Attention, Perception, & Psychophysics (2022) 84:1220–1233
https://doi.org/10.3758/s13414-022-02473-8

Can faces affect object-based attention? Evidence from online experiments

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Accepted: 6 March 2022 / Published online: 8 April 2022
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Abstract

This study tested how human faces affect object-based attention (OBA) through two online experiments in a modified double-rectangle paradigm. The results of Experiment 1 revealed that faces did not elicit the OBA effect as non-face objects, which was caused by a longer response time (RT) when attention is focused on faces relative to non-face objects. In addition, by observing faster RTs when attention was engaged horizontally rather than vertically, we found a significant horizontal attention bias, which might override the OBA effect if vertical rectangles were the only items presented; these results were replicated in Experiment 2 (using only vertical rectangles) after directly measuring horizontal bias and excluding its influence on the OBA effect. This study suggested that faces cannot elicit the same-object advantage in the double-rectangle paradigm and provided a method to measure the OBA effect free from horizontal bias.

Keywords Faces · Object-based attention · Horizontal bias · Double-rectangle paradigm

Introduction

Object-based attention (OBA) is among the selective attention mechanisms focused on an object as a unit (Duncan, 1984; Egly et al., 1994; for a review, see also Chen, 2012). When attention is attracted to one part of an object, subsequent attentional operation on this object is accelerated. The double-rectangle paradigm is widely used to assess OBA (Egly et al., 1994). In this paradigm, two rectangles are presented to participants, either horizontally or vertically. A target is presented after a cue flashes in the corner of one rectangle. The target's location depends on the experimental condition. In the valid condition, the target and the cue are displayed in the same location. In the within-object condition, the target appears in the same rectangle as the cue, but in another corner. In the between-object condition, the target appears at the near end of the uncued rectangle. The results usually reveal that the response time (RT) is faster in valid trials, supporting the well-known spatial effect (Posner et al., 1980). RTs are also faster in the within- than in the between-object trials. Furthermore, since the distance between the cue and the target is kept equal in these two conditions, the difference in RTs is evidence of the OBA effect.

Numerous studies have followed this paradigm and replicated this effect in various modified versions (Avrahami, 1999; Moore et al., 1998; Watson & Kramer, 1999). The concept of objects in OBA was extended from the original geometric rectangles to objects that perceptually obey the Gestalt law (Marrara & Moore, 2003; Moore et al., 1998), objects stored in memory (Bao et al., 2007; Woodman et al., 2003; Xie et al., 2021), and objects under the perceptual threshold (Chou & Yeh, 2012; Norman et al., 2013). Objects related more closely to real life also elicit the OBA effect, such as words grouped by Chinese characters (Li & Logan, 2008; Yuan & Fu, 2014), objects endowed with social information (Yin et al., 2018; Zhao et al., 2020), and objects presented in a real-world scene (Malcolm & Shomstein, 2015). This evidence sheds light on the heterogeneous ways that OBA phenomena could be applied in daily life.

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Can faces elicit object-based attention (OBA)?

Human faces are highly socially relevant and can be perceived automatically, in that they are especially rapid, mandatory, and capacity free (Thoma,, & Volker., 2014; for a review, see also Palermo & Rhodes, 2007). Previous research has also indicated that faces attract attention in a different way than do non-face objects (Bruce & Young, 2013). For example, faces are endowed with more attentional resources (Zhu et al., 2010), and attention is preferentially directed and engaged longer by faces (Langton et al., 2008; Theeuwes & Van der Stigchel, 2006). It is therefore interesting to ask whether faces can be selected as an attentional unit and thus affect object-based components.

In light of the above, Valenza et al. (2014) asked whether faces can modulate the OBA effect of visual attention differently than non-face objects. They adopted a modified double-rectangle paradigm, in which two rectangles were replaced by upright, inverted, and scrambled faces. An eye-tracking device was used to record cue-target saccadic latencies. The results showed that for adult participants, the OBA effect was only found in scrambled faces (i.e., non-face objects), not normal faces (both upright and inverted). The same finding was replicated in typically developing children (Valenza & Calignano, 2021). These results indicated that faces tend not to elicit the OBA effect like other objects. Song et al. (2021) reported an opposing result using the double-rectangle paradigm, in which faces elicited significant OBA effects with different gaze directions (Song et al., 2021). It thus remains controversial whether faces elicit the OBA effect in the double-rectangle paradigm.

Potential issue: Horizontal bias of attention

The studies by Valenza et al. (2014) and Song et al. (2021) presented only vertical objects (faces), which might be a methodological flaw. Although a seminal study revealed that the OBA effect was not affected by object orientation (Egly et al., 1994), several subsequent studies modified this paradigm and found that the OBA effect was only observed in horizontal objects, not in vertical ones (Al-Janabi & Greenberg, 2016; Greenberg et al., 2014; Pilz et al., 2012).

Previous studies have revealed that participants pay a higher attentional cost in crossing the horizontal meridian (Barnas & Greenberg, 2016), and those attentional operations suggest that when visual stimuli cross the horizontal meridian, they could be processed by both hemispheres, thus entailing more attentional resources (Sereno & Kosslyn, 1991). The presence of the OBA effect according to different object orientations might therefore result from attentional operation being better engaged with horizontally rather than with vertically oriented objects (Thornton et al., 2021). More direct evidence from spatial cueing paradigms also revealed that responses are generally faster when the target is located horizontally relative to the cued location rather than vertically (Barnas & Greenberg, 2016; Clevenger et al., 2019) – that is, the covert attentional shift is faster when deployed horizontally rather than vertically, leading to a horizontal bias.

In the double-rectangle paradigm, the within-object condition always corresponds to a horizontal shift of attention when the rectangles are horizontally presented. In contrast, when the rectangles are vertically presented, the within-object condition always corresponds to a vertical shift of attention. In other words, when only vertical objects are presented in the double-rectangle paradigm, the absence of the OBA effect might indicate that it is being overridden by the horizontal bias of attention rather than indicating a real absence of this effect. Thus, to rule out any potential horizontal bias, OBA studies applying the double-rectangle paradigm usually deployed both vertical and horizontal rectangles (e.g., Donovan et al., 2017; Nah et al., 2018; Yeshurun & Rashal, 2017). In short, if only rectangles oriented in one direction are used in the double-rectangle paradigm, the OBA effect might be contaminated by the horizontal bias of attention.

The present study

Given the potential influence of using only vertical objects, we attempted to replicate the findings of Valenza et al. (2014) in a more cautious design with both vertical and horizontal objects. We predicted the same finding as theirs: the OBA effect should interact with the object type. For non-face objects, the OBA effect was expected to be replicated. For faces, due to their socially significant traits, processing might require more time and further prevent the presence of the OBA effect.

Experiment 1

Experiment 1 was a replication of previous findings on the effect of faces on the OBA. Specifically, we were inspired by the study of Valenza et al. (2014), who first used the double-rectangle paradigm to address whether and how faces can affect the OBA. However, as mentioned, only vertical objects and faces were presented in their study, which might contaminate the OBA effect with a horizontal bias. To curb this, we added a horizontal orientation condition in this experiment. The non-face objects we chose were mosaic rectangles, which were expected to elicit the OBA effect. For the faces, no OBA or a smaller OBA effect was predicted.

In addition, instead of using a spatial cueing task, we adopted the dual targets comparison task (Lamy & Egeth, 2002). In this task, two sequential targets appear on the rectangles, and the first plays a role similar to that of the spatial cue to attract attention. Then the second target draws attention to the within- or between-object location. This task makes the experiment more trial-saving by excluding the valid condition.

Method

The experiment was conducted online through the JATOS platform (Lange et al., 2015). Before receiving the experimental link, the participants read a PDF file containing the task instruction and provided informed consent. In this file, they were asked to (1) turn off all irrelevant software and maintain a good internet connection; (2) set the screen resolution at 1,024 × 768 pixels or the same ratio; (3) keep their eyes in front of the screen at a distance of about 60 cm for the duration of experiment; (4) run the experiment in a quiet and undisturbed environment. An informed consent form was presented after this introduction slide. After the participants had read the form, we provided them with the experimental link and assigned a subject ID to each participant.

Participants

The sample size calculated by G*Power 3.1 (Faul et al., 2007) was 36, with the middle effect size (0.25) and a test force (1-β) of 0.9. The previous literature has shown that online experiments might feature peculiar aspects, such as non-systematic noise in terms of timing (Barnhoorn et al., 2015), distraction by unpredictable factors (Sauter et al., 2020), and fewer experimental trials restricted by duration. We therefore decided to use a larger sample size (at least 70) to override any potential problems in our study.

