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Interocular grouping without awareness

San-Yuan Lin [a], Su-Ling Yeh [a,b,c,*]

[a] Department of Psychology, National Taiwan University, Taipei, Taiwan
[b] Graduate Institute of Brain and Mind Sciences, National Taiwan University, Taipei, Taiwan
[c] Neurobiology and Cognitive Science Center, National Taiwan University, Taipei, Taiwan

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ABSTRACT

Interocular grouping occurs when different parts of an image presented to each eye bound into a coherent whole. Previous studies anticipated that these parts are visible to both eyes simultaneously (i.e., the images altered back and forth). Although this view is consistent with the general consensus of binocular rivalry (BR) that suppressed stimuli receive no processing beyond rudimentary level (i.e., adaptation), it is actually inconsistent with studies that use continuous flash suppression (CFS). CFS is a form of interocular suppression that is more stable and causes stronger suppression of stimuli than BR. In the present study, we examined whether or not interocular grouping needs to occur at a conscious level as prior studies suggested. The modified double-rectangle paradigm used by Egly, Driver, and Rafal (1994) was adopted, and object-based attention was directed for successful grouping. To induce interocular grouping, we presented complementary parts of two rectangles dichoptically for possible interocular grouping and a dynamic Mondrian in front of one eye (i.e., CFS). Two concurrent targets were presented after one of the visible parts of the rectangles was cued. Participants were asked to judge which target appeared first. We found that the target showed on the cued rectangle after interocular grouping was reported to appear first more frequently than the target on the uncued rectangle. This result was based on the majority of trials where the suppressed parts of the objects remained invisible, which indicates that interocular grouping can occur without all the to-be-grouped parts being visible and without awareness.

Binocular rivalry (BR, Porta, 1593, cited in Wade, 1996) is a visual phenomenon that occurs when two eyes receive different stimuli (e.g., picture of a jungle in one eye and a chimpanzee in the other eye) and viewer's percept alternates between the two stimuli (i.e., seeing either jungle or chimpanzee). As percepts change while stimuli remain the same, BR could be used to understand the neural correlates of consciousness because neuronal activity has been shown to fluctuate concurrently with the subjective percept changes during BR (Logothetis, Leopold, & Sheinberg, 1996; Logothetis & Schall, 1989; Tong, Nakayama, Vaughan, & Kanwisher, 1998; but see Blake, Brascamp, & Heeger, 2014). For example, Tong et al. (1998) presented various overlapping face and house images with red and green filters to their participants. BR was induced in this scenario because participants could only alternatively see either the face or the house image one at a time instead of seeing both images at the same time. Based on their data, subjective reports of seeing the stimulus (e.g., face) correlated with the change of blood oxygen level dependent (BOLD) signal in the corresponding area (e.g., the fusiform 'face' area) while the other area (e.g., the parahippocampal 'place' area) showed little or no BOLD signal change. Thus, it appears that individuals must subjectively perceive the dominant or visible image in order to activate related brain areas beyond certain threshold to process the visual information. On the other hand, the suppressed or invisible image seems to have little or no input on individuals' visual perception. According to Lee and Blake (2004), during BR, visual processing only occurred for the dominant (visible) stimuli, but not for the suppressed (invisible) stimuli.

Instead of presenting separate rivalrous stimuli to each eye (e.g., jungle vs. chimpanzee) as in the conventional BR studies, Kovács, Papathomas, Yang, and Fehér (1996) presented a montage of red and green dots in one eye and dots of reversed colors at corresponding locations in the other eye (e.g., if a dot on the left side of fixation was red in the left eye, it was green in the right eye)[1]

* Corresponding author at: Department of Psychology, National Taiwan University, Taipei 10617, Taiwan.
E-mail address: suling@ntu.edu.tw (S.-L. Yeh).

[1] We thank the reviewer for pointing out that Diaz-Caneja was the first one who found this effect in 1928. For the detail of his work, please see the English translation of Alais, O'Shea, Mesana-Alais, and Wilson (2000).

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to their participants. They found that participants perceived not only a mixture of red and green dots, but also a coherent array of red or green dots. Thus, Kovács et al. (1996) demonstrated the phenomenon of interocular grouping under BR setup—grouping occurred between stimuli in dominant and non-dominant (suppressed) eyes and emerged into consciousness as a whole. Indeed, the suppressed stimuli was processed.

