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Subliminal spatial cues capture attention and strengthen between-object link

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ABSTRACT

According to the spreading hypothesis of object-based attention, a subliminal cue that can successfully capture attention to a location within an object should also cause attention to spread throughout the whole cued object and lead to the same-object advantage. Instead, we propose that a subliminal cue favors shifts of attention between objects and strengthens the between-object link, which is coded primarily within the dorsal pathway that governs the visual guidance of action. By adopting the two-rectangle method and using an effective subliminal cue to compare with the classic suprathreshold cue, we found a different result pattern with suprathreshold cues than with subliminal cues. The suprathreshold cue replicated the conventional location and object effects, whereas a subliminal cue led to a different-object advantage with a facilitatory location effect and a same-object advantage with an inhibitory location effect. These results support our consciousness-dependent shifting hypothesis but not the spreading hypothesis.

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1. Introduction

To recognize an object in a multi-object scene, our brain needs to calculate the relation of properties—shape, color, configuration, and so on—*within* objects. For example, a pail with a curvature on the side can be a mug, but if the curvature is on the top of the pail, it is more likely to be a bucket (Biederman, 1987). Visual attention can facilitate processing of properties belonging to the same object, that is, *object-based attention* (Duncan, 1984; Egly, Driver, & Rafal, 1994), and this kind of object-based attention may be achieved by strengthening the *within-object link* that is critical for object recognition. However, to act in a multi-object environment, our brain needs to calculate the relation of properties—orientation, size, and distance—*between* objects. For example, to hit a baseball, it is critical to know the moment-by-moment distance between the ball and the bat. In this case, it is likely that attention helps action execution by strengthening the *between-object link* (Davis, 2001; Humphreys, 1998) that is important for visually guided action.

Indeed, two visual pathways have been identified for the two main functions of vision: object recognition and action (Goodale & Milner, 1992). The ventral pathway—from visual primary cortex (V1) to temporal cortex—is mainly involved in object recognition, whereas the dorsal pathway—from V1 to frontal-parietal cortex—is mainly involved in the visual guidance of action (Goodale, Milner, Jakobson, & Carey, 1991; Kluver & Bucy, 1938). The double-dissociation demonstrated by neuropsychological patients provides evidence for the two-pathway theory. On one hand, patients with lesion areas in the

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ventral pathway lose *conscious* vision for object recognition but not the *unconscious* vision to act (Goodale & Milner, 2004). For example, Patient DF cannot report the orientation of a pencil, but she can posture her hand correctly as she reaches out to grasp it (Goodale et al., 1991). On the other hand, patients with lesions in the dorsal pathway have intact *object recognition* but impaired *visually guided* action. These optic ataxia patients are able to report the orientation of a slot cut in a disk, but they cannot reach out and pass their hand through it (Perenin & Vighetto, 1988). Contrary to Patient DF, the optic ataxia patients have *conscious* vision for object recognition but they cannot use this vision to guide their action. This double-dissociation of *conscious* and *unconscious* vision revealed by neuropsychological patients with damage in ventral and dorsal pathways, respectively, hints at the possibility that manipulating normal participants' consciousness of the stimuli can dissociate the two pathways and show their difference in affecting performance. This is the goal of the current study.

In a seminal paper, Egly and colleagues (1994) used a cueing paradigm with a double-rectangle display to demonstrate the existence of within-object link. They presented two outlined rectangles, with one end of one rectangle brightened as a cue to indicate the possible location of a target. The target was a small solid square, shown subsequently within one end of a rectangle. Within-object link was indicated by the *same-object advantage*: RTs were shorter when the target appeared at the uncued end of the *cued* than at the *uncued* rectangle, with an equal cue-to-target distance between the two. Egly, Driver, and Rafal (1994) suggest that there is a cost of shifting attention between objects (see also Lamy & Egeth, 2002). As with Egly et al. (1994), a series of studies showing this same-object advantage have used suprathreshold stimuli that supposedly trigger *conscious* vision in the ventral pathway (e.g., Abrams & Law, 2000; Lamy & Tsai, 2000; Moore, Yantis, & Vaughan, 1998). Here we suggest that vision for action, which is triggered by *unconscious* vision, may favor shifts of attention *between* objects relative to shifts of attention *within* objects. Therefore, we hypothesize that if *subliminal* stimuli are used, *different-object advantage*—that is, faster response to a target within an uncued object than within a cued object—should be obtained instead because *unconscious* vision involved in the dorsal pathway is primarily for action, and action requires a between-object link (cf. Davis, 2001).