A total of 78 participants (aged 21 ± 2.24 years, 24 males, one left-hander) from Guangzhou University were recruited for Experiment 1, and provided with a reward of 30 Yuan (about US$4.60) per hour or course credit. All participants had normal or corrected-to-normal vision (self-reported) and were naïve to this experiment. Each participant voluntarily enrolled and read an informed consent form before the experiments. The study protocol was approved by the local institutional review board of the School of Education, Department of Psychology of Guangzhou University.

Materials and stimuli

The following parameter is based on a screen size of 33 × 18.5 cm, with a viewing distance of 60 cm. The specific size of the stimuli would vary slightly depending on the participants' screen. The stimuli consisted of rectangles that subtended 8.3° × 16.5°. The target stimuli were the uppercase letters T and L, which subtended 2° × 2° and were rendered in blue (RGB: 0, 0, 255). The fixation was a black plus sign and subtended 0.5° × 0.5°, and the error feedback was a red cross subtending 4° × 4°. The rectangle was filled with either a face or a mosaic, depending on the experimental condition. These stimuli were presented on a gray background (RGB: 100, 100, 100).

The facial stimuli were Asian faces selected from the Chicago Face Database (Ma et al., 2015). In this experiment, we selected 32 Asian faces (half of them male). The faces were trimmed with a length-width ratio of 2:1. Two faces form a combination, as shown in Fig. 1, with four possible orientations. The horizontally presented faces were rotated 90° or 270° from the upright faces without being stretched.

The mosaic, which lost any facial information, was created by crystallizing the face images in Photoshop. Stimulus presentation and manual response measurements were controlled by Open Sesame software (Mathôt et al., 2012).

Design and procedure

Experiment 1 was a 2 (objecthood: between- vs. within-object condition) × 2 (object type: mosaic vs. face) within-subject design. The within-object condition was when two targets appeared in the same object, while the between-object condition was when the two targets appeared in different objects. Two targets never appeared diagonally. The object type depended on the rectangle's content – that is, for the mosaic condition, the rectangle was filled with the mosaic, and the rectangle contained a face for the face condition.

The task was to judge whether the two targets were the same or not by pressing the F or J keys on the keyboard, which were counterbalanced between the participants. Participants were told to maintain their visual attention on the fixation during the experiment and respond quickly and correctly.

Two object orientations (horizontal vs. vertical), two response types (same vs. different), and four locations of the first target (up-left, down-left, up-right, down-right) were also kept equal and intermixed throughout the whole experiment. Experiment 1 consisted of 128 trials overall (32 trials of the within-object condition in faces, 32 trials of the between-object condition in faces, 32 trials of the within-object condition in mosaic, 32 trials of the between-object condition in mosaic). All 128 trials were subdivided into two blocks in the formal test, with a self-terminal break between them. Before the formal test, participants had to pass a practice session that required them to make at least eight correct responses in a row. The whole experiment lasted approximately 10 min.

The sequence of events in each trial is shown in Fig. 1. Each trial began with a 500-ms fixation followed by a 1,000-ms object presentation. Then, two targets appeared sequentially with a stimulus onset asynchrony (SOA) of 300 ms. The two targets and objects were maintained on the screen for 2,000 ms or until response. If the wrong response or a non-response was detected, the error feedback would be provided for 500 ms (both in the practice session and in the formal test). The trial ended with another 500-ms fixation.

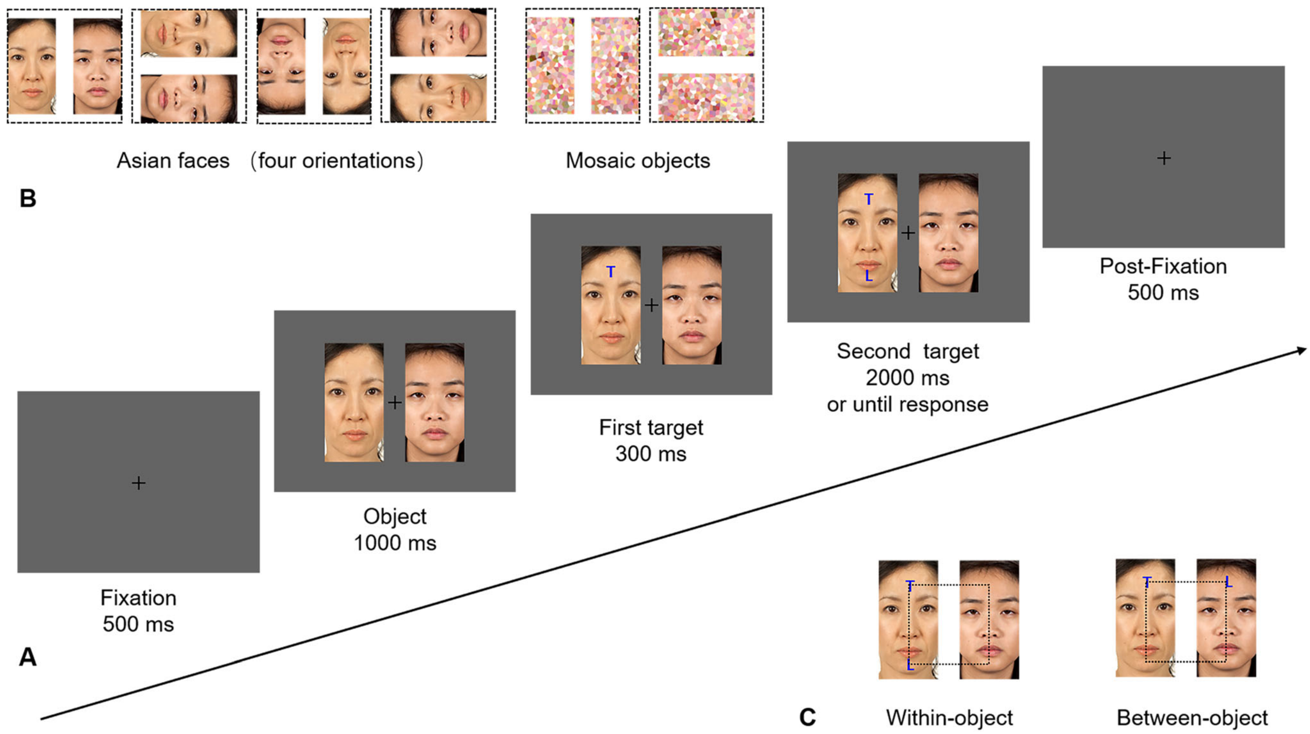

Fig. 1 **Panel** A illustrates the procedure for each trial. Panel B displays examples of facial and mosaic objects with different orientations. Two faces or mosaics are displayed inside a square. Panel C displays examples of the within- and between-object conditions. The targets appear at two vertexes of a square. The dashed line is for presentation and did not show in the experiment. The faces are reproduced with permission from the Chicago Face Database

Results and analyses

Two participants were excluded because their experimental duration exceeded 20 min. Six participants were excluded because their accuracy was lower than 85%. Therefore, only 70 participants were included in the analysis. Overall, incorrect responses (5.5%), trials with RTs faster than 150 ms or slower than 1,000 ms (4.7%), and trials with RTs outside 2 standard deviations (SDs) (4.5%) were discarded. Therefore, 85.3% of the total trials were included in the statistical model. Only RT analyses were used here because no significant results appeared in the accuracy (ACC) analyses. The primary ACC data and analyses are provided in the Appendix. No indication of a speed-accuracy trade-off was found. The RT results of Experiment 1 are shown in Fig. 2.

Simon effect

The experiment was unsupervised and our experimental design made it impossible to test for the presence of the spatial cueing effect. Therefore, we ascertained data quality by testing for the presence of the Simon effect (Lu & Proctor, 1995; Simon & Rudell, 1967), a robust psychological effect manifested by a slower response when the target appears on the other side of the response button, compared to appearing on the same side.

A 2 × 2 repeated-measures ANOVA was conducted on the RTs, with the target side (left vs. right) and the response side (left vs. right) as within-subject factors. The main effect of the response side was not significant, $F(1,69) = 0.507$, $p = .479$, $\eta_p^2 = .007$. The main effect of the target side was significant, $F(1,69) = 5.55$, $p = .021$, $\eta_p^2 = .074$, with shorter RTs when the second target appeared on the right (597 ± 9 ms) than on the left side (604 ± 10 ms). The interaction was significant, $F(1,69) = 5.91$, $p = .018$, $\eta_p^2 = .079$. RTs were shorter when the target side and the response side were consistent, indicating the presence of the Simon effect.