To reconcile with the finding of Kovács et al. (1996), Lee and Blake (2004) proposed a *patch-based account* for BR. Using a similar design as in Kovács et al. (1996), Lee and Blake asked their participants to attend to a circular region of the display above the fixation. When participants reported seeing one stimulus (e.g., jungle) through interocular grouping, stimuli in the attended circular region were swapped and participants were required to report whether the percept in the circular region changed or not after the swap. Lee and Blake noted that participants claimed a percept change (e.g., seeing the chimpanzee's eye in the picture of jungle) in most of the swap trials. This finding suggested that interocular grouping was not entirely eye- or object-based. Perhaps, interocular grouping was supported when small patches from each eye were consciously processed for grouping.

Based on this account, Lee and Blake (2004) suggested that interocular grouping, as proposed by Kovács et al. (1996), may somehow be supported by the small patches in each eye that alternatively dominated one's percept during rivalry. In another word, their study emphasized the importance of feature dominance on rivalry dynamics over other potentially influential factors. They suggested that non-dominant image features were suppressed from individuals' consciousness during rivalrous situations. Hence, it appears that Lee and Blake supported the view that the grouping between stimuli across different eyes may partly occur at a conscious level that requires all parts of the to-be-grouped object to be visible. Since very little work has been done to investigate the relationship between BR and consciousness, we took this idea that Lee and Blake briefly discussed relating to interocular grouping and referred to it as the *conscious grouping hypothesis*.

While the conscious grouping hypothesis is consistent with the 'no dominance, no processing' assumption of BR (Sobel & Blake, 2002, but see Lin & He, 2009), it contradicts other previous findings that illustrated processing for invisible stimuli (Chen & Yeh, 2012; Chou & Yeh, 2012; Kanai, Tsuchiya, & Verstraten, 2006; Lo & Yeh, 2008; Mudrik, Breska, Lamy, & Deouell, 2011; Stein, Senju, Peelen, & Sterzer, 2011; Stein & Sterzer, 2012; Tsuchiya & Koch, 2005; Wang, Weng, & He, 2012; Yang & Yeh, 2011). For example, Tsuchiya and Koch (2005) used a masking paradigm CFS (Tsuchiya & Koch, 2005)—also a form of interocular suppression as with BR (Tsuchiya, Koch, Gilroy, & Blake, 2006)— to demonstrate that suppressed stimuli were processed. In this paradigm, the to-be-suppressed stimulus was presented to one eye while a stream of constantly flashing high-contrast Mondrians was presented to the other eye. It resulted in stable suppression that was much longer in duration and 10-fold stronger than BR (Tsuchiya et al., 2006). Using CFS, unconscious processing (i.e., the critical stimuli that were processed under the suppressed state) has been found for a range of stimuli (see Faivre, Berthet, & Kouider, 2014; for a review), including color (Tsuchiya & Koch, 2005), orientation (Kanai et al., 2006), Kanizsa figures (Wang et al., 2012), word meaning (Lin & Yeh, 2015; Yang & Yeh, 2011), gaze direction (Chen & Yeh, 2012; Stein et al., 2011), faces (Stein & Sterzer, 2012), objects (Chou & Yeh, 2012) and complex scenes (Mudrik et al., 2011; Tan & Yeh, 2015).

In the present study, we examined the conscious grouping hypothesis by providing a more stable suppression method. We presented to-be-grouped objects to separate eyes with a constantly refreshing Mondrian in one eye (i.e., CFS, behind the complementary parts of the objects that are visible) to attain stable suppression of the stimulus in the other eye. Objective performance and subjective report data were collected to investigate whether or not interocular grouping occurs in such dichoptic and disassembled presentation and whether or not the occurrence of interocular grouping requires all the to-be-grouped objects to be visible as suggested (Lee & Blake, 2004).

1. Experiment 1

To examine if interocular grouping occurs only when stimuli in both eyes are visible as the conscious grouping hypothesis suggested, we adopted the CFS technique and used the double-rectangle cueing paradigm from the article by Egly, Driver, and Rafal (1994; Fig. 1). Two concurrent targets with equivalent cue-to-target distance were presented, one on the cued rectangle of the expected double-rectangle display (Fig. 2A) and one on the uncued rectangle. Participants indicated which target appeared first[2] (i.e., the temporal-order judgment task [TOJ], Abrams & Law, 2000; Shore, Spence, & Klein, 2001). In the earlier work by Abrams and Law (2000), targets that appeared on a circle and linked to the cued circle with a bar forming a dumbbell-like object was reported to appear earlier than the other targets that appeared on the isolated circle that was not linked to the cued circle. While linked and unlinked circles were equidistant to the cued circle, the misperception that target on linked circle appear earlier than unlinked circle was viewed as the result of attentional prioritization in an object-based (dumbbell in this case) way. In another word, attention was prioritized for the processing of the linked circle over the unlinked one because the linked circle was treated as the same object as the cued one (for detail, please see Figs. 3 and 4 in Abrams & Law, 2000). In the current study, the *object-based advantage*—the target on the cued object that seemed to appear first—was used to create successful groupings between stimuli presented to the two eyes. Such a difference in participants' TOJ for the concurrent targets suggest that the object formed by combining the images presented to the two eyes affected the judgment via object-based advantage, thus indicating the occurrence of interocular grouping. Furthermore, if the invisible parts of the grouped object remained invisible while object-based advantage was obtained, then it suggests that the grouping occurred despite the level of awareness on the grouped object. Therefore, interocular grouping occurred unconsciously.

