

Object-based attention guided by an invisible object

Xilin Zhang & Fang Fang

Experimental Brain Research

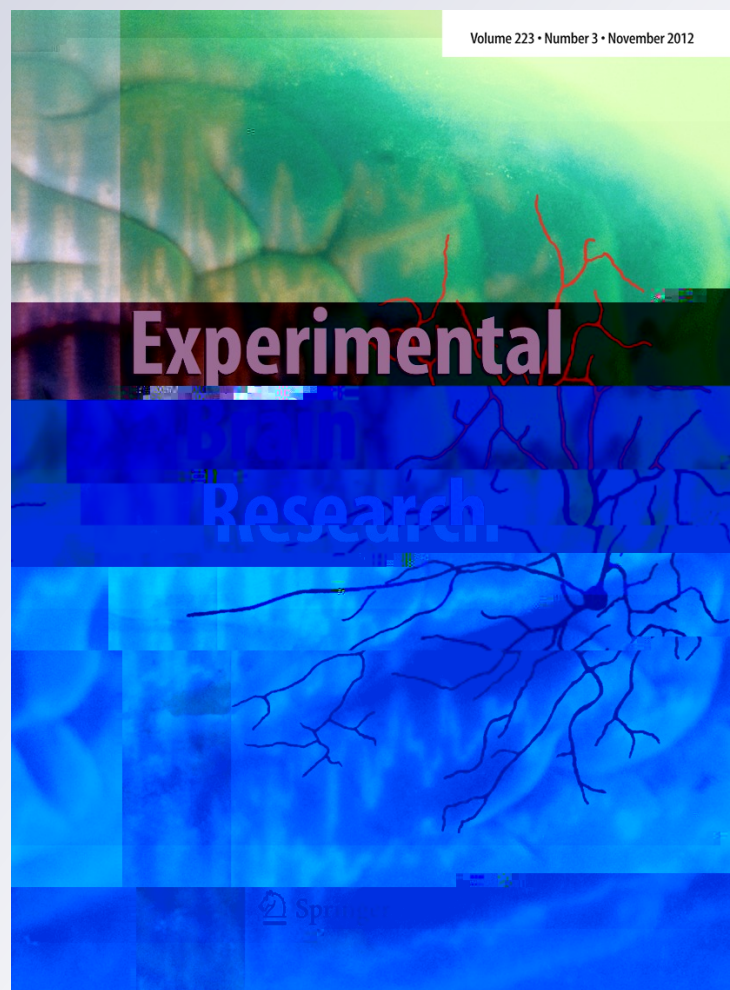
ISSN 0014-4819

Volume 223

Number 3

Exp Brain Res (2012) 223:397-404

DOI 10.1007/s00221-012-3268-4



Your article is protected by copyright and all rights are held exclusively by Springer-Verlag. This e-offprint is for personal use only and shall not be self-archived in electronic repositories. If you wish to self-archive your work, please use the accepted author's

Object-based attention guided by an invisible object

Xilin Zhang · Fang Fang

Received: 14 June 2012 / Accepted: 9 September 2012 / Published online: 19 September 2012
Springer-Verlag 2012

Abstract Evidence for object-based attention typically comes from studies using displays with visible objects, and little is known about whether object-based attention can occur with invisible objects. We investigated this issue with a modified double-rectangle cuing paradigm, which was originally developed by Egly et al. (*J Exp Psychol Gen* 123:161–177, 1994). In this study, low-contrast rectangles were presented very briefly, which rendered them invisible to subjects. With the invisible rectangles, we found a classical object-based attentional effect as indexed by the same-object effect. We also found the instantaneous object effect—object-based attention was dependent on the orientation of the rectangles presented with the target, providing evidence for the dynamic updating hypothesis (Ho and Yeh in *Acta Psychol* 132:31–39, 2009). These results suggest that object-based attention can be guided by an invisible object in an automatic way, with a minimal influence from high-level top-down control.

Keywords Attention · Object-based attention · Awareness · Same-object effect · Instantaneous object effect

X. Zhang · F. Fang
Department of Psychology and Key Laboratory of Machine Perception (Ministry of Education), Peking University, Beijing 100871, People's Republic of China

F. Fang
Peking-Tsinghua Center for Life Sciences, Peking University, Beijing 100871, People's Republic of China

F. Fang (✉)
IDG/McGovern Institute for Brain Research, Peking University, Beijing 100871, People's Republic of China
e-mail: ffang@pku.edu.cn
URL: www.psy.pku.edu.cn/en/fangfang.html