In contrast to this consciousness-dependent shifting hypothesis, the influential spreading hypothesis of object-based attention would make an opposite prediction (Richard, Lee, & Vecera, 2008). The spreading hypothesis states that when attention is cued to a location within an object, attention will spread automatically from the cued location to the whole object. Consequently, a subliminal cue that can successfully capture attention to a specific location within an object should also cause attention to spread throughout the whole cued object. In sum, regardless of the participant's awareness of the cue, a conventional *same-object advantage* is expected.

To test these two hypotheses, we designed four experiments orthogonally by crossing the cue type (subliminal, suprathreshold) with the cue-to-target stimuli-onset-asynchrony (SOA; 100 ms, 1000 ms). A subliminal cue was followed by suprathreshold cue in each pair of experiments. The experiments were structured as follows:

- Experiment 1: subliminal cue, 100-ms SOA.
- Experiment 2: suprathreshold cue, 100-ms SOA.
- Experiment 3: subliminal cue, 1000-ms SOA.
- Experiment 4: suprathreshold cue, 1000-ms SOA.

Manipulation of SOA allows us to examine the object effects induced by the spatial cue across different time courses. Past studies using suprathreshold cues have shown that one's attention is attracted first to the cued location but then is inhibited from going there again, as indicated by an early facilitation (faster RT) followed by late inhibition (slower RT) at the cued location (for a review, see Klein, 2000). Bennett and Pratt (2001) examined the spatial distribution of the late-inhibition component and found facilitation in the quadrant *opposite* to the cued (inhibited) location. Assuming that attention relocates to the opposite quadrant in the long-SOA condition, the uncued object in the current study becomes "attended-object," and a reversed object effect should be obtained. Indeed, with suprathreshold cues, results opposite to that obtained in the short SOAs were found instead (Jordan & Tipper, 1999).

A recent study by Mulckhuysse, Talsma, and Theeuwes (2007) has shown the same bi-phasic mode of early facilitation and late inhibition with a subliminal spatial cue. Thus, we hypothesize that opposite object effects should be obtained for a long-SOA condition compared with a short-SOA condition for the subliminal cue as well. That is, with subliminal cues, we should expect to find a *different-object advantage* for a short SOA and a *same-object advantage* for a long SOA. In contrast, the spreading hypothesis (Richard et al., 2008) predicts conventional object effects—*same-object advantage* for a short SOA (Egly et al., 1994) and *different-object advantage* for a long SOA (Jordan & Tipper, 1999)—as long as a subliminal cue attracts attention to its location.

2. Method

2.1. Participants

Seventy-seven paid volunteers participated in this study ($N = 29, 20, 17,$ and 11 in Experiments 1–4, respectively). All participants had normal or corrected-to-normal vision and were naïve as to the purpose of the experiment.

2.2. Stimuli, apparatus, and design

The stimuli were presented on a VGA monitor with the resolution of 640×480 pixels in a 256-color mode. A visual C++ computer program was run on an IBM-compatible computer to present the stimuli and collect the RT data. Participants sat in a dimly lit chamber with a viewing distance of 57 cm. Head position was maintained with a chin rest.

Fig. 1 illustrates the stimuli and sequence of events for a target-present trial (83% of total trials) in each experiment. The displays were comprised of a pair of adjacent rectangles, oriented either vertically or horizontally. The fixation cross was a red plus sign ($1^\circ \times 1^\circ$). Each rectangle ($2^\circ \times 8^\circ$, with a stroke width 0.2°) was centered 3° from fixation. The cue, masks ($1^\circ \times 1^\circ$ solid gray squares), and the target (a solid black disk with 0.3° in diameter) were all centered 4.24° from fixation.

2.3. A spatial pre-cue was presented at one end of a rectangle, with one of the three cue-target relationships

1. *Valid*: The target appeared at the cued location.
2. *Invalid same-object (IS)*: The target appeared at the uncued location within the cued object.
3. *Invalid different-object (ID)*: The target appeared at the near end of the uncued object.

The distance between the cue and the target were equal in the IS and ID conditions, making any RT difference between IS and ID conditions not attributable to location. There were four blocks of 58 trials each, including 16 valid, 16 IS, 16 ID, and 10 catch trials, presented in random order.