OBA effect

A 2 × 2 repeated-measures ANOVA was conducted on RTs, with the objecthood (within- vs. between-object) and object type (face vs. mosaic) as within-subject factors. The main effect of the objecthood (OBA) and the object type were not significant, $F(1,69) = 0.652$, $p = .422$, $\eta_p^2 = .009$, and $F(1,69) = 2.18$, $p = .144$, $\eta_p^2 = .031$, respectively. However, the interaction was significant, $F(1,69) = 28.45$, $p < .001$, $\eta_p^2 = .290$. The post hoc test with Holm correction revealed that, in the facial object, there was no difference between the within- (603 ± 10 ms) and between-object conditions (593 ± 9 ms), $t(69) = 1.76$, $p = .244$. By contrast, in the mosaic object, RTs were shorter in the within- (593 ± 10 ms) than in the between-object

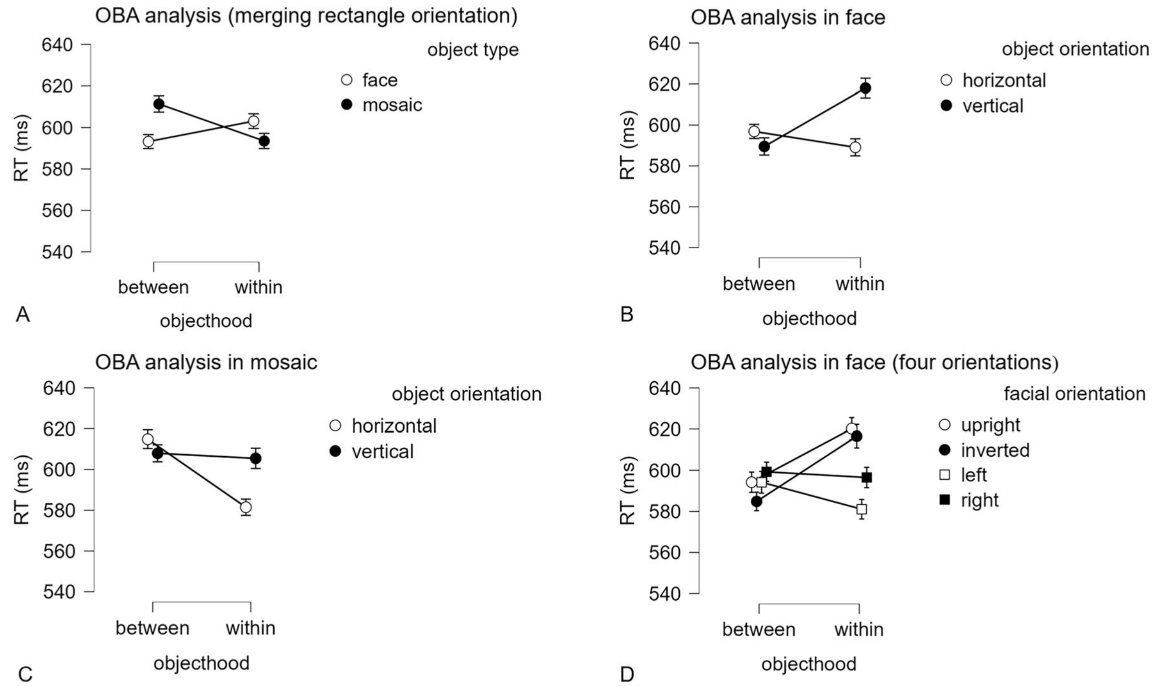

Fig. 2 Descriptive results from Experiment 1 are shown in the line chart. Panel A displays the object-based attention (OBA) analysis when the object orientation was merged. Panels B and C display the OBA analysis for facial and mosaic objects, respectively. Panel D displays the OBA analysis for the facial object, with facial orientation as a factor. The error bar is the standard error

condition (611 ± 9 ms), $t(69) = -3.19$, $p = .009$, providing evidence for the presence of the OBA effect.

OBA effect affected by object orientation

A 2 × 2 × 2 repeated-measures ANOVA was conducted on the RTs, with the objecthood (within- vs. between-object condition), object type (face vs. mosaic), and object orientation (horizontal vs. vertical) as within-subject factors. The main effect of the object orientation was significant, $F(1,69) = 15.39$, $p < .001$, $\eta_p^2 = .180$, with shorter RTs in horizontally presented rectangles (596 ± 10 ms) than vertical rectangles (606 ± 10 ms). The interaction between the object type and the objecthood was significant, $F(1,69) = 29.98$, $p < .001$, $\eta_p^2 = .300$. The interaction between the objecthood and the object orientation was significant, $F(1,69) = 33.95$, $p < .001$, $\eta_p^2 = .330$. None of the other main effects or interactions were significant. The post hoc test combined with the object type revealed that when the rectangles were horizontally presented, RTs were faster in the within- than in the between-object condition, $t(69) = -3.58$, $p = .003$, which indicates an OBA effect. When the rectangles were vertically presented, RTs were marginally faster in the between- than in the within-object condition, $t(69) = -2.26$, $p = .077$. This interaction suggested that the orientation of the rectangles had a huge impact on the OBA effect.

In addition, there were four facial orientations (upright, inverted, left-oriented, and right-oriented) in Experiment 1 and we merged them into two conditions (horizontal and vertical). Hence, the results did not provide information about the effect of facial orientation on the OBA effect. Accordingly, another 4 × 2 repeated-measures ANOVA (facial orientation: upright vs. inverted vs. left-oriented vs. right-oriented; objecthood: within- vs. between-object) for the facial object was conducted. The main effect of the objecthood was marginally significant. RTs in the between-object condition (591 ± 10 ms) were shorter than the within-object condition (600 ± 11 ms), $F(1, 69) = 3.85$, $p = .054$, $\eta_p^2 = .053$, showing an inverse OBA effect. The main effect of the facial orientation was significant, $F(3, 207) = 6.46$, $p < .001$, $\eta_p^2 = .086$. The post hoc test showed that RTs in the left-oriented face (588 ± 10 ms) were shorter than in the upright face (598 ± 10 ms), $t(69) = -4.32$, $p < .001$, and the inverted face (601 ± 11 ms), $t(69) = -2.88$, $p = .022$. Other p-values were not significant between each of the two facial orientations. The interaction was significant, $F(3, 207) = 12.15$, $p < .001$, $\eta_p^2 = .150$. Post hoc tests revealed that the OBA effects were inversed in the upright face [−26 ms, $t(69) = -3.42$, $p = .017$] and inverted face [−32 ms, $t(69) = -4.17$, $p = .001$]. The OBA effects were absent in the left-oriented [13 ms, $t(69) = 1.73$, $p = 1.00$] and right-oriented faces [2 ms, $t(69) = 0.36$, $p = 1.00$].

The three-way repeated-measures ANOVA clearly showed the influence of the object orientation on the OBA effect. To further test whether facial orientation affects the OBA effect, we conducted another two 2 × 2 repeated-measures ANOVAs (within- vs. between-object condition, facial orientation: upright/left-oriented vs. inverted/right-oriented) for horizontal and vertical faces, respectively. For vertical faces, there was no significant interaction, $F(1,69) = 0.57$, $p = .453$, $\eta_p^2 = .008$, which suggests that upright or inverted faces did not affect the OBA effect. For vertical faces, the interaction was also not significant, $F(1,69) = 1.18$, $p = .280$, $\eta_p^2 = .017$, which suggests that left- or right-oriented faces did not affect the OBA effect.

In summary, the object orientations interacted with the OBA effect. However, a facial orientation sharing the same object orientation (i.e., upright and inverted faces in vertical rectangles or left- and right-oriented faces in horizontal rectangles) did not affect the OBA effect.

Discussion

The presence of the Simon effect suggested that the online procedure used in the first experiment was methodologically sound, and the data quality was reliable. Specifically, we observed a significant OBA effect only in the mosaic objects but not with regards to the faces. This finding was in line with the finding (Valenza et al., 2014) that human faces do not elicit the OBA effect. Moreover, the interaction between the OBA effect and the object orientation indicated that the ability to shift attention within an object was subject to the object orientation. Thus, the mere use of vertical rectangles might bias the OBA effect. Nevertheless, even under the mixed-orientation rectangle condition, we still replicated the finding that human faces do not elicit the OBA effect in the double-rectangle paradigm.

However, the horizontally presented faces might be methodologically suboptimal given the low ecological validity. Indeed, we are less likely to see horizontally presented faces in the real world. Thus, the horizontally presented faces in this experiment could be problematic, because participants might not perceive these faces as "real" faces but as something else. In other words, the facial stimuli adopted in Experiment 1 might not represent human faces well. In light of this, only vertically presented faces were used in Experiment 2 to avoid any potential influence of horizontally oriented faces.