Introduction

Because neural resources are severely limited, efficiently processing visual information requires selecting only a fraction of the multitude of information available to the visual system at any one instant. Attention plays a central role in this selection process. Many studies have demonstrated that the unit of attentional selection can be spatial location (Brefczynski and DeYoe 1999; Eriksen and Yeh 1985; Kastner et al. 1999; McMains and Somers 2004; Posner et al. 1980); or visual feature (e.g., Liu et al. 2007; Maunsell and Treue 2006; Saenz et al. 2002; Serences and Boynton 2007; Treue and Martinez-Trujillo 1999; Zhang and Luck 2009). A seminal double-rectangle cuing paradigm developed by Egly et al. (1994) showed that attentional selection can also be object-based. In this paradigm, Egly and colleagues presented two parallel rectangles of equal length. A cue appeared at one end of a rectangle to indicate the possible location of a target. The target appeared at the validly cued location frequently (75 % of trials) and at invalidly cued locations occasionally (25 % of trials). There were two types of invalidly cued targets: one appearing at the uncued end of the cued object and the other appearing in the uncued object. Both of these invalidly cued targets were equidistant from the cued location. The object-based attention manifested as the same-object effect: subjects' detection of the invalidly cued target in the cued object is faster and more accurate than that appearing in the equidistant location in the uncued object.

The double-rectangle cuing paradigm has been widely used to investigate various properties of object-based attention (e.g., Abrams and Law 2000; Albrecht et al. 2008; Behrmann et al. 1998; Marino and Scholl 2005; Moore and Fulton 2005; Moore et al. 1998; Muller and Kleinschmidt 2003; Pilz et al. 2012; Pratt and Sekuler 2001; Richard

et al. 2008; Shomstein and Behrmann 2006; Vecera and Farah 1994; Watson and Kramer 1999). All these studies focused on how visible objects guided attention (for a review, see Scholl 2001). However, little is known about whether object-based attention can occur with invisible objects or whether attention can select an object even when the object was invisible to us. Previous studies have shown that attention can select a spatial location (Bahrami et al. 2007; Jiang et al. 2006; Kanai et al. 2006; Mulckhuyse et al. 2007; Zhang et al. 2012) or a visual feature (Kanai et al. 2006; Melcher et al. 2005

contained two vertical or horizontal rectangles (luminance: 31.9 cd/m^2 ; size: $1.6^\circ \times 16^\circ$). In the vertical rectangle condition, they were orientated as columns centered 7.2° left and right of fixation, and in the horizontal rectangle condition, they were orientated as rows centered 7.2° above and below fixation. The four ends of the two rectangles (i.e., the possible locations of cue and target) occupied the same locations in these two conditions. Horizontal and vertical rectangles appeared equiprobably and randomly in the experiment. The cue (luminance: 103 cd/m^2 ; size: $1.6^\circ \times 1.6^\circ$) was an empty square that overlapped one end of a rectangle. Following the cue frame and a 200-ms fixation display, a target frame was presented for 10 ms, which also contained two rectangles. The rectangles had the same properties as those in the cue frame except that the rectangle orientation consistency between the cue and

the target frames was manipulated. In half of the trials, the rectangle orientations in the cue and the target frames were the same (the same orientation condition), and in the remaining trials, they were orthogonal to each other (the orthogonal orientation condition). The target (luminance: 103 cd/m^2 ; size: $1.6^\circ \times 1.6^\circ$) was a solid square that overlapped one end of a rectangle. Subjects were asked to press a button as rapidly as possible whenever a target was detected at any of the four rectangle ends. Their reaction times (RTs) were recorded.

Experiment 1 consisted of 20 blocks of 96 trials. In a block, the target appeared in 80 trials and was absent in the remaining 16 catch trials. Any response in a catch trial was recorded as an error. The target appeared at the cued rectangle end in 60 trials (the valid condition, VC). It could also appear at the uncued end of the cued rectangle in 10 trials (the