2.4. Procedure

Each trial began with a fixation display containing the fixation cross and two rectangles, with its duration jittered from 300 to 800 ms to reduce anticipation. In Experiment 1, following the fixation display, the cue display was presented for 16 ms and was then replaced by an 84 ms mask display, making the cue-to-target SOA 100 ms. Then the target (or, in the catch trials, nothing) was presented and remained visible until the participants either responded or, if there was no response, for 1000 ms. The next trial began after a 1000-ms intertrial interval, during which the screen was blank.

The subliminal cue was a small patch appearing at one end of the two rectangles in the cue display. The cue was presented 16 ms earlier than the other patches shown in the other three ends, giving the impression that all four patches appear simultaneously. The participants were asked to fixate at the central cross throughout each trial, and their task was to press the space bar on a computer keyboard as rapidly as possible whenever they detected the target. A 500-ms feedback beep was presented if the participant made a response to a catch trial that contained no target. Before the experimental trials, the participant was given 20 practice trials that were randomly selected from the experimental conditions.

After conducting the target-detection task, participants were asked to perform a cue-report task, which assessed whether participants were indeed unable to perceive the cue. Sixty-four trials ($16 \text{ trials} \times 4 \text{ possible cue locations}$) with identical

(A) Subliminal cue (Experiment 1 and 3) (B) Suprathreshold cue (Experiment 2 and 4)

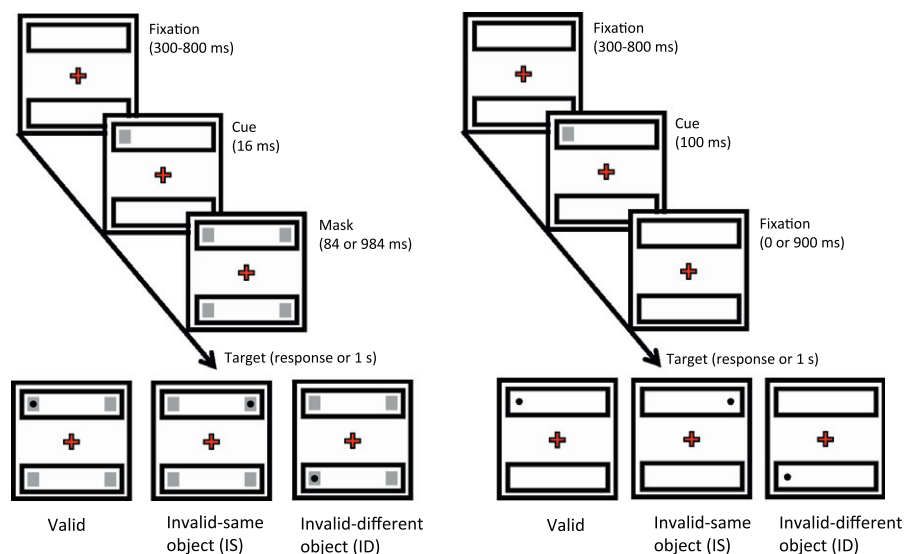


Fig. 1. Example displays for each of the four experiments. The rectangles were oriented either horizontally or vertically. The cue was a small patch appearing at one end of the two rectangles. The task was to detect the target (a black disk).

procedure to the trials in the target-detection task were conducted. Participants were asked to ignore the target but to indicate which of the patches was presented earlier than the other three patches by pressing a one of four designated keys on a computer keyboard. Each trial ended when a response was given and no feedback was provided. After this objective measure, the participants were asked directly about whether they had seen any patches occur before the others during the whole experiment. This open question served as a subjective measure of the awareness of the cue.

Instead of the subliminal cue used in Experiment 1, a suprathreshold cue was provided in Experiment 2. In Experiment 2, following the fixation display, the cue display was presented for 100 ms and then replaced by the target display. Instead of the short cue-to-target SOAs (100 ms) in the first two experiments, the SOAs were 1000 ms in Experiments 3 and 4. In Experiment 3, the cue display was presented for 16 ms and replaced by a 984-ms mask display. In Experiment 4, the cue display was presented for 100 ms and then replaced by a 900-ms fixation display.

3. Results

3.1. Cue-report task

All participants in Experiments 1 and 3 reported that they were unable to perceive the cue, which was corroborated by the objective measure. The mean detection accuracy of the four-alternative-forced-choice cue-report tasks were not significantly above chance level (27% and 25%, respectively; $p > .30$). All participants in Experiments 2 and 4 were fully aware of the cue.