1.1. Method

1.1.1. Participants

Sixteen undergraduates from the National Taiwan University participated in this experiment. All participants had normal or corrected-to-normal vision and they were naïve about the purpose of this experiment. All the experiments in this study were approved by the internal review board of the Department of Psychology of the National Taiwan University. Informed consent were obtained from the participants before the experiments.

1.1.2. Apparatus

The stimuli were prepared and presented via a 21-inch CRT (Eizo T966) under Windows XP using Matlab r2012b with Psychophysics toolbox extensions (Brainard, 1997; Pelli, 1997). Participants were asked to watch the display through a set of four

[2] Please refer to the work of Gayet, Van der Stigchel, and Paffen (2014) for alternative interpretation for the results obtained by measuring the time the stimuli release from suppression as an index of unconscious high-level processing (i.e. beyond crude visual processing). In this study, we have avoided the conventional practice of measuring the time the stimuli take to release from suppression. We thank the reviewer for referring us to the work of Gayet et al. (2014).

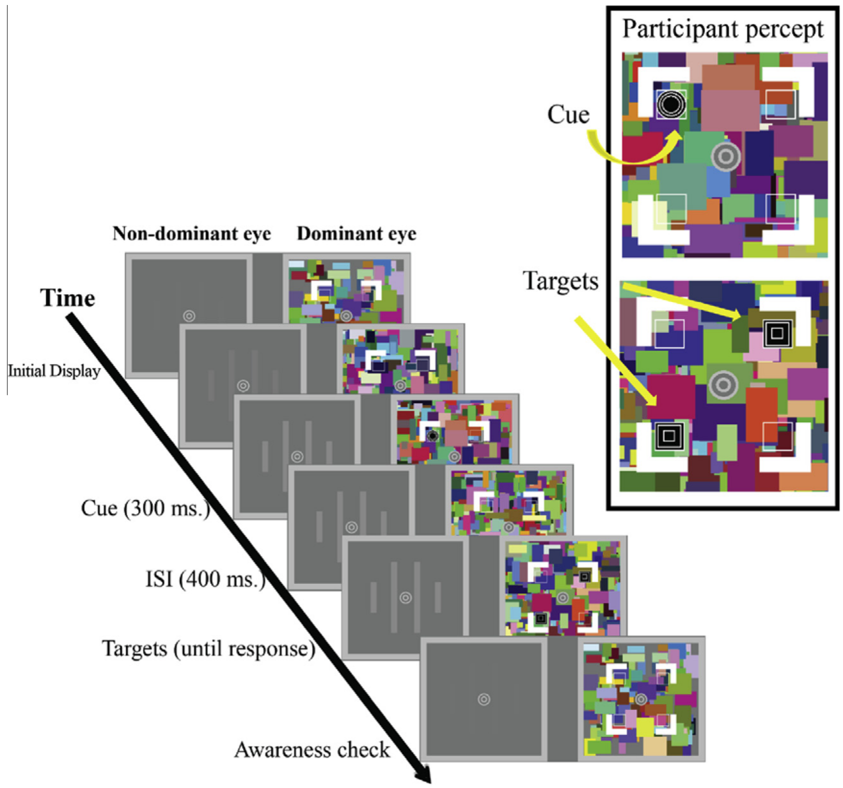

Fig. 1. The procedure in Experiment 1. The Mondrian refreshed every 100 ms (10 Hz) so participants would perceive the display in their dominant eye while the display in the non-dominant eye (could be horizontal lines, vertical lines, or none) remained invisible. After the cue (see the inset on top-right), participants were required to report which of the two concurrent targets (top-right inset) appeared first. Subsequently, in the awareness check, participants were asked to indicate whether they saw the vertical (or horizontal) lines in the non-dominant eye or not.

mirrors (Tsuchiya & Koch, 2005) that helped them to fuse the left and right halves of the display. Their head was placed on a head and chin rest to ensure a standardized distance of 75 cm from the display.