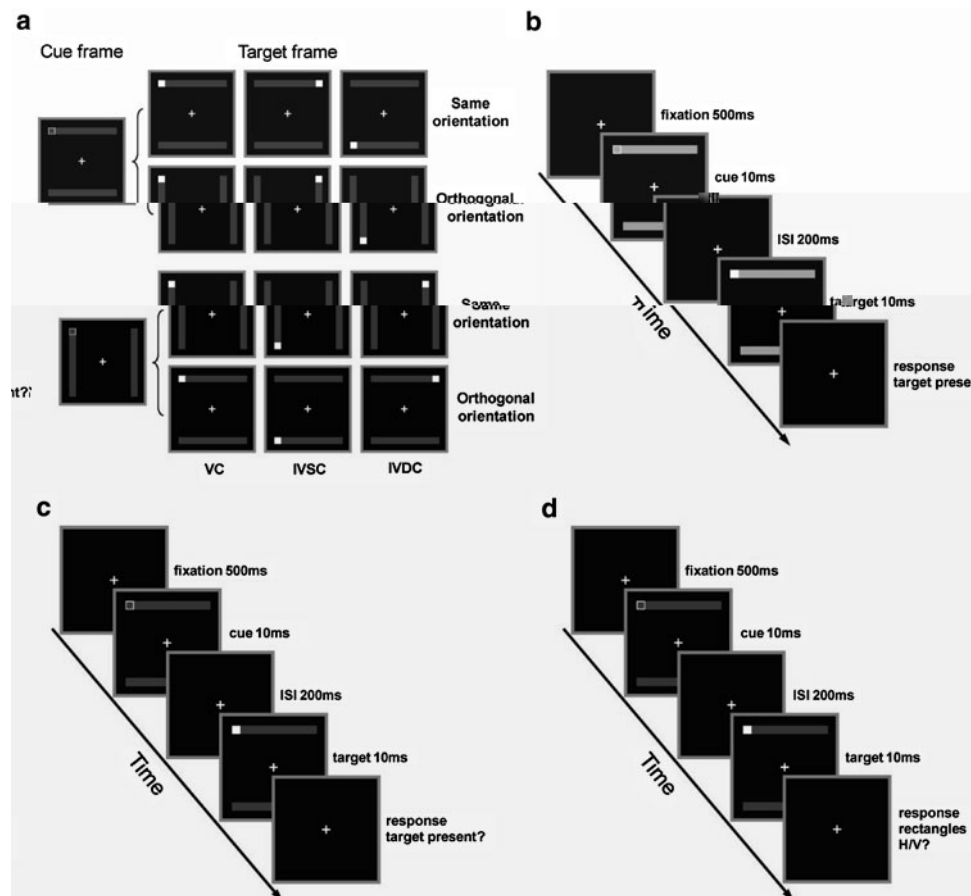


Fig. 1 Stimuli and experimental procedures. **a** Visual stimuli. The rectangles in the cue frame and the target frame were either the same or orthogonal to each other. The target appeared frequently at the cued rectangle end (the valid condition, VC). It could also appear at the uncued end of the cued rectangle (the invalid-same condition, IVSC) or at the equidistant end of the uncued rectangle (the invalid-different condition, IVDC). **b** Procedure of Experiment 1. A trial began with a 500-ms fixation, followed by a cue frame presented for 10 ms. After a 200-ms fixation display, a target frame was presented

for 10 ms. Subjects were asked to press a button as rapidly as possible whenever a target was detected at any of the four rectangle ends. **c** Procedure of Experiment 2. It was identical to that of Experiment 1 except that the contrast of the rectangles was very low. The rectangles here are rendered with a higher contrast for illustration purpose. **d** Procedure of Experiment 3. It was similar to that of Experiment 2. The only difference is that subjects were asked to judge the rectangle orientation in the cue and target frames (horizontal or vertical).

invalid-same condition, IVSC) or at the equidistant end of the uncued rectangle in 10 trials (the invalid-different condition, IVDC). In other words, in all invalid-cue trials (i.e., the IVSC and IVDC conditions), the target appeared at a rectangle end, which was a reflection from the cued end across either the horizontal or vertical meridian. The target never appeared at the rectangle end diametrically opposite to the cued end. All conditions (VC, IVSC, IVDC, and catch trial) were randomized in a block. Subjects received the percentage of correct responses after each block.

The stimuli and procedure in Experiment 2 were the same as those in Experiment 1 except that the luminance of the rectangles in the cue and the target frames was 1.85 cd/m². The low contrast (Michelson contrast: 0.0725) and the short duration (i.e., 10 ms) of the rectangles rendered them invisible to subjects, as confirmed by Experiment 3 (see “Results”). Experiment 3 was identical to Experiment 2 except that, after stimulus presentation in a trial, subjects needed to make a forced choice judgment twice to indicate the orientation of the rectangles in both the cue and target frames.

Results

In Experiments 1 and 2, false alarm rates were 3.53 and 3.64 %, and miss rates were 0.39 and 0.42 %, respectively. There was no difference in false alarm rate and miss rate across conditions. Correct RTs shorter than 150 ms and beyond three standard deviations from the mean RT in each condition were removed, which resulted in 1.52 and 1.69 % removal rates in Experiments 1 and 2, respectively.

Experiment 1: Visible object

The first goal of Experiment 1 was to use the double-rectangle cuing paradigm to measure object-based attention as indexed by the same-object effect. A second goal of the experiment was to test the dynamic updating hypothesis (Ho and Yeh 2009). The first goal can be achieved by analyzing RTs when the orientation of the rectangles in the target frame was the same as that in the cue frame. The second goal can be achieved by analyzing RTs when their orientations were orthogonal to each other. Both the same-object effect and the instantaneous effect were quantified as the RT difference between IVSC and IVDC.