3.2. Target-detection task

Fig. 2 shows the mean correct RTs collapsed across rectangle orientation in all experiments, since orientation did not affect the RTs, nor did it interact with validity ($p > .05$). The collapsed data were submitted to a one-way repeated measures Analysis of Variance (ANOVA) with the factor of validity (valid, IS, ID). The main effects of validity were significant in all four experiments [$F(2, 28) = 4.00$, $MSE = 43.59$, $p < .05$; $F(2, 19) = 17.76$, $MSE = 86.12$, $p < .0001$; $F(2, 16) = 4.33$, $MSE = 33.28$, $p < .05$; $F(2, 10) = 17.86$, $MSE = 101.61$, $p < .0001$ for Experiments 1–4, respectively]. Mean error rates (i.e., false alarms on catch trials) were 2.9%, 3.1%, 3.5%, and 2.5% for Experiments 1–4, respectively. RTs shorter than 100 ms and longer than 1000 ms (0.7% of all trials) were omitted from analysis. There were no differences in error rates across conditions in each experiment (see Fig. 2).

In Experiment 1 (subliminal cue; 100-ms SOA), planned comparisons (two-tailed, paired t test) showed faster RTs for valid than for IS trials ($t(28) = 5.46$, $p < .05$, Cohen's $d = 0.24$), replicating the finding that a subliminal cue can capture participants' attention (e.g., Mulckhuyse et al., 2007). More importantly, the subliminal spatial cue led to the *different-object* advantage: Participants responded faster when the target appeared at the uncued object (ID) than at the cued object (IS) ($t(28) = 5.61$, $p < .05$, Cohen's $d = 0.23$).

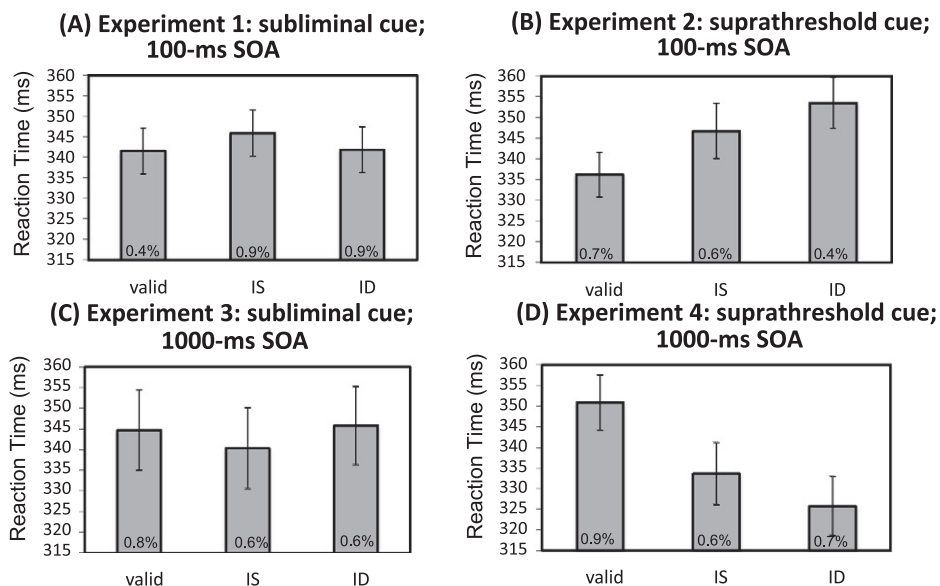


Fig. 2. Mean correct reaction times in each of the four experiments. Error bars represent one standard error of the mean. IS: invalid same-object; ID: invalid different-object. The number shown in each bar denotes the percent error of each condition.

In Experiment 2 (suprathreshold cue; 100-ms SOA), the RTs of valid trials were shorter than those of IS trials ($t(19) = 8.25$, $p < .01$, Cohen's $d = 0.40$), and the RTs of IS trials were shorter than were those of ID trials ($t(19) = 11.00$, $p < .005$, Cohen's $d = 0.24$). Experiment 2 replicated the typical patterns from a suprathreshold cue with a short SOA—location-based facilitation and same-object advantage. Comparing Experiments 1 and 2 reveal reversed object effects with subliminal and suprathreshold cues: *different*-object advantage for subliminal cues and *same*-object advantage for suprathreshold cues.