Experiment 2

In Experiment 2, only vertical rectangles (both facial and mosaic) were used. However, this would bring about the influence of horizontal bias, as mentioned in the *Introduction*. To exclude this influence, we introduced a baseline condition to test horizontal bias, which resulted in a faster shifting of attention from the left to the right side (and vice versa) than from the bottom to the top (and vice versa) of the visual field. Therefore, in line with previous findings (Al-Janabi & Greenberg, 2016; Chen & Cave, 2019), we should expect this bias to affect the magnitude of the OBA and, consequently, use this knowledge to correct for it.

Method

Participants

Seventy-five participants (aged 21.3 ± 2.2 years, 22 males, one left-hander) from Guangzhou University were recruited for Experiment 2, with a reward of 30 Yuan (about US$4.60) per hour or course credit. All participants had normal or corrected-to-normal vision (self-reported) and were naïve to this experiment. Each participant voluntarily enrolled and read an informed consent form before the experiment.

Design and procedure

Experiment 2 introduced 64 trials of the baseline condition, in which no object would appear. In other words, the two targets appeared in the background under this condition. The baseline condition was randomly intermixed with other conditions. In addition, only vertical rectangles were adopted. Thus, Experiment 2 consisted of 192 trials (64 trials of baseline condition, 32 trials for the within-object condition with faces, 32 trials for the between-object condition with faces, 32 trials for the within-object condition with the mosaic, and 32 trials for the between-object condition with the mosaic). The whole duration of the experiment lasted about 12 min.

Results and analyses

Two participants were excluded because their experimental duration exceeded 20 min. One participant was excluded because her RTs were extremely low, so that no RTs survived after the data trimming under some conditions. Therefore, only 72 participants were included in the analyses. Overall, incorrect responses (5.1%), trials with RTs faster than 150 ms or slower than 1,000 ms (3.5%), and trials with an RT outside 2 SDs (4.8%) were discarded. Therefore, 86.6% of the total trials were included in the statistical model. Only the RT analyses were reported here; the primary ACC data and analyses are provided in the Appendix. The RT results of Experiment 2 are shown in Fig. 3.

Simon effect

A 2 × 2 repeated-measures ANOVA was conducted on the RTs, with the target side (left vs. right) and the response side (left vs. right) as within-subject factors. The main effect of the response side and the target side was not significant, $F(1, 71) = 0.21$, $p = .651$, $\eta_p^2 = .003$, and $F(1, 71) = 0.17$, $p = .679$, $\eta_p^2 = .002$ respectively. The interaction was significant, $F(1, 71) = 4.61$, $p = .035$, $\eta_p^2 = .061$. RTs were shorter when the target side and the response side were consistent, indicating the presence of the Simon effect.

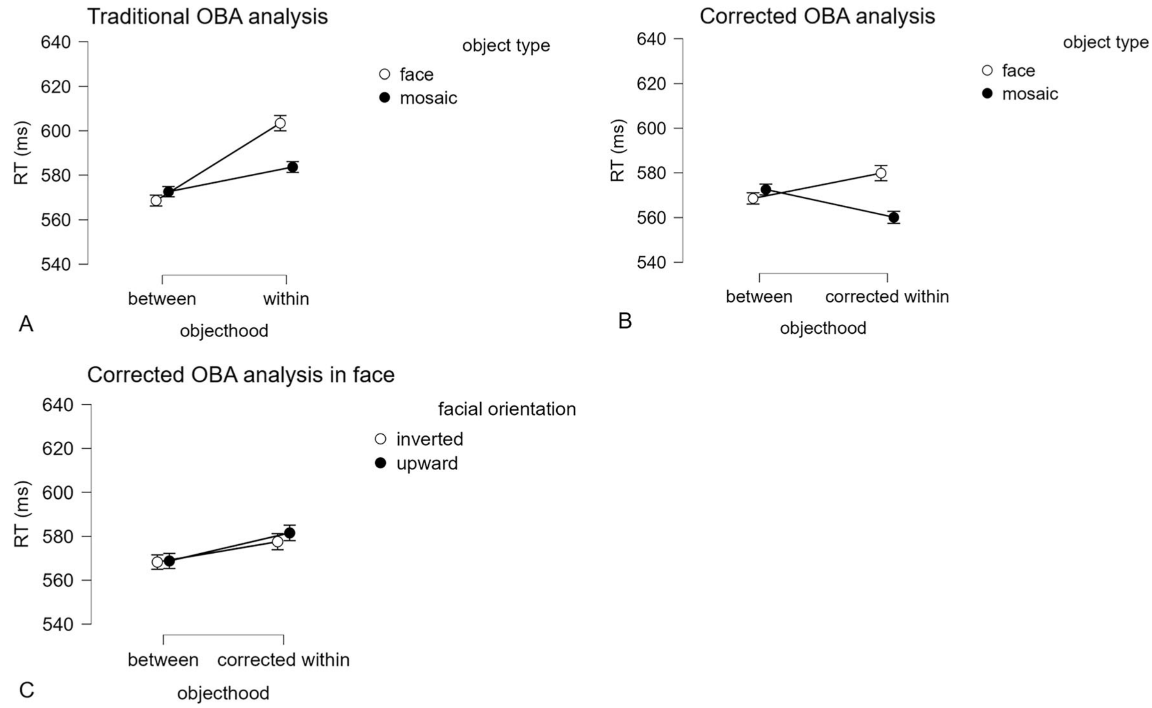

Fig. 3 Descriptive results from Experiment 2 are shown in the line chart. Panel A displays the traditional object-based attention (OBA) analysis, which shows an inverse OBA effect for facial and mosaic objects. Panel B displays the corrected OBA analysis, which shows the OBA effect for the mosaic objects but the inverse OBA effect for the facial objects. Panel C displays the corrected OBA analysis for the facial object, with facial orientation as a factor. The error bar is the standard error

Traditional OBA

A 2 × 2 repeated-measures ANOVA was conducted on the RTs, with the objecthood (within- vs. between-object condition) and the object type (face vs. mosaic) as within-subject factors. The main effect of the objecthood was significant, $F(1,71) = 51.02$, $p < .001$, $\eta_p^2 = .418$, with shorter RTs in the between- (569 ± 13 ms) than in the within-object condition (592 ± 14 ms), showing an inverse OBA effect. The main effect of the object type was significant $F(1,71) = 12.22$, $p < .001$, $\eta_p^2 = .147$, with shorter RTs for the mosaic object (577 ± 13 ms) than for the facial object (584 ± 14 ms). The interaction was significant, $F(1,71) = 21.78$, $p < .001$, $\eta_p^2 = .235$. The post hoc test revealed that, for the facial object, RTs were shorter in the between- (567 ± 13 ms) than the within-object condition (603 ± 10 ms), $t(71) = -8.50$, $p < .001$. For the mosaic object, RTs were shorter in the between-object (573 ± 8 ms) than the within-object condition (583 ± 9 ms), $t(71) = -2.71$, $p = .015$. This interaction suggested that the inverse OBA effect was larger for the facial object.

Horizontal attention bias

The horizontal bias was calculated in the baseline condition, which was divided into two attentional direction conditions: horizontal (i.e., two horizontally presented targets) and vertical (i.e., two vertically presented targets). A one-way repeated-measures ANOVA was conducted on the RTs, with the attentional direction (horizontal vs. vertical) as the within-subject factor. The main effect was significant, $F(1,71) = 48.55$, $p < .001$, $\eta_p^2 = .406$, with faster RTs for the horizontal direction (597 ± 9 ms) than for the vertical direction (621 ± 10 ms), showing a horizontal bias.

Corrected OBA analyses

The only difference between the corrected OBA and traditional OBA is that we used a baseline correction for the within-object condition instead of the traditional method. The corrected within-object condition was defined as the RT of the within-object condition minus the horizontal bias. We then compared the between- and corrected within-object conditions.

A 2 × 2 repeated-measures ANOVA was conducted on the RTs, with the objecthood (corrected within-object vs. between-object condition) and the object type (face vs. mosaic) as within-subject factors. The main effect of the objecthood was not significant, $F(1,71) = 0.026$, $p = .873$, $\eta_p^2 < .001$, indicating no OBA main effect. The main effect of the object type was significant, $F(1,71) = 12.22$, $p < .001$, $\eta_p^2 = .147$, with shorter RTs in the mosaic object (566 ± 8 ms) than the facial object (574 ± 8 ms). The interaction was significant, $F(1,71) = 21.78$, $p < .001$, $\eta_p^2 = .235$. The post hoc test revealed that in the facial object, RTs were shorter in the between- (569 ± 8 ms) than the corrected within-object condition (580 ± 9 ms), $t(71) = -2.76$, $p = .034$, showing an inverse OBA effect. In the mosaic object, RTs were shorter in the corrected within- (560 ± 8 ms) than in the between-object condition (573 ± 8 ms), $t(71) = -5.81$, $p < .001$, showing an OBA effect.