Correct RTs were submitted to a two-way repeated-measures ANOVA with orientation consistency (same vs. orthogonal) and target location (VC, IVSC vs. IVDC) as within-subject factors. The main effect of orientation consistency ($F_{(1,11)} = 0.005, p = .945$) was not significant. The main effect of target location was significant ($F_{(2,22)} = 196.435, p < .001$), and the interaction between

orientation consistency and target location was significant ($F_{(2,22)} = 186.344, p < .001$) (Fig. 2).

We further compared RTs at three target locations (VC, IVSC, and IVDC) in the same orientation condition. RTs (mean \pm SEM) for VC, IVSC, and IVDC were 341 \pm 7 ms, 366 \pm 8 ms, and 380 \pm 7 ms, respectively. Paired *t* tests showed that their differences were significant (VC vs. IVSC: $t_{11} = 11.281, p < .001$; IVSC vs. IVDC: $t_{11} = 18.189, p < .001$). The difference between IVSC and IVDC demonstrated a classical object-based attention effect. Subjects' detection of the invalidly cued target in the cued object (IVSC) was faster than that appearing in the equidistant location in the uncued object (IVDC). The same-object effect was 14.7 \pm 1.9 ms.

We then compared RTs in the orthogonal orientation condition. RTs (mean \pm SEM) for VC, IVSC, and IVDC were 342 \pm 7 ms, 380 \pm 8 ms, and 364 \pm 8 ms, respectively. Paired *t* tests showed that their differences were significant (VC vs. IVSC: $t_{11} = 11.544, p < .001$; IVSC vs. IVDC: $t_{11} = 15.569, p < .001$). Contrary to the same orientation condition, RTs for IVSC were slower than those for IVDC in the orthogonal orientation condition. The instantaneous object effect was 16.1 \pm 2.1 ms. This result supports the dynamic updating hypothesis—when the cued rectangle was suddenly replaced by an orthogonal rectangle, object-based attention was reallocated according to the new rectangle rather than the original one.

Experiment 2: Invisible object

Data were analyzed in the same way as that in Experiment 1. A two-way repeated-measures ANOVA showed that the main effect of orientation consistency ($F_{(1,11)} = 0.471, p = .507$) was not significant, the main effect of target location was significant ($F_{(2,22)} = 56.825, p < .001$), and the interaction

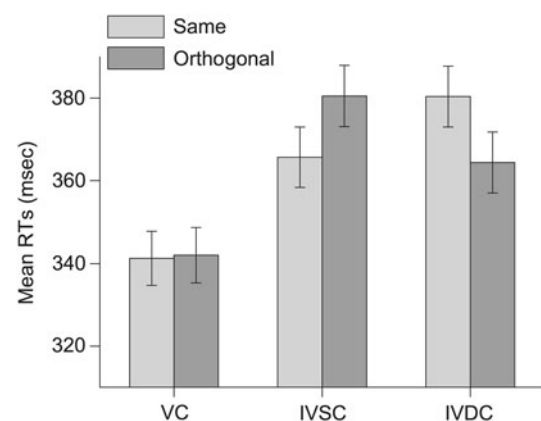


Fig. 2 Results of Experiment 1. Mean RTs are shown for VC, IVSC, and IVDC in the same and orthogonal orientation conditions. Data were averaged across twelve subjects. Error bars denote 1 SEM calculated across subjects

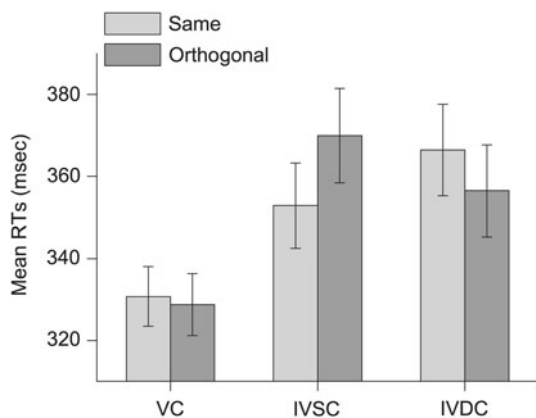


Fig. 3 Results of Experiment 2. Mean RTs are shown for VC, IVSC, and IVDC in the same and orthogonal orientation conditions. Data were averaged across twelve subjects. Error bars denote 1 SEM calculated across subjects

between orientation consistency and target location was significant ($F_{(2,22)} = 40.551, p < .001$) (Fig. 3).