In Experiment 3 (subliminal cue; 1000-ms SOA), the RTs of valid trials were longer than those of IS trials ($t(16) = 6.10$, $p < .05$, Cohen's $d = 0.21$), indicating a late-inhibition component of the subliminal cue with long SOA and also replicating the findings of Mulckhuysen et al. (2007). More importantly, participants responded faster when the target appeared at the cued object (IS) than at the uncued one (ID) ($t(16) = 6.72$, $p < .05$, Cohen's $d = 0.24$). That is, the subliminal spatial cue in a long-SOA condition led to location-based *inhibition* accompanied with object-based *facilitation*.

In Experiment 4 (suprathreshold cue; 1000-ms SOA), the RTs of valid trials were longer than those of IS trials ($t(10) = 12.20$, $p < .001$, Cohen's $d = 0.73$), which were longer than those of ID trials ($t(10) = 6.53$, $p < .05$, Cohen's $d = 0.33$). Namely, Experiment 4 found both location- and object-based *inhibition* and replicated the findings of Jordan and Tipper (1999). By comparing Experiments 3 and 4, we confirm that the subliminal cue and the suprathreshold cue led to reversed object effects also in a long-SOA condition.

4. Discussion

Our results show that a subliminal cue caused *different*-object advantage for short SOA (Experiment 1) and *same*-object advantage for long SOA (Experiment 3). These results are opposite to the object effects obtained with a suprathreshold cues used in Experiments 2 and 4 in which conventional object effects were replicated: *same*-object advantage for short SOA (e.g., Abrams & Law, 2000; Egly et al., 1994; Lamy & Tsai, 2000; Moore et al., 1998) and *different*-object advantage for long SOA (e.g., Jordan & Tipper, 1999; List & Robertson, 2007). The critical difference predicted by the spreading hypothesis and the consciousness-dependent shifting hypothesis lies in the results with the use of subliminal cue (Experiments 1 and 3); we have demonstrated that the subliminal cue we used indeed did not reach consciousness, as confirmed by both subjective and objective measures of participants' awareness of the cue. Furthermore, the subliminal cue we used was effective in capturing attention to its location, as indicated by *faster* responses to targets shown at the cued location with short SOA and *slower* responses with long SOA, replicating early facilitation and late inhibition with a subliminal cue proven by Mulckhuysen et al. (2007). The fact that the suprathreshold and subliminal cues led to opposite object effects supports our consciousness-dependent shifting hypothesis but not the spreading hypothesis.

The critical results lie in the subliminal cue we used in the current study. In our design, the cue and the masks were identical stimuli in Experiments 1 and 3 and the cue was signaled by a slightly earlier onset (16 ms) than the masks that appeared at the uncued locations. One may doubt that the latter onsets of the masks may have caused a disruptive effect on orienting attention to the initially cued location and thus led to result patterns opposite to the typical ones. However, we think it is unlikely for the following reason. In both Experiments 1 and 3 where subliminal cues were used, we found faster responses to targets shown at the *cued location* with 100 ms SOA and slower responses with 1000 ms SOA, as compared to those at the IS condition ($t(28) = 5.46$, $p = .0269 < .05$; $t(16) = 6.10$, $p = .0252 < .05$). Consequently, we suggest that the first unique onset (the subliminal cue) did orient attention to the initially cued location.

The results of early facilitation with short SOA that leads to *same*-object advantage for suprathreshold cues and *different*-object advantage for subliminal cues can be explained as follows: The suprathreshold cue triggers the ventral pathway that is mainly responsible for conscious object recognition. Object recognition heavily relies on within-object link—thus, properties within the same object should be strengthened altogether—leading to the *same*-object advantage. In this case, there is a cost of shifting attention between objects (Egly et al., 1994; Lamy & Egeth, 2002). The subliminal cue, however, triggers the dorsal pathway that is mainly responsible for visually guided action. Action heavily relies on between-object link—and, thus, properties between different objects should be strengthened instead—leading to the *different*-object advantage. This “vision-for-action” pathway favors shifts of attention between objects relative to shifts of attention within objects. The reversed result patterns triggered by the late inhibition with long SOA follow the same reasoning.