In addition, for the facial object, a 2 × 2 repeated-measures ANOVA was conducted on the RTs, with the objecthood (corrected within-object vs. between-object) and facial orientation (upright vs. inverted) as within-subject factors. The main effect of the facial orientation was not significant, $F(1,71) = 0.629$, $p = .431$, $\eta_p^2 = .009$. The main effect of the objecthood was significant, $F(1,71) = 5.54$, $p = .021$, $\eta_p^2 = .072$, showing an inverse OBA effect. There was no significant interaction, $F(1,71) = 0.477$, $p = .492$, $\eta_p^2 = .007$. These results indicate that upright or inverted faces did not affect the corrected OBA effect.

Discussion

The traditional OBA analysis showed an inverse OBA effect in facial and mosaic objects. These results were in line with studies that did not observe the OBA effect in vertically presented rectangles (Greenberg et al., 2014; Pilz et al., 2012). By comparing the attentional direction in the baseline condition, we found a 24-ms horizontal bias of attention, which explains the absence of the OBA effect in the traditional analysis.

After the OBA effect was corrected, the finding of Experiment 1 was replicated: faces did not elicit the expected OBA effect, based on faster RTs in the between- than in the corrected within-object conditions. We still found, however, that mosaic objects did elicit the expected OBA effect. This finding also revealed how the horizontal bias overrides the OBA effect if the double-rectangle paradigm only presents rectangles oriented in a single direction. Furthermore, as in the results of Experiment 1, upright or inverted faces did not influence the OBA effect, which was consistent with the results of Valenza et al. (2014).

General discussion

The purpose of this research was to understand whether human faces could elicit the OBA effect. Accordingly, we replaced the rectangles with faces in the double-rectangle paradigm to test how the faces affect attention compared to non-face objects (mosaic objects).

In two experiments, we observed the classic OBA effect for mosaic objects but not for faces (even showing a reverse pattern of OBA in Experiment 2). These results indicate that, although faces were presented in the rectangle framework, their peculiarity as socially relevant perceptual units prevents them from eliciting the OBA effect as non-face objects do.

We also found a horizontal bias of attention – that is, there was a faster attentional shift horizontally than vertically. Thus, the use of only vertical objects in the double-rectangle paradigm may be problematic because this bias might override the OBA effect. Consequently, in Experiment 2, we introduced a baseline condition aimed explicitly at ruling out the influence of horizontal bias. In this case, the double-rectangle paradigm could be adopted for those studies that contain only vertically presented objects.

What contributes to the absence of the OBA effect in faces?

The results of our study suggest that mosaic objects could elicit the OBA effect in the double-rectangle paradigm, but faces could not. Finding the OBA for mosaic objects is not novel, as this effect has been consistently reported (Egly et al., 1994; Lamy & Egeth, 2002; Shomstein & Behrmann, 2008); what is interesting, however, is why the OBA effect was absent in faces.

Song et al. (2021) reported the OBA effect in faces, but this result might be due to an essential detail in the design. In their study, the two faces belonged to the same person in the double-rectangle paradigm. Note that the repeated presentation of the same face could lead to this face being seen less like a face – that is, when the same pairs of faces are presented repeatedly, the social information contained in the faces might be weakened due to fatigue or adaptation (Webster & MacLeod, 2011). Therefore, the face in their study may eventually become more like a non-face object after several trials of repetition, which then resulted in the significant OBA effect. In addition, Song et al. (2021) focused on the role of gaze direction and did not include a non-face object for comparison. For this reason, that study did not fully explore how faces affect the OBA effect compared with non-face objects. To address this issue, we put forward three possibilities that might result in the absence of OBA for faces: (1) the acceleration of response in the between-object condition, (2) the deceleration of response in the within-object condition, or (3) both the acceleration and the deceleration in between- and within-object conditions, respectively.

According to Valenza et al. (2014), the absence of the OBA effect in faces can be explained by the different attentional focus when seeing different objects. Faces are special objects endowed with high social information; thus, they imply a processing advantage over other objects (Palermo & Rhodes, 2007). The focus of attention would be enlarged when viewing faces, leading to the same cost in the within- and the between-object conditions. In contrast, when viewing non-face objects, the focus of attention might be narrow, leading to a higher cost in the between-object condition (Valenza et al., 2014). Accordingly, the absence of the OBA effect should be due to the acceleration of response in the between-object condition. That is, RTs in the between-object condition should be faster for faces than for mosaic objects. However, our data did not support this assumption. In both experiments, RTs showed no difference for faces and mosaic objects for the between-object condition.

In contrast, in the within-object or corrected within-object conditions, RTs for faces were slower than for mosaic objects: the absence of the OBA effect in faces resulted from the deceleration of the response in the within-object condition rather than the acceleration of the response in the between-object condition. This supposition also aligned with the descriptive data of Valenza et al. (2014): in the within-object condition, the saccade latencies were longer in normal faces than in scrambled faces. We therefore proposed another explanation for the absence of the OBA effect in faces: shifting attention within a face takes longer than for non-face objects. In other words, when looking at faces, the attention would dwell longer on the faces than on non-face objects.

Why the OBA effect is absent in faces

Combined with the previous finding that faces have the advantage of being detected (Eger et al., 2003; Pegna et al., 2004) and require fewer resources to process (Hershler & Hochstein, 2005; Reddy et al., 2004), our findings indicate that faces might lead to a longer retained attention. Perhaps because facial expressions might contain signals that are important for life (Ekman, 1993; Posamentier & Abdi, 2003), it takes more time to process faces more thoroughly than other objects. These special social features of faces might result in the absence of the OBA effect.

Another potential explanation for the attention dwelling longer on faces is the filtering cost incurred when two distinct perceptual units compete for attention (Kahneman et al., 1983; Treisman et al., 1983). In line with this, Chen (2000) found that participants' RTs for comparing the height of two target vertices were positively correlated with the number of intervening distractors. Resultantly, the filtering cost could be object-based. A more relevant study by Chen et al. (2020) manipulated the region complexity between two targets in a modified version of the double-rectangle paradigm and found that the cost in RTs was observed when the region between the two targets was more complex. This result indicated that region complexity played an essential role in the OBA effect (Chen et al., 2020). A more complex region between two relevant locations might result in a higher filtering cost and, consequently, contribute to longer RTs in the within-object condition.

This object-based filtering cost could explain our results. In the face condition, the region between two targets was more complex in the within-object condition than in the between-object condition, because there was a face between the two targets in the same face (within-object) but no face between the two targets for two faces (between-object). This might lead to a higher filtering cost in the within-object condition and further result in the absence of the OBA effect in faces. In contrast, in the mosaic condition, the difference in region complexity between the within- and between-object conditions was less pronounced than in the face condition, and the equal filtering cost could not reverse the OBA effect. This possibility was also supported by the longer within-object condition RTs in the face condition than in the mosaic condition and by the same pattern of OBA effects in the upright and inverted faces.

However, the same pattern of OBA effect in the upright and inverted faces seems to contradict the extensive literature that inverted faces have different effects on attention than upright faces (see Tim,, & Valentine., 1988, for a review). This raises the question of why facial orientation in our study did not influence the OBA effect. Regarding this issue, we propose three possible explanations. First, although inverted faces do have a different effect on attention than upright faces, numerous studies suggested that inverted faces are not processed qualitatively differently from upright faces (Murphy et al., 2020; Richler et al., 2011; Sekuler et al., 2004; Willenbockel et al., 2010). Furthermore, studies suggested that eyes play a special role in face processing (Itier et al., 2006; Itier et al., 2007), and given that both upright and inverted faces have eyes on them, their effects on attention may be similar. This evidence suggested that the nature of processing upright and inverted faces might not differ intrinsically. For this reason, the upright and inverted face might have little impact on the OBA effect. Second, studies that compared the effects of upright and inverted faces on attention usually adopted recognition tasks, which meant that the faces in those studies are task-relevant. In contrast, the faces in our study were irrelevant to the task. When facial information is not relevant to the task, no significant differences were found when searching for an inverted or upright face in an array of images (VanRullen, 2006). In this situation, the influence of upright and inverted faces on attention might be less pronounced. Third, the study by Valenza et al. (2014) showed that for adult subjects, the OBA effect was independent of facial orientation (upright and inverted). However, for infant subjects, the OBA effect was only observed in inverted faces, not in upright faces. Valenza et al. (2014) explained these results as the experience acquired by the viewer, that is, infants have less chance to view inverted faces, so the inverted face is more like a non-face object for them. However, adults treat inverted faces as faces because they can view the face with different poses in life, allowing them to identify the inverted face as a face. Therefore, the familiarity with inverted faces might result in it affecting OBA like upright faces. Nevertheless, these are only possible explanations, and our current results could not provide a direct conclusion for this issue. Probably, one or several of these possibilities result in the same OBA pattern in inverted and upright faces. To resolve this issue more thoroughly, further empirical research is required.