Paired t tests were used to compare RTs at three target locations (VC, IVSC, and IVDC). In the same orientation condition, RTs for VC, IVSC, and IVDC were 331 ± 7 ms, 353 ± 10 ms, and 366 ± 11 ms, respectively. Their differences were significant (VC vs. IVSC: $t_{11} = 5.194, p = .001$; IVSC vs. IVDC: $t_{11} = 5.643, p < .001$). The difference between IVSC and IVDC demonstrated that the same-object effect (13.5 ± 2.4 ms) could occur with invisible objects.

In the orthogonal orientation condition, RTs for VC, IVSC, and IVDC were 328 ± 8 ms, 370 ± 12 ms, and 356 ± 11 ms, respectively. Paired t tests showed that their differences were significant (VC vs. IVSC: $t_{11} = 9.569, p < .001$; IVSC vs. IVDC: $t_{11} = 8.112, p < .001$). Contrary to the same orientation condition, RTs for IVSC were slower than those for IVDC in the orthogonal orientation condition. The instantaneous object effect was 13.4 ± 1.7 ms.

The above analyses revealed that the same-object effect and the instantaneous object effect could occur with both visible and invisible objects. We further examined how awareness affected these two effects by comparing the data in Experiment 1 (visible object) and Experiment 2 (invisible object). RT differences between IVSC and IVDC were submitted to a two-way repeated-measures ANOVA with visibility (visible vs. invisible) and effect type (same-object effect vs. instantaneous object effect) as within-subject factors (Fig. 4). The main effects of visibility ($F_{(1,11)} = 0.750, p = .405$) and effect type ($F_{(1,11)} = 0.225, p = .645$) were not significant. The interaction between visibility and effect type ($F_{(1,11)} = 0.631, p = .444$) was also not significant. These results demonstrated that the same-object effect and the instantaneous object effect were independent of object awareness (Fig. 4).

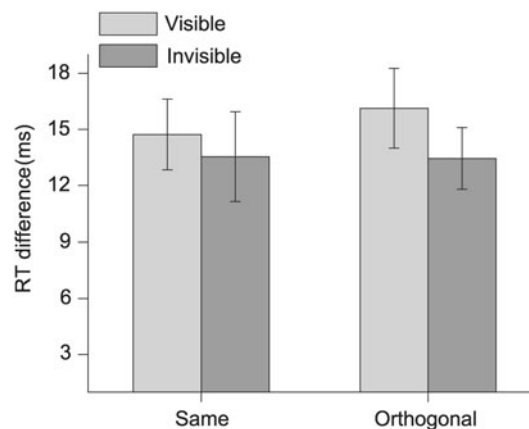


Fig. 4 Mean RT differences between IVSC and IVDC in the same and orthogonal orientation conditions in Experiments 1 (visible) and 2 (invisible). Data were averaged across twelve subjects. Error bars denote 1 SEM calculated across subjects

Experiment 3: Awareness manipulation check

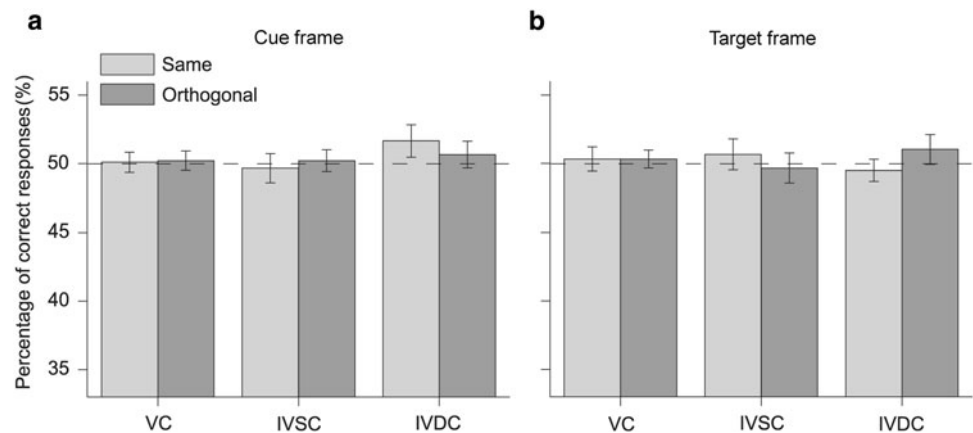
Two characteristics of the rectangles in Experiment 2—low contrast and brief presentation, rendered them invisible to subjects, as confirmed by the 2-AFC test in Experiment 3. Figure 5 shows the mean accuracies of subjects' judgment of the rectangle orientation in both the cue and target frames for VC, IVSC, and IVDC. None of the accuracies was significantly different from the chance level (all $t_{11} < 1.749, p > .108$) (Fig. 5). These results provided an objective confirmation that the rectangles were indeed invisible to subjects in Experiment 2. We rerun Experiment 3 after Experiment 2 and obtained similar results (data not shown here), which further demonstrate that our awareness manipulation is robust.