1.1.3. Stimuli

Two rectangles (each subtended 2° by 6°, line width 0.5°) separated by 8° were decomposed into two complementary parts. The decomposed display was presented to both eyes in a similar fashion as in Kovács et al. (1996) so that the double-rectangle display could only be formed by integrating inputs from both eyes. Four L-shaped corners (Fig. 1; each arm subtended 0.5° by 1.5° in white, pixel value 255) were presented in the dominant eye while the remaining four straight lines (either horizontal or vertical, Fig. 2; luminance contrast [Weber contrast] ramped up from 0% to 20% in 1.6 s) were presented in the non-dominant eye. To reach stable suppression, we used CFS by presenting Mondrian patterns that refreshed every 100 ms (10 Hz) in the dominant eye (the filled color squares in the Mondrian patterns have a mean width of 1.2° and a uniform randomization of ±0.8°). Participants' percept included the four outer corners of the double-rectangle display in the dominant eye (visible), while the remaining four straight lines in the suppressed eye were unseen. To aid fusion, the fixation—a three-ring concentric circle (1° radius, gray, pixel value 196)—was presented both in the dominant and non-dominant eyes. The cue (concentric rings with outer ring of 1° radius, white, pixel value 255) and the targets (concentric squares with outer square of 1° by 1°) were presented only in front of the dominant eye at the location of the placeholders (outlined squares, each subtended 1° by 1°).

1.2. Design and procedure

Object-based advantage—the resulting prioritized processing when attention is directed to one object over another—was used to indicate the occurrence of interocular grouping. At the beginning of each trial, participants were required to look at the fixation point. The contrast of the four straight lines in the non-dominant eye increased at 1.6 s and remained the same. After the contrast stabilized, the cue was presented at one of the four placeholders for 300 ms. After an inter-stimulus interval of 400 ms, targets were presented concurrently at two placeholders that were in the diagonal direction different from the one occupied by the cue. The participants were encouraged to press the 'z' key on the keyboard with their left index finger or the '/' key with their right index finger (on a U.S. 101-key keyboard layout) to indicate which target appeared first. After responding to the targets, the contrast of the straight lines decreased linearly to zero in 800 ms and an awareness check was performed. To ensure that the awareness check could be performed, participants were instructed to close one of their eyes at a time to see the displays in the dominant and non-dominant eyes respectively before the practice session. During the awareness check, we showed a question ("Did you see anything else?") on the upper part of the display and participants were asked to answer whether or not they saw the four straight lines in the non-dominant eye by pressing yes (the 'z' key) or no (the '/' key) response.

We presented only concurrent targets while excluding temporally asynchronous targets that were used conventionally because we wanted to control our session within one hour to prevent exhausting our participants. Since the typical percept of participants was only the outer corners of the two rectangles (the