In addition, our study concluded that faces could not elicit the OBA effect; however, this conclusion should be expressed more specifically, in that faces are incapable of eliciting a same-object advantage in the double-rectangle paradigm. Several neuroimaging studies have found evidence that attention could select the face as a processing unit like other objects such as houses in the overlapping stimuli paradigm (Baldauf & Desimone, 2014; O'Craven et al., 1999; Serences et al., 2004; Yantis & Serences, 2003). Moreover, Curby et al. (2013, 2016) physically misaligned the backgrounds of the face in a modified composite-face paradigm. This manipulation disrupted the cohesiveness of the face as a unit of selection. It was found that this allowed attention to more effectively target the task-relevant part compared to when the backgrounds of the face were aligned (Curby et al., 2013; Curby et al., 2016). These studies also suggest that attention selects the face as a unit, or faces can elicit OBA.

However, these results do not necessarily contradict our findings, given that the paradigm and the definition of the OBA effect differed. The OBA effect is the response advantage in the overlapping stimuli paradigm when the task-relevant features belong to the same object. As such, the composite-face paradigm measures the OBA effect with the idea that disrupting holistic face perception would facilitate the response to task-relevant features on faces. In contrast, the OBA effect in the double-rectangle paradigm is the response advantage when the target appears in the within-object over the between-object condition. The absence of the OBA effect in the rectangle filled with a face did not preclude that the face could be selected as an attentional unit. Rather, our results showed that RTs were longer for faces than for mosaic objects for the corrected within-object condition. This indicated that the response to the target is disturbed when it appears on the face, suggesting that the face is processed as a unit. Nevertheless, the absence of the OBA effect in faces was limited only to the double-rectangle paradigm.

In sum, we proposed that in the double-rectangle paradigm, the region complexity of the face and its special social features contribute to the absence of the OBA effect in faces.

The influence of horizontal attention bias on the OBA effect

In line with previous studies (Al-Janabi & Greenberg, 2016; Chen & Cave, 2019; Pilz et al., 2012), we only observed the OBA effect in horizontally presented rectangles. Meanwhile, the horizontal bias in the baseline condition directly reflects the benefit when attention shifts horizontally. This orientation preference typically revolves around the idea that horizontal stimuli may be more prevalent and relevant in our visual world (Pilz et al., 2020; Rottach et al., 1996)

The OBA effect in the double-rectangle paradigm might be overridden if only vertical objects were used. Therefore, it is not certain whether the OBA effect is absent or hidden in vertically presented objects. However, due to the particularity of some objects we used (i.e., faces), their horizontal presentation might not be reasonable. Under this limitation, we introduced a solution for the double-rectangle paradigm with only vertical objects. In the same experiment, the horizontal bias was measured in the baseline condition. The OBA effect was then corrected by subtracting the horizontal bias in the within-object condition. In this case, the imbalance of the attentional set in different orientations was counteracted, and the corrected OBA effect should be free from the contamination of horizontal bias.

Importantly, horizontal bias may not always override the OBA effect in vertical objects. Chen and Cave (2019) suggested that the horizontal bias of attention would be subject to an attentional zoom that depends on the task. In the spatial cueing task, the target is more likely to appear at the cued location, encouraging participants to set a small attentional zoom. In the two-target comparison task, participants tend to deploy a broad attentional zoom, because the two targets appear at one of two sets of locations (within- and between-object conditions) with equal possibility (Chen & Cave, 2019). The horizontal bias therefore overrides the OBA effect in the double-rectangle paradigm, which might only be triggered when the attentional zoom is broad.

The spatial nature of the baseline condition (no objects) may make it less appropriate to correct the OBA effect. This correction of the OBA effect was made by assuming that the horizontal bias is the same when measured during spatial versus object-based mechanisms. Thus, we supplemented an analysis in Experiment 1, using the within-object shifts during vertical rectangles minus that during horizontal rectangles as the indicator for the horizontal bias in the object-based mechanism. This horizontal bias was calculated by merging the face and mosaic conditions and correcting the OBA in vertical rectangles.

The results showed that this horizontal bias (27 ms) was significant, $F(1,69) = 34.0$, $p < .001$, $\eta_p^2 = .330$. For vertical faces, RTs did not differ between the corrected within-object condition (591 ± 9 ms) and the between-object condition (590 ± 9 ms), $F(1,69) = 0.081$, $p = .776$, $\eta_p^2 = .001$, showing no OBA effect. For vertical mosaic objects, RTs in the corrected within-object condition (567 ± 9 ms) were shorter than in the between-object condition (611 ± 9 ms), $F(1,69) = 38.54$, $p < .001$, $\eta_p^2 = .358$, showing a significant OBA effect. In addition, an independent samples t-test was conducted on the horizontal bias in two experiments (Experiment 1 was calculated in the object-based mechanism, Experiment 2 was calculated in the baseline condition). The results showed no difference, $t(140) = 0.56$, $p = .577$; this suggested that when the horizontal bias was calculated during the object-based mechanism, its influence on the OBA effect was similar to that calculated in space.

In short, this study introduced a method to measure the OBA effect in the double-rectangle paradigm with only vertical objects. Likewise, the OBA effect in horizontal objects could be corrected similarly. Thus, our solution might be helpful in OBA studies that contain single orientation objects in the double-rectangle paradigm.

Potential limitations of the online experiment

Due to the COVID-19 pandemic, we exploited the possibility of collecting online data, and some potential issues should be noted (see also the overview of online experiments; Grootswagers, 2020; Sauter et al., 2020). First, for cognitive attentional experiments, the experimental environment is often very demanding. We informed the participants of the requirements of the experimental environment before starting the experiment, but we could not guarantee and know whether they met the requirements. To minimize this influence, we adopted a rigid criterion to exclude participants (experimental duration over 20 min or an accuracy lower than 85%), and trimmed data more strictly (only RTs lower than 1,000 ms and within 2 SDs were analyzed).

Second, since different participants had different devices, their screen sizes and reflash rates would vary. Our experiment did not require high timing precision to present stimuli, so the influence of the reflash rate was negligible. However, the screen size would directly affect the size of the stimuli, in that the stimulus size was not precisely the same, although we required participants to maintain the same distance in front of the screen. To minimize this influence, we required participants to adjust their screen resolution before the experiment so that the stimuli ratio would remain equal.

Third, the online experiment constrained the experimental duration. The trials of each critical condition were thus limited to only 16 (taking Experiment 1, e.g., 128 total trails / 2 object type / 2 objecthood / 2 object orientation). Further laboratory replication with a higher number of trials for each condition is needed to reinforce our conclusion.

Even so, our data quality should be reliable for the following reasons: (1) We replicated the Simon effect, indicating that the participants were seriously experimenting. (2) The duration of the experiments was short (about 10 min), so it was less likely for the participants to become bored or weary. (3) Although this was an online experiment, the recruitment was not anonymous; we contacted each participant before and after the experiment to instruct them and request feedback, which could significantly increase the data quality and reduce the dropout rate (Zhou & Fishbach, 2016). Thus, although our study might not be as precise as a laboratory experiment, our data should still be considered valid.

Conclusion

This study drew two main conclusions: First, we found that human faces did not elicit the same-object advantage in the double-rectangle paradigm because the attention dwelled longer on faces. Second, we revealed that the horizontal bias of attention was non-negligible in the double-rectangle paradigm. We also introduced a horizontal bias-free method to analyze the corrected OBA effect.

Appendix

Accuracy data and analyses of experiment 1

The ACC was 94.8 ± 4.7% in the left–left (response side–target side) condition, 94.7 ± 5.4% in the left–right condition, 94.3 ± 5.7% in the right–left condition, and 94.3 ± 5.4% in the right–right condition.