Discussion

Using a modified double-rectangle cuing paradigm, we investigated whether object-based attention could be guided by an invisible object. Experiment 1 used visible objects. It not only showed that the paradigm could yield a classical object-based attention effect (i.e., the same-object effect), but also revealed the instantaneous object effect, supporting the dynamic updating hypothesis. Experiment 2 demonstrated that both the same-object effect and the instantaneous object effect could occur with invisible objects. Notably, the magnitudes of the two effects were comparable between visible and invisible objects.

Recently, Chou and Yeh (2012) combined the double-rectangle cuing paradigm and the CFS technique (Tsuchiya and Koch 2005) to study the dependence of object-based attention on object awareness. Rectangles were presented in the nondominant eye and dynamic Mondrians (i.e., the

Fig. 5 Results of Experiment 3. Mean accuracies are shown for VC, IVSC and IVDC in the same and orthogonal orientation conditions (Left cue frame, right target frame). Data were averaged across twelve subjects. Error bars denote 1 SEM calculated across subjects



masks) were in the dominant eye. Due to the interocular suppression from the Mondrians, subjects were not aware of the rectangles. They found that the invisible rectangles could still induce the same-object effect and guide object-based attention. This study and ours provide strong evidence, supporting that object-based attention can be guided by an invisible object. In other words, object awareness is not necessary for object-based attention, and visible and invisible objects may trigger the same attentional process (Astle et al. 2010), making attention either shift faster within the cued object (Egly et al. 1994) or spread throughout the whole cued object, as compared with the uncued object (Richard et al. 2008; Weber et al. 1997).

The current study provides evidence for a long-standing debate whether attention and consciousness are independent (Fang and He 2005; Koch and Tsuchiya 2006, 2012; Watanabe et al. 2011). Previous studies have demonstrated that an invisible stimulus can capture attention to a spatial location (Bahrami et al. 2007; Jiang et al. 2006; Mulckhuyse et al. 2007; Zhang et al. 2012) or to a visual feature (Kanai et al. 2006; Melcher et al. 2005) for further processing. Here, we extended previous work to object-based attention: attention also can select an object even when the object is invisible to us. The ability of object-based attentional guidance by an invisible object seems to have an ecological function: some potentially important objects may be able to capture attention and undergo deeper processing before they enter consciousness. For example, a predator appearing in the peripheral visual field of a prey could trigger the prey's escape behavior even if it is not consciously aware of the predator. Object-based attention without awareness might be intrinsically related to high-level unconscious processing, including word meaning, scene gist, object category, and face emotion (Naccache et al. 2002; Li et al. 2002; Fang and He 2005; Almeida et al. 2008; Jiang and He 2006; Yang et al. 2007). A recent fMRI study (Kouider et al. 2009) has shown that

attention was necessary for unconscious face priming, providing direct evidence for this view.

It should be pointed out that, although both Chou and Yeh's study and ours demonstrated object-based attention without awareness, the neural mechanisms underlying the two phenomena might be different. Neuroimaging studies have shown that posterior parietal cortex, object-selective cortical areas in the ventral stream, as well as early visual cortex contributed to object-based attention (O'Craven et al. 1999; Muller and Kleinschmidt 2003; Shomstein and Behrmann 2006). Chou and Yeh used the CFS technique to suppress the rectangles from awareness. It is believed that CFS could block the processing of suppressed information in higher visual areas, especially in the ventral stream (Leopold and Logothetis 1996; Fang and He 2005; Almeida et al. 2008; Jiang and He 2006). Thus, posterior parietal cortex might be critical for the object-based attention in Chou and Yeh's study. In the current study, we used very weak stimuli to assure their invisibility. We believe that the weak stimuli were able to activate higher visual areas in both the dorsal and the ventral streams, although the activation magnitude could be much reduced compared to visible stimuli (Dehaene et al. 2001; Kouider et al. 2009). In the future, it is worthwhile to perform brain imaging studies to investigate the neural mechanisms of object-based attention with invisible objects.

A second finding of the current study is that object-based attention was dependent on the orientation of the rectangles presented with the target, regardless of subjects' awareness of the rectangles, which provides evidence for the dynamic updating hypothesis (Ho and Yeh 2009). After the cued object disappeared, the cued location remained operational and might be used to link to the new object (Brown and Denney 2007). The sudden onset of the new object may immediately capture attention (Enns et al. 2001; Franconeri and Simons 2003; Yantis 1993), which led to the instantaneous object effect. This finding seems to

be contradictory to Lamy and Tsal's result (2000). We believe that the similarity between the originally cued object and later changed object may account for the discrepancy. They used two similar objects (a rectangle and an hourglass), but we used orthogonal rectangles.