Therefore, this study provides evidence of dissociating unconscious vision (dorsal) and conscious vision (ventral) pathways with neuropsychologically intact observers. Unlike previous studies supporting object-based attention that all used suprathreshold stimuli (e.g., Baylis & Driver, 1993; Brawn & Snowden, 2000; Duncan, 1984; Egly et al., 1994), the current study demonstrates opposite results from suprathreshold and subliminal cues by manipulating participants' consciousness regarding the cue.¹

Note that the task our participants performed was to detect a target within one end of two objects, which is considered a type of “vision-for-perception” task. Thus, it is reasonable that previous studies using suprathreshold cues found

¹ We can manipulate participants' consciousness regarding not only the cue but also the objects and the target. However, in the cueing paradigm, the cue itself is the most relevant component as to the visually guided action carried out in the dorsal pathway (Goodale & Milner, 2004). Therefore, manipulating consciousness regarding the cue is the first step to test our hypothesis. Indeed, different result patterns would be predicted when conscious perception of the objects is manipulated. We perceive objects in our daily visual world at a different degree of awareness, but they all signify the relation of properties—such as shape, color, texture, configuration, and so on—within objects, all related to the perception for object recognition. It is thus predicted that manipulating conscious perception of the objects should trigger the same “vision-for-perception” (ventral) pathway. Further studies are needed to confirm this conjecture.

same-object advantage because the within-object link was emphasized in such perception tasks that supposedly are processed in the ventral pathway. When an action (i.e., pointing) that triggered the dorsal pathway was required, the same-object advantage was disrupted (Linnell, Humphreys, McIntyre, Laitinen, & Wing, 2005). Why would the same perception task with a subliminal spatial cue in the current study prove to be processed in the dorsal pathway that enhances between-object link? It is possible that unconscious spatial cues can bypass the constraint of task demands, making the dorsal pathway dominate the ventral pathway. The subliminal cue indexes a given location, then sent along the dorsal pathway, which is also known to process location information (Ungerleider & Haxby, 1994) without being masked by the influence of within-object links.

Davis, Welch, Holmes, and Shepherd (2001) used a divided-attention task wherein participants were asked to compare two target features within an object or across objects, and they also found a different-object advantage: a faster response when the two features belonged to different objects than to the same object (see also Cepeda & Kramer, 1999). Davis and colleagues suggest that different-object advantage was obtained due to processes in the magnocellular pathway. Their assertion bears some similarities to our hypothesis because it has been suggested that the ventral and dorsal pathways are the cortical extensions of separate subcortical parvocellular and magnocellular pathways (Livingstone & Hubel, 1987). However, there is now considerable evidence showing that although the dorsal pathway is largely—though not entirely—dependent on magnocellular inputs, the ventral pathway receives major contributions from both magnocellular and parvocellular inputs (Merigan & Maunsell, 1993). Our study also differs from that of Davis et al. (2001). They manipulated the stimulus presentation that favors one pathway over the other and found same-object advantage in one case (e.g., only high-spatial frequency information available that favors the ventral pathway) and different-object advantage in the other (e.g., presenting the objects and target features simultaneously that favors the magnocellular pathway). However, we obtained both the same- and different-object advantage using the same stimulus displays. In our procedure, the objects were presented for 300–800 ms before the cue was shown, and the cue-to-target SOA was 100 ms or 1000 ms. Davis et al. (2001) suggest that it is the time interval between the objects and the target features (delayed 2400 ms or simultaneous) that determines whether a same- or a different-object advantage is observed. Although it is difficult to compare the cuing task and the divided-attention task, the object preview time in our procedures and the cue-to-target SOAs were long enough for the parvocellular pathway to operate. It is possible that the 16-ms subliminal cue triggers the magnocellular pathway, which is sensitive to transient changes; however, what we emphasize here is that the conscious status (but not the stimulus factors) is critical for modulating the object effects.

Learning exactly how conscious and unconscious visual processes function will enrich our understanding of human visual processing that, on one hand, leads to object recognition and, on the other hand, to visually guided action. In practice, subliminal information can be useful in commercial and clinical settings to provide unconscious suggestions for undefended receptive advertisements and in behavioral modification (Greenwald, Spangenberg, Pratkanis, & Eskenazy, 1991; Karremans, Stroebe, & Claus, 2006; Merikle & Skanes, 1992). Further, our findings suggest that conscious state and timing are both critical factors that must be considered, not only for future studies but also for application purposes.

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