A 2 × 2 ANOVA was conducted on the ACC, with the target side (left vs. right) and the response side (left vs. right) as within-subject factors. The main effects of the response side and the target side were not significant, $F(1,69) = 0.608$, $p = .438$, $\eta_p^2 = .009$, and $F(1,69) <. 001$, $p = 1.000$, $\eta_p^2 < .001$, respectively. The interaction was also not significant, $F(1,69) = 0.007$, $p = .936$, $\eta_p^2 < .001$.

The ACC was 94.6 ± 5.0% in the face–between condition, 94.9 ± 4.9% in the face–within condition, 94.0 ± 5.0% in the mosaic–between condition, and 94.7 ± 4.7% in the mosaic–within condition.

A 2 × 2 ANOVA was conducted on the ACC, with the objecthood (within- vs. between-object) and object type (face vs. mosaic) as within-subject factors. The main effects of the objecthood (OBA) and the object type were not significant, $F(1,69) = 0.182$, $p = .371$, $\eta_p^2 = .012$, and $F(1,69) = 0.95$, $p = .333$, $\eta_p^2 = .014$, respectively. The interaction was also not significant, $F(1,69) = 0.124$, $p = .726$, $\eta_p^2 = .002$.

Accuracy data and analyses of experiment 2

The ACC was 95.6 ± 4.0% in the left–left (response side–target side) condition, 94.5 ± 4.3% in the left–right condition, 94.5 ± 4.4% in the right–left condition, and 94.9 ± 5.1% in the right–right condition.

A 2 × 2 ANOVA was conducted on the ACC, with the target side (left vs. right) and the response side (left vs. right) as within-subject factors. The main effects of the response side and the target side were not significant, $F(1, 71) = 0.534$, $p = .467$, $\eta_p^2 = .007$, and $F(1, 71) = 0.524$, $p = .472$, $\eta_p^2 = .007$, respectively. The interaction was marginally significant, $F(1,$

71) = 3.57, p = .063, η_p^2 = .048, showing a trend of the Simon effect.

The ACC was 96.0 ± 3.8% in the face–between condition, 93.2 ± 5.6 % in the face–within condition, 95.2 ± 4.0% in the mosaic–between condition, and 94.7 ± 4.8% in the mosaic–within condition.

A 2 × 2 ANOVA was conducted on the ACC, with the objecthood (within- vs. between-object condition) and the object type (face vs. mosaic) as within-subject factors. The main effect of the objecthood was significant, $F(1,71) = 11.13$, $p <$ .001, η_p^2 = .136, showing an inverse OBA effect. The main effect of the object type was not significant, $F(1,71) = 0.487$, p = .488, η_p^2 = .007. The interaction was significant, $F(1,71)$ = 7.44, p = .008, η_p^2 = .095. A post hoc test revealed that in faces, ACC was higher in the between relative to the within condition, $t(71) = 4.31$, $p < .001$, showing an inverse OBA effect. No other significant results were found in the post hoc test.

The ACC in the baseline condition for the horizontal direction of attention was 95.6 ± 4.8%, and for the vertical direction of attention was 94.7 ± 4.7%.

A one-way repeated measure ANOVA was conducted on the ACC, with the attentional direction (horizontal vs. vertical) as within-subject factors. The main effect was not significant, $F(1,71) = 1.27$, p = .263, η_p^2 = .018. The ACC results did not show the horizontal bias, so no further corrected OBA analysis was conducted for the ACC data.

Acknowledgements This research was supported by the National Natural Science Foundation of China (No. 31970993). This work was carried out under the scope of the research program "Dipartimenti di Eccellenza" (art.1, commi 314–337 legge 232/2016), which was supported by a grant from MIUR to the Department of General Psychology, University of Padua.

References

Al-Janabi, S., & Greenberg, A. S. (2016). Target–object integration, attention distribution, and object orientation interactively modulate object-based selection. *Attention Perception & Psychophysics, 78*(7), 1–17.

Avrahami, J. (1999). Objects of attention, objects of perception. *Perception & Psychophysics, 61*(8), 1604–1612.

Baldauf, D., & Desimone, R. (2014). Neural mechanisms of object-based attention. *Science, 344*(6182), 424–427.

Bao, M., Li, Z. H., & Zhang, D. R. (2007). Binding facilitates attention switching within working memory. *Journal of Experimental Psychology: Learning Memory & Cognition, 33*(5), 959–969.

Barnas, A. J., & Greenberg, A. S. (2016). Visual field meridians modulate the reallocation of object-based attention. *Attention Perception & Psychophysics, 78*(7), 1985–1997.

Barnhoorn, J. S., Haasnoot, E., Bocanegra, B. R., & van Steenbergen, H. (2015). QRTEngine: An easy solution for running online reaction time experiments using Qualtrics. *Behavior Research Methods, 47*(4), 918–929.

Bruce, V., & Young, A. (2013). *Face perception*: Psychology Press.

Chen, Z. (2000). An object-based cost of visual filtering. *Perception & Psychophysics, 62*(3), 482–495.

Chen, Z. (2012). Object-based attention: A tutorial review. *Attention Perception & Psychophysics, 74*(5), 784–802.

Chen, Z., & Cave, K. R. (2019). When is object-based attention not based on objects? *Journal of Experimental Psychology: Human Perception and Performance, 45*(8), 1062–1082.

Chen, Z., Cave, K. R., Basu, D., Suresh, S., & Wiltshire, J. (2020). A region complexity effect masquerading as object-based attention. *Journal of Vision, 20*(7), 24–24.

Chou, W. L., & Yeh, S. L. (2012). Object-based attention occurs regardless of object awareness. *Psychonomic Bulletin & Review, 19*(2), 225–231.

Clevenger, J., Yang, P.-L., & Beck, D. M. (2019). An advantage for targets located horizontally to the cued location. *bioRxiv*. https://doi.org/10.1101/740712

Curby, K. M., Entenman, R. J., & Fleming, J. T. (2016). Holistic face perception is modulated by experience-dependent perceptual grouping. *Attention, Perception, & Psychophysics, 78*(5), 1392–1404.

Curby, K. M., Goldstein, R. R., & Blacker, K. (2013). Disrupting perceptual grouping of face parts impairs holistic face processing. *Attention, Perception, & Psychophysics, 75*(1), 83–91.

Donovan, I., Pratt, J., & Shomstein, S. (2017). Spatial attention is necessary for object-based attention: Evidence from temporal-order judgments. *Attention Perception & Psychophysics, 79*(3), 753–764.

Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology: General, 113*(4), 501–517.

Eger, E., Jedynak, A., Iwaki, T., & Skrandies, W. (2003). Rapid extraction of emotional expression: Evidence from evoked potential fields during brief presentation of face stimuli. *Neuropsychologia, 41*(7), 808–817.

Egly, R., Driver, J., & Rafal, R. D. (1994). Shifting visual attention between objects and locations: Evidence from normal and parietal lesion subjects. *Journal of Experimental Psychology: General, 123*(2), 161–177.

Ekman, P. (1993). *Facial expression and emotion. American psychologist, 48*(4), 376–379.

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191.

Greenberg, A., Hayes, D., Roggeveen, A., Creighton, S., Bennett, P., Sekuler, A., & Pilz, K. (2014). Object-based attention is modulated by shifts across the meridians. *Journal of Vision, 14*(10), 1062–1062.

Grootswagers, T. (2020). A primer on running human behavioural experiments online. *Behavior Research Methods, 52*(6), 2283–2286.

Hershler, O., & Hochstein, S. (2005). At first sight: A high-level pop out effect for faces. *Vision Research, 45*(13), 1707–1724.

Itier, R. J., Alain, C., Sedore, K., & McIntosh, A. R. (2007). Early face processing specificity: it's in the eyes! *Journal of Cognitive Neuroscience, 19*(11), 1815–1826.

Itier, R. J., Latinus, M., & Taylor, M. J. (2006). Face, eye and object early processing: What is the face specificity? *NeuroImage, 29*(2), 667–676.

Kahneman, D., Treisman, A., & Burkell, J. (1983). The cost of visual filtering. *Journal of Experimental Psychology: Human Perception and Performance, 9*(4), 510–522.

Lamy, D., & Egeth, H. (2002). Object-based selection: The role of attentional shifts. *Perception & Psychophysics, 64*(1), 52–66.

Lange, K., Kühn, S., & Filevich, E. (2015). "just another tool for online studies" (JATOS): An easy solution for setup and management of web servers supporting online studies. *PLoS One, 10*(6), e0130834.

Langton, S., Law, A. S., Burton, A. M., & Schweinberger, S. R. (2008). Attention capture by faces. *Cognition, 107*(1), 330–342.

Li, X., & Logan, G. D. (2008). Object-based attention in Chinese readers of Chinese words: Beyond gestalt principles. *Psychonomic Bulletin & Review, 15*(5), 945–949.