In conclusion, we found that the same-object effect and the instantaneous object effect could occur even when objects were not consciously perceived, suggesting that object-based attention can be guided by an invisible object in an automatic way, with a minimal influence from top-down control.

Acknowledgments This work was supported by the National Natural Science Foundation of China (Project 91024032, 30925014 and 90920012) and the Ministry of Science and Technology of China (2011CBA00405 and 2010CB833903).

References

- Abrams RA, Law MB (2000) Object-based visual attention with endogenous orienting. *Percept Psychophys* 62:818–833
- Albrecht AR, List A, Robertson LC (2008) Attentional selection and the representation of holes and objects. *J Vis* 8(13):8, 1–10
- Almeida J, Mahon BZ, Nakayama K, Caramazza A (2008) Unconscious processing dissociates along categorical lines. *Proc Natl Acad Sci USA* 105:15214–15218
- Astle DE, Nobre AC, Scerif G (2010) Subliminally presented and stored objects capture attention. *J Neurosci* 30(10):3567–3571
- Bahrami B, Lavie N, Rees G (2007) Attentional load modulates responses of human primary visual cortex to invisible stimuli. *Curr Biol* 17:509–513
- Behrmann M, Zemel R, Mozer M (1998) Object-based attention and occlusion: evidence from normal subjects and a computational model. *J Exp Psychol Hum Percept Perform* 24:1011–1036
- Brefczynski JA, DeYoe EA (1999) A physiological correlate of the "spotlight" of visual attention. *Nat Neurosci* 2:370–374
- Brown JM, Denney HI (2007) Shifting attention into and out of objects: evaluating the processes underlying the object advantage. *Percept Psychophys* 69:606–618
- Chou WL, Yeh SL (2012) Object-based attention occurs regardless of object awareness. *Psychon Bull Rev* 19(2):225–231
- Dehaene S et al (2001) Cerebral mechanisms of word masking and unconscious repetition priming. *Nat Neurosci* 4:752–758
- Egly R, Driver J, Rafal RD (1994) Shifting visual attention between objects and locations: evidence from normal and parietal lesion subjects. *J Exp Psychol Gen* 123:161–177
- Enns JT, Austen EL, Di Lollo V, Rauschenberger R, Yantis S (2001) New objects dominate luminance transients in attentional capture. *J Exp Psychol Hum Percept Perform* 27:1287–1302
- Eriksen CW, Yeh YY (1985) Allocation of attention in the visual field. *J Exp Psychol Hum Percept Perform* 5:583–597
- Fang F, He S (2005) Cortical responses to invisible objects in human dorsal and ventral pathways. *Nat Neurosci* 8(10):1380–1385
- Franconeri SL, Simons DJ (2003) Moving and looming stimuli capture attention. *Percept Psychophys* 65:999–1010
- Goldsmith M, Yeari M (2003) Modulation of object-based attention by spatial focus under endogenous and exogenous orienting. *J Exp Psychol Hum Percept Perform* 29:897–918
- Ho MC, Yeh SL (2009) Effects of instantaneous object input and past experience on object-based attention. *Acta Psychol* 132:31–39
- Jiang Y, He S (2006) Cortical responses to invisible faces: dissociating subsystems for facial-information processing. *Curr Biol* 16:2023–2029
- Jiang Y, Costello P, Fang F, Huang M, He S (2006) A gender- and sexual orientation-dependent spatial attentional effect of invisible images. *Proc Natl Acad Sci USA* 103:17048–17052
- Kanai R, Tsuchiya N, Verstraten FA (2006) The scope and limits of top-down attention in unconscious visual processing. *Curr Biol* 16:2332–2336
- Kastner S, Pinsk MA, De Weerd P, Desimone R, Ungerleider LG (1999) Increased activity in human visual cortex during directed attention in the absence of visual stimulation. *Neuron* 22:751–761
- Koch C, Tsuchiya N (2006) Attention and consciousness: two distinct brain processes. *Trends Cogn Sci* 11:16–22
- Koch C, Tsuchiya N (2012) Attention and consciousness: related yet different. *Trends Cogn Sci* 16:103–105
- Kouider S, Eger E, Dolan R, Henson RN (2009) Activity in face-responsive brain regions is modulated by invisible, attended faces: evidence from masked priming. *Cereb Cortex* 19:13–23
- Lamy D, Tsal Y (2000) Object features, object locations, and object sets: which does selective attention activate and when? *J Exp Psychol Hum Percept Perform* 26:1387–1400
- Leopold DA, Logothetis NK (1996) Activity changes in early visual cortex reflect monkeys' percepts during binocular rivalry. *Nature* 379:549–553
- Li FF, VanRullen R, Koch C, Perona P (2002) Rapid natural scene categorization in the near absence of attention. *Proc Natl Acad Sci USA* 99:9596–9601
- Liu T, Larsson J, Carrasco M (2007) Feature-based attention modulates orientation selective responses in human visual cortex. *Neuron* 55:313–323
- Marino AC, Scholl BJ (2005) The role of closure in defining the "objects" of object-based attention. *Percept Psychophys* 67:1140–1149
- Maunsell JH, Treue S (2006) Feature-based attention in visual cortex. *Trends Neurosci* 29:317–322
- McMains SA, Somers DC (2004) Multiple spotlights of attentional selection in human visual cortex. *Neuron* 42:677–686
- Melcher D, Papathomas TV, Vidnyanszky Z (2005) Implicit attentional selection of bound visual features. *Neuron* 46:723–729
- Moore CM, Fulton C (2005) The spread of attention to hidden portions of occluded surfaces. *Psychon Bull Rev* 12:301–306
- Moore CM, Yantis S, Vaughn B (1998) Object-based visual selection: evidence from perceptual completion. *Psychol Sci* 9:104–110
- Mulckhuyse M, Talsma D, Theeuwes J (2007) Grabbing attention without knowing: automatic capture of attention by subliminal spatial cues. *Vis Cogn* 15:779–788
- Muller NG, Kleinschmidt A (2003) Dynamic interaction of object- and space-based attention in retinotopic visual areas. *J Neurosci* 23:9812–9816
- Naccache L, Blandin E, Dehaene S (2002) Unconscious masked priming depends on temporal attention. *Psychol Sci* 13:416–424
- O'Craven K, Downing P, Kanwisher N (1999) fMRI evidence for objects as the units of attentional selection. *Nature* 401:584–587
- Pilz KS, Roggeveen AB, Creighton SE, Bennett PJ, Sekuler AB (2012) How prevalent is object-based attention? *PLoS ONE* 7(2):e30693
- Posner MI, Snyder CR, Davidson BJ (1980) Attention and the detection of signals. *J Exp Psychol* 109:160–174
- Pratt J, Sekuler AB (2001) The effects of occlusion and past experience on the allocation of object-based attention. *Psychon Bull Rev* 8:721–727
- Richard AM, Lee H, Vecera SP (2008) Attentional spreading in object-based attention. *J Exp Psychol Hum Percept Perform* 34:842–853
- Saenz M, Buracas GT, Boynton GM (2002) Global effects of feature-based attention in human visual cortex. *Nat Neurosci* 5:631–632
- Scholl BJ (2001) Objects and attention: the state of the art. *Cognition* 80:1–46