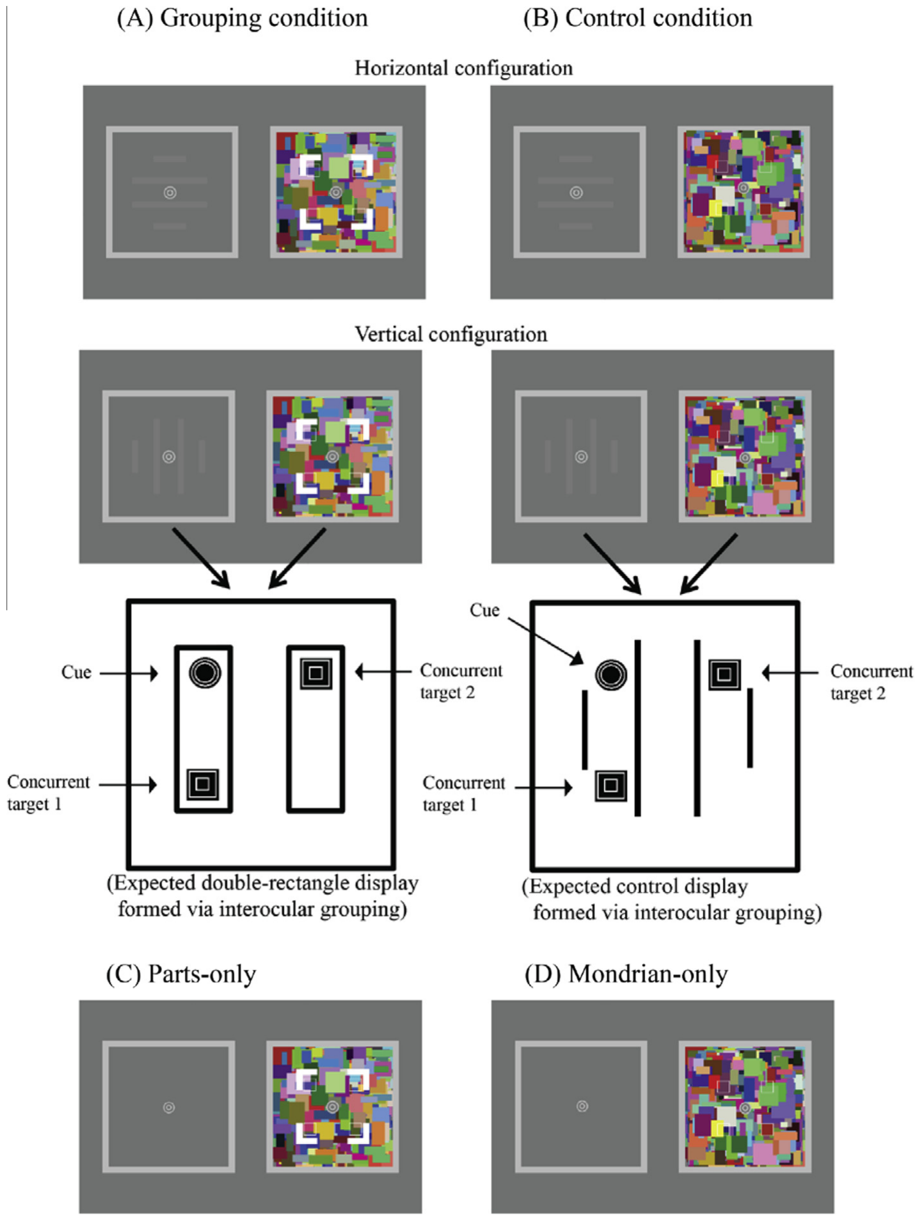

Fig. 2. Four conditions manipulated in Experiment 1 and the expected interocular grouping displays for the critical grouping condition and the control condition. (A) The Grouping condition: parts of two rectangles from both eyes could form two rectangles, with either a horizontal or a vertical configuration. (B) The Control condition: only straight lines were presented. (C) The Part-only condition: only L-shapes were presented in dominant eye. (D) The Mondrian-only condition: no parts of rectangles were presented.

top-right inset of Fig. 1), participants had no visible clues to bias their judgments toward either one of the two concurrent targets.

The experiment itself consisted of a practice session of 30 trials and the formal experiment of 320 trials that were both presented in random orders. All the experimental trials were divided into four conditions. (A) The *Grouping* condition (Fig. 2; both L-shaped parts and lines were presented but in separate eyes): the object parts presented in the two eyes could form two rectangles. If interocular grouping occurred, a higher proportion of judging the concurrent target 1 to occur earlier than the concurrent target 2 was expected because the former was on the cued rectangle. (B) The *Control* condition: only lines were presented in the non-dominant eye to ensure the TOJ was affected by grouping only and not by straight lines. No difference in the TOJ for the concurrent target 1 and 2 appearing earlier was expected because there was no objects being formed to be selected by attention. To disguise the Grouping and Control conditions, two other conditions were also introduced: (C) the *Parts-only* condition (only L-shaped parts were presented in dominant eye) and, (D) the *Mondrian-only* condition (no object parts presented in either eye).

There were 80 trials for each of the four conditions, and within each condition the cue and the targets appeared in each of the four placeholders with equal probability. Trials in the Grouping and Control conditions were each categorized by participants' responses. If the target on the cued object was judged to appear first, the trial would be labeled as *Same-Object-Target* trial. If the other target on the uncued object was judged to appear first, the trial would be labeled as *Different-Object-Target* trial.

1.3. Results

We analyzed a total of 160 trials for each conditions, the Grouping (Fig. 2A) and the Control (Fig. 2B) conditions. During the awareness check, Grouping condition participants reported seeing

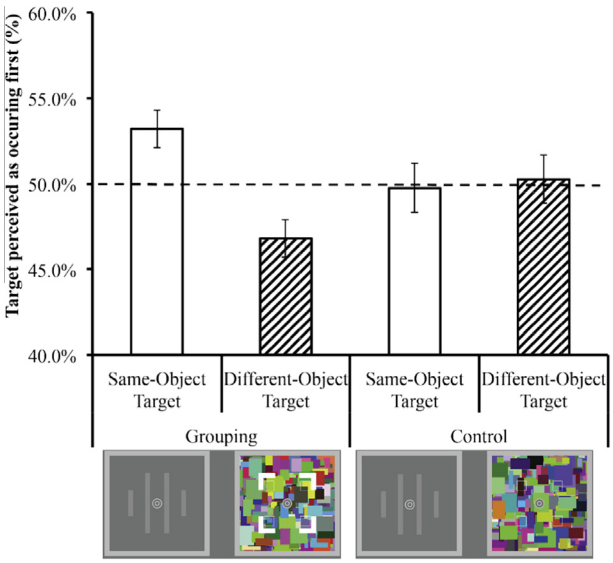

Fig. 3. The results of Experiment 1. The vertical axis represents the proportion of trials in each condition that were judged to appear first. The horizontal axis represents the trials categorized by the participant responses. The error bar denotes ±1 standard error. Same-Object Target trials are those in which the target on the same object as the cue was judged to appear first, and Different-Object Target trials are those in which the target on a different object as the cue was judged to appear first.

