; Visser, 2007). Converging evidence for this is that manipulations that likely increased T1 processing time exacerbated the attentional blink, even when T1 processing time was not directly measured, such as by increasing the difficulty of differentiating T1 from distractors (Dux & Coltheart, 2005; Raymond, Shapiro, & Arnell, 1995) or when T1 was inherently salient (e.g., an emotionally arousing image; Most, Smith, Cooter, Levy, & Zald, 2007). Thus, if placing stimuli in near-hand space compels observers to devote more attentional resources to the first target in the RSVP stream, this could explain why Abrams et al. (2008) found an increased attentional blink under these conditions.

In OSM, the increased attention paid to the target helped to undo the deleterious effects of the mask. The mask, however, should have also received boosted attentional processing. Although difficult to do in practice, it would be interesting to see whether we could increase the magnitude of our observed effect if we increased the temporal resolution of the visual system exclusively for the target rather than for both the target and mask as we did in our two experiments. Although consolidation of the mask as a separate object helps protect the target from temporal fusion, increasing the salience and perceived duration of the mask also concomitantly increases the raw physical power of the mask to obscure the target (Lleras & Moore, 2003; Tata & Giaschi, 2004). This means that increasing attention to the mask by placing the hands near the screen during mask exposure may have also had the effect of decreasing target visibility. Thus, the fact that we saw an improvement in target visibility in the hands-near condition relative to the hands-far condition means that increasing the temporal resolution during target exposure must facilitate separate representations of the target and mask to such an extent that it outweighs any competing effect in the opposite direction.

An alternative explanation for our findings is that the observed reduction in masking in near-hand space was due to the upregulation of the contribution of the fast, coarse, luminance-sensitive magnocellular pathway relative to the parvocellular pathway (Gozli et al., 2012). This view, although still speculative, holds intuitive appeal if one considers the function of the hands. That is, the magocellular pathway, which connects predominately to the dorsal stream, shows a distinct preference for processing luminance, motion, and action-oriented visual information (see Welsh & Pratt, 2008; Wykowska, Schubö, & Hommel, 2009). For example, if an object is moving toward one's body, locating this object and its trajectory in order to use the hand to divert it would rely mostly on the magnocellular pathway and the dorsal stream. In this situation, the finer details of the object (processed by the parvocelluar pathway) are less important than is the rapid detection of its trajectory.

The attentional-prioritization and magnocellular-pathway accounts of perception in near-hand space, rather than being mutually exclusive, could be seen as different levels of analysis of the same underlying phenomenon. That is, the magnocellular pathway may be the physiological mediator of the enhanced attentional processing in near-hand space. However, in order to provide definitive evidence in favor of this account, it would be necessary to directly test the underlying physiology—for example, via intracellular recording of magnocellular-pathway neurons. This means that although Gozli et al. (2012) have provided behavioral evidence in favor of an increased magnocellular-pathway contribution in near-hand space, this account remains speculative, pending further research.

In sum, our results show that a manipulation as simple as placing one's hands near a target array can override a perceptual phenomenon as powerful as masking. Given that this manipulation is known to enhance the temporal resolution of the visual system via the allocation of attentional resources to these stimuli, this implies that OSM is indeed characterized by temporal fusion of the target and mask objects. This fusion is the result of mechanisms necessary for maintaining coherent object representations through time and space, which tells us that the construction of object representations from ongoing sensory input can be influenced by where one's hands are in space.

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Declaration of Conflicting Interests

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

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Note

1. This task constituted one block of a larger experiment.

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