- Serences JT, Boynton GM (2007) Feature-based attentional modulations in the absence of direct visual stimulation. *Neuron* 55:301–312
- Shomstein S, Behrmann M (2006) Cortical systems mediating visual attention to both objects and spatial locations. *Proc Natl Acad Sci USA* 130:11387–11392
- Treue S, Martinez-Trujillo JC (1999) Feature-based attention in unattended motion processing gain in macaque visual cortex. *Nature* 399:575–579
- Tsuchiya N, Koch C (2005) Continuous flash suppression reduces negative afterimages. *Nat Neurosci* 8:1096–1101
- Vecera SP, Farah MJ (1994) Does visual attention select objects or locations? *J Exp Psychol General* 123:146–160
- Watanabe M et al (2011) Attention but not awareness modulates the BOLD signal in the human V1 during binocular suppression. *Science* 334:829–831
- Watson SE, Kramer AF (1999) Object-based visual selective attention and perceptual organization. *Percept Psychophys* 61:31–49
- Weber TA, Kramer AF, Miller GA (1997) Selective processing of superimposed objects: an electrophysiological analysis of object-based attentional selection. *Biol Psychol* 45:159–182
- Yang E, Zald DH, Blake R (2007) Fearful expressions gain preferential access to awareness during continuous flash suppression. *Emotion* 7:882–886
- Yantis S (1993) Stimulus-driven attentional capture and attentional control settings. *J Exp Psychol Hum Percept Perform* 19:676–681
- Zhang W, Luck SJ (2009) Feature-based attention modulates feedforward visual processing. *Nat Neurosci* 12:24–25
- Zhang X, Zhaoping L, Zhou T, Fang F (2012) Neural activities in V1 create a bottom-up saliency map. *Neuron* 73:183–192