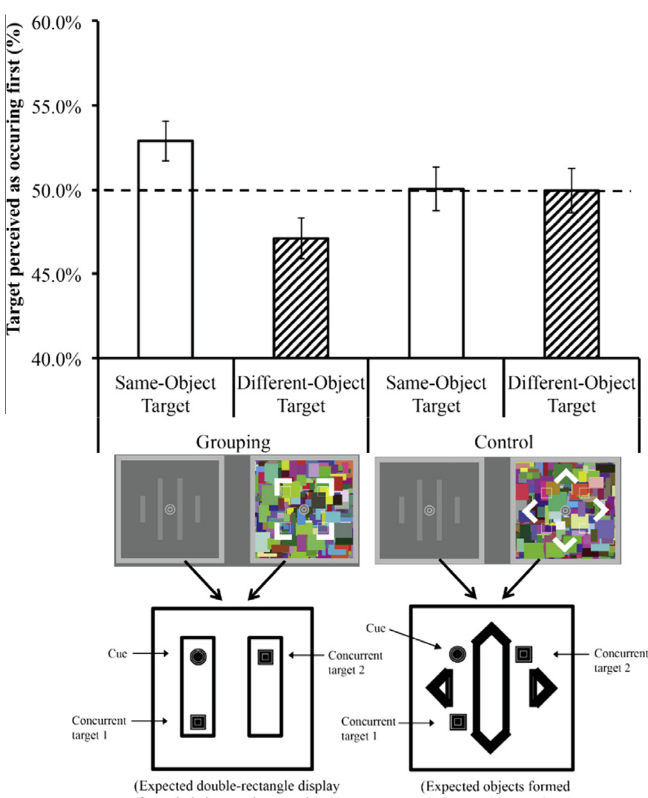

Fig. 4. The stimuli and results of Experiment 2. The error bar denotes ±1 standard error. The visible parts of the to-be-grouped stimuli were rotated by 45° to control for binocular inputs that were present in both conditions. In the lower-right inset: the cue on the top-left (concentric circles) and the targets (concentric squares) on the other diagonal direction were shown to illustrate their positions relative to the grouped shapes.

images in the non-dominant eye in 6.3% of the trials. As for participants in the Control condition, they reported seeing images in the non-dominant eye in 7.2% of the trials. Thus, these "seen" trials were excluded. There was no difference between the two conditions ($t(15) = 0.40$, $p = .88$) in the exclusion rate, which means that the potential interocular grouping in the Grouping condition did not increase the visibility of the content in the non-dominant eye. It also suggests that the content of the non-dominant eye was largely unconscious in both conditions.

To examine whether the TOJ for the two concurrent targets was affected by the arrangement of the grouped rectangles, trials in the Grouping condition were divided according to the orientation of the straight lines (horizontal versus vertical lines). In both orientations, the proportion of the Same-object target trials for horizontally-grouped objects (horizontal parallel) was not significantly different from that of vertically-grouped objects (horizontal rectangles: 51.29%, vertical rectangles: 53.42%, $t(15) = 0.26$, $p = .79$). The factor of rectangle orientation was thus collapsed between horizontal and vertical rectangles for subsequent analysis.

The fact that the proportion of Same-object-target trials in the Grouping condition (53.2%, $\sigma_{\bar{x}} = 0.01$, 95% CI = [52.6, 53.8]; Fig. 3) was significant (50%; $t(15) = 2.89$, $p = .01$) with a medium effect size (Cohen's $d = 0.72$) in a paired t-test seems to further support the idea that interocular grouping occurs unconsciously. The objects that were formed via interocular grouping affected appearance order of the concurrent targets, leading to a higher proportion of trials for which the target on the cued object was judged to appear earlier than when the target was presented on the uncued object. Furthermore, in another paired t-test, there was no evidence for interocular grouping in the trials of the Control condition since the proportion of the Same-object-target trials (49.7%, $\sigma_{\bar{x}} = 0.01$, 95% CI = [49, 50.6]) was no more than chance level ($t(15) = 0.17$, $p = .86$). This suggests that four straight lines alone could not drive the effect found in the Grouping condition. After controlling the family-wise error rate at $\alpha = 0.05$ ($\alpha_{\text{per comparison}} = 0.025$), the result in Grouping condition ($p = 0.01$) was significant while the result in Control condition ($p = .89$) remained insignificant.