Lu, C.-H., & Proctor, R. W. (1995). The influence of irrelevant location information on performance: A review of the Simon and spatial Stroop effects. *Psychonomic Bulletin & Review, 2*(2), 174–207.

Ma, D. S., Correll, J., & Wittenbrink, B. (2015). The Chicago face database: A free stimulus set of faces and norming data. *Behavior Research Methods, 47*(4), 1122–1135.

Malcolm, G. L., & Shomstein, S. (2015). Object-based attention in real-world scenes. *Journal of Experimental Psychology: General, 144*(2), 257–263.

Marrara, M. T., & Moore, C. M. (2003). Object-based selection in the two-rectangles method is not an artifact of the three-sided directional cue. *Perception & Psychophysics, 65*(7), 1103–1109.

Mathôt, S., Schreij, D., & Theeuwes, J. (2012). OpenSesame: An open-source, graphical experiment builder for the social sciences. *Behavior Research Methods, 44*(2), 314–324.

Moore, C. M., Yantis, S., & Vaughan, B. (1998). Object-based visual selection: Evidence from perceptual completion. *Psychological Science, 9*(2), 104–110.

Murphy, J., Gray, K. L., & Cook, R. (2020). Inverted faces benefit from whole-face processing. *Cognition, 194*, 104105.

Nah, J. C., Neppi-Modona, M., Strother, L., Behrmann, M., & Shomstein, S. (2018). Object width modulates object-based attentional selection. *Attention Perception & Psychophysics, 80*(11), 1–15.

Norman, L. J., Heywood, C. A., & Kentridge, R. W. (2013). Object-based attention without awareness. *Psychological Science, 24*(6), 836–843.

O'Craven, K. M., Downing, P. E., & Kanwisher, N. (1999). fMRI evidence for objects as the units of attentional selection. *Nature, 401*(6753), 584–587.

Palermo, R., & Rhodes, G. (2007). Are you always on my mind? A review of how face perception and attention interact. *Neuropsychologia, 45*(1), 75–92.

Pegna, A. J., Khateb, A., Michel, C. M., & Landis, T. (2004). Visual recognition of faces, objects, and words using degraded stimuli: Where and when it occurs. *Human Brain Mapping, 22*(4), 300–311.

Pilz, K. S., Äijälä, J. M., & Manassi, M. (2020). Selective age-related changes in orientation perception. *Journal of Vision, 20*(13), 1–12.

Pilz, K. S., Roggeveen, A. B., Creighton, S. E., Bennett, P. J., & Sekuler, A. B. (2012). How prevalent is object-based attention? *PLoS One, 7*(2), e30693.

Posamentier, M. T., & Abdi, H. (2003). Processing faces and facial expressions. *Neuropsychology Review, 13*(3), 113–143.

Posner, M. I., Snyder, C. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General, 109*(2), 160–174.

Reddy, L., Wilken, P., & Koch, C. (2004). Face-gender discrimination is possible in the near-absence of attention. *Journal of Vision, 4*(2), 106–117.

Richler, J. J., Mack, M. L., Palmeri, T. J., & Gauthier, I. (2011). Inverted faces are (eventually) processed holistically. *Vision Research, 51*(3), 333–342.

Rottach, K. G., Zivotofsky, A. Z., Das, V. E., Averbuch-Heller, L., Discenna, A. O., Poonyathalang, A., & Leigh, R. J. (1996). Comparison of horizontal, vertical and diagonal smooth pursuit eye movements in Normal human subjects. *Vision Research, 36*(14), 2189–2195.

Sauter, M., Draschkow, D., & Mack, W. (2020). Building, hosting and recruiting: A brief introduction to running behavioral experiments online. *Brain Sciences, 10*(4), 251–262.

Sekuler, A. B., Gaspar, C. M., Gold, J. M., & Bennett, P. J. (2004). Inversion leads to quantitative, not qualitative, changes in face processing. *Current Biology, 14*(5), 391–396.

Serences, J. T., Schwarzbach, J., Courtney, S. M., Golay, X., & Yantis, S. (2004). Control of object-based attention in human cortex. *Cerebral Cortex, 14*(12), 1346–1357.

Sereno, A. B., & Kosslyn, S. M. (1991). Discrimination within and between hemifields: A new constraint on theories of attention. *Neuropsychologia, 29*(7), 659–675.

Shomstein, S., & Behrmann, M. (2008). Object-based attention: Strength of object representation and attentional guidance. *Perception & Psychophysics, 70*(1), 132–144.

Simon, J. R., & Rudell, A. P. (1967). Auditory SR compatibility: The effect of an irrelevant cue on information processing. *Journal of Applied Psychology, 51*(3), 300–304.

Song, F., Zhou, S., Gao, Y., Hu, S., Zhang, T., Kong, F., & Zhao, J. (2021). Are you looking at me? Impact of eye contact on object-based attention. *Journal of Experimental Psychology: Human Perception and Performance, 47*(6), 765–773.

Theeuwes, J., & Van der Stigchel, S. (2006). Faces capture attention: Evidence from inhibition of return. *Visual Cognition, 13*(6), 657–665.

Thoma, & Volker. (2014). Face-specific capacity limits under perceptual load do not depend on holistic processing. *Psychonomic Bulletin & Review, 21*(6), 1473–1480.

Thornton, I. M., Vuong, Q. C., & Pilz, K. S. (2021). A search advantage for horizontal targets in dynamic displays. *i-Perception, 12*(2), 1–10.

Tim, & Valentine. (1988). Upside-down faces: A review of the effect of inversion upon face recognition. *British Journal of Psychology, 79*, 471–491.

Treisman, A., Kahneman, D., & Burkell, J. (1983). Perceptual objects and the cost of filtering. *Perception & Psychophysics, 33*(6), 527–532.

Valenza, E., & Calignano, G. (2021). Attentional shift within and between faces: Evidence from children with and without a diagnosis of autism spectrum disorder. *PLoS One, 16*(5), e0251475.

Valenza, E., Franchin, L., & Bulf, H. (2014). How a face may affect object-based attention: Evidence from adults and 8-month-old infants. *Frontiers in Integrative Neuroence, 8*(27), 1–10.

VanRullen, R. (2006). On second glance: Still no high-level pop-out effect for faces. *Vision Research, 46*(18), 3017–3027.

Watson, S. E., & Kramer, A. F. (1999). Object-based visual selective attention and perceptual organization. *Perception & Psychophysics, 61*(1), 31–49.

Webster, M. A., & MacLeod, D. I. (2011). Visual adaptation and face perception. *Philosophical Transactions of the Royal Society B: Biological Sciences, 366*(1571), 1702–1725.

Willenbockel, V., Fiset, D., Chauvin, A., Blais, C., Arguin, M., Tanaka, J. W., & Gosselin, F. (2010). Does face inversion change spatial frequency tuning? *Journal of Experimental Psychology: Human Perception and Performance, 36*(1), 122–135.

Woodman, G. F., Vecera, S. P., & Luck, S. J. (2003). Perceptual organization influences visual working memory. *Psychonomic Bulletin & Review, 10*(1), 80–87.

Xie, T., Nan, W., & Fu, S. (2021). Attention can operate on object representations in visual sensory memory. *Attention Perception & Psychophysics*, 1–17.

Yantis, S., & Serences, J. T. (2003). Cortical mechanisms of space-based and object-based attentional control. *Current Opinion in Neurobiology, 13*(2), 187–193.

Yeshurun, Y., & Rashal, E. (2017). The typical advantage of object-based attention reflects reduced spatial cost. *Journal of Experimental Psychology: Human Perception and Performance, 43*(1), 69–77.

Yin, J., Xu, H., Duan, J., & Shen, M. (2018). Object-based attention on social units: Visual selection of hands performing a social interaction. *Psychological Science, 29*(7), 1040–1048.

Yuan, J., & Fu, S. (2014). Attention can operate on semantic objects defined by individual Chinese characters. *Visual Cognition, 22*(6), 770–788.

Zhao, J., Song, F., Zhou, S., Hu, S., Liu, D., Wang, Y., & Kong, F. (2020). The impact of monetary stimuli on object-based attention. *111*(3), 460-472.

Zhou, H., & Fishbach, A. (2016). The pitfall of experimenting on the web: How unattended selective attrition leads to surprising (yet false) research conclusions. *Journal of Personality and Social Psychology, 111*(4), 493–504.

Zhu, W., Xu, D., Zhang, J., Ma, Y., Zhou, C., & Zhao, L. (2010). *Face capture more attentional resource than no-face object: An ERP study*. Paper presented at the 2010 Sixth International Conference on Natural Computation.

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