To ensure that the L-shapes in the Parts-only condition would not affect the performance of the TOJ, only reports that did not see the stimuli in the suppressed eye (96% of the trials, while there was indeed no stimuli in the suppressed eye) were examined. Results showed that, including all four cue locations, there was no significant difference between the percentages of left and right responses ('left' response: 47.6%, 'right' response: 52.4%, $t(15) = 0.697$, $p = .48$). Also, for each of the four cue locations, there were no significant differences between the percentages of 'left' and 'right' responses ($ps > 0.26$). These results suggested that L-shapes alone in the Parts-only condition did not affect the TOJ for the two concurrent targets.

In addition to the desired grouping comparison between the Grouping and Control conditions, one major difference between these two conditions was the presence of binocular inputs of stimuli (i.e., L-shaped parts and straight lines) in the Grouping condition. Thus, it might be the binocular inputs of stimuli, whether these binocularly complementary parts actually formed rectangular shape or not, that drive the effect we found. In the next experiment, we introduced similar stimuli in both Grouping and Control conditions that might otherwise group into different shapes.

2. Experiment 2

In order to provide binocular inputs (parts of to-be-grouped stimuli present for both eyes) for both the Grouping and Control conditions, stimuli were presented in the same way for both conditions. However, the Control condition differed from the Grouping condition in terms of how the stimuli were grouped. In the Control condition, the visible four L-shaped parts were rotated around the fixation by 45° (Fig. 4) to induce a configuration that could not affect the TOJ of concurrent targets. If binocular inputs alone played a role in deriving the effect in Experiment 1, we would expect the same to happen in the Control condition whether the complimentary parts could be grouped to form objects or not. Furthermore, with different grouping configurations in the Grouping and Control conditions, we could examine whether or not the results of Experiment 1 could be replicated.

2.1. Method

2.1.1. Participants

Sixteen undergraduates at the National Taiwan University participated in this experiment. All participants had normal or corrected-to-normal vision.

2.1.2. Apparatus, stimuli, and procedure

The apparatus, stimuli, and procedure were replicated from the previous experiment, except that we also presented four L-shaped parts in the dominant eye in the Control condition by rotating the L-shaped parts in the Grouping condition by 45° (Fig. 4).

2.1.3. Design

The design was the same as in Experiment 1 except for two changes. First, since most participants were unaware of the content of the non-dominant eye in both the Grouping and Control conditions in Experiment 1, there was no need to disguise these conditions with the Parts-only or Mondrian-only conditions like in Experiment 1. Therefore, only the critical conditions (Grouping and Control conditions) were examined (Fig. 4). Second, the current experiment consisted of a practice session of 30 trials (randomly drawn from formal session) and a formal session of 160 trials (80 trials for each condition).

2.2. Results

In the awareness check, 3.3% of the content presented in front of the non-dominant eye in the Grouping condition and 2.8% in the Control condition were reported to be seen. There was no difference in the exclusion rate between the two conditions ($t(15) = 1.19$, $p = .25$) and, just like in Experiment 1, these 'seen' trials were excluded from further analysis.

We analyzed the TOJ responses using similar method as in Experiment 1 to see if interocular grouping did occur in both conditions with binocular inputs. In the Grouping condition, the proportion of Same-object-target trials (52.9%, $\sigma_{\bar{x}} = 0.01$, 95% CI = [52.2, 53.6]) was significantly more than chance level (50%; $t(15) = 2.32$, $p = .04$, Cohen's $d = 0.6$). In another word, participants were more likely to judge the target on the cued object to appear earlier than the target on the uncued object, which confirmed again that interocular grouping did occur. In contrast, the proportion of Same-object-target trials (50%, $\sigma_{\bar{x}} = 0.01$, 95% CI = [49.2, 50.9]) was not significantly different from chance level in the Control condition ($t(15) = 0.71$, $p = .49$). Moreover, after controlling for family-wise error rate at $\alpha = 0.05$ ($\alpha_{\text{per comparison}} = 0.025$), the result in the Grouping condition ($p = .04$) was close to significant while the result in the Control condition ($p = .49$) remained insignificant.

By providing binocular inputs of the stimuli in both the Grouping and Control conditions, we found evidence for interocular grouping in the Grouping condition only. This finding not only replicated the finding in Experiment 1 but also suggested that the effect found in Experiment 1 was not induced by mere binocular inputs.

3. Experiment 3

In the first two experiments, participants were required to report whether they saw the suppressed lines or not. This subjective awareness check might include trials in which the participants saw the lines vaguely but responded conservatively as 'unseen'. To ensure that participants are truly unaware of the suppressed lines, it is necessary to add an objective measure after the original subjective awareness check. In this experiment, participants were asked to indicate the orientation of the suppressed lines after reporting whether they saw the lines or not. Only trials that participants reported 'unseen' and judged the orientation of the lines incorrectly were considered to be perceived unconsciously. Adding this objective measure allows us to see whether the reports are at chance level or not. In addition to this objective awareness check, a binocular viewing condition in which the contrast of the lines were ramped up for both eyes was introduced to provide the participants a referential impression of 'seeing the lines'. This additional condition was introduced to reduce the uncertainty about whether they sense the lines or not during the awareness check. With the objective measure to reduce the possibility of underestimating the seen trials and the binocular viewing condition to reduce the uncertainty, our conclusion that interocular grouping occurs unconsciously might be supported if the findings of the previous two experiments are replicated.

3.1. Method

3.1.1. Participants

Sixteen undergraduates of the National Taiwan University participated in this experiment. All participants had normal or corrected-to-normal vision and they were naïve about the purpose of this experiment.

3.1.2. Apparatus, stimuli, and procedure

The apparatus, stimuli, and procedure were the same as in Experiment 1 except the following two changes. First, an objective awareness check was added at the end of each trial. The objective awareness check required the participants to indicate the orientation of the suppressed lines by pressing the 'z' key (vertical) or the '/' key (horizontal) on the keyboard. Second, in addition to the four conditions used in Experiment 1, a fifth condition (binocular viewing; 40 trials) was added, making the formal experiment now consisted a total of 360 trials where conditions were presented in a random order. In the newly added condition, the arrangement of the stimuli was the same as those in the Grouping condition except that an additional set of parallel lines appearing with the same intensity ramp as in the non-dominant eye were presented in the dominant eye. A practice session of 30 trials were now drawn from these five conditions randomly.

3.2. Results

We analyzed 80 trials from each of the Grouping (Fig. 2A) and the Control (Fig. 2B) conditions. In the subjective awareness check, the images presented in front of the non-dominant eye were reported to be seen for 31.1% of the trials in the Grouping condition and 29.1% in the Control condition. There was no difference between the two conditions ($t(15) = 0.44$, $p = .78$) in the exclusion rate, which suggested that the potential interocular grouping in the Grouping condition did not increase the visibility of the content in the non-dominant eye. Also, the binocular viewing trials were reported to be seen for 39.2%. In the objective awareness check task, the orientation of the lines presented in front of the non-dominant eye were reported with an average of 58%

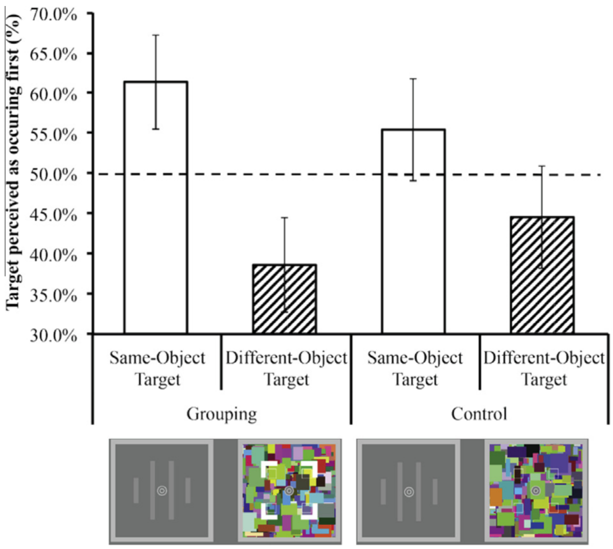

Fig. 5. The results of Experiment 3. The vertical axis represents the proportion of trials in each condition that were judged to appear first. The horizontal axis represents the trials categorized by the participant responses. The error bar denotes ±1 standard error. Same-Object Target trials are those in which the target on the same object as the cue was judged to appear first, and Different-Object Target trials are those in which the target on a different object as the cue was judged to appear first.

($\sigma_{\bar{x}} = 0.05$) in the Grouping condition and 54% ($\sigma_{\bar{x}} = 0.05$) in the Control condition. No significant difference was found between these two conditions ($t(15) = 1.11$, $p = .28$). More importantly, participants showed a chance level performance (respectively, $t(15) = 2.03$, $p = .06$; $t(15) = 1.39$, $p = .18$). These "seen" and correct trials were excluded from analysis. Only those unseen trials with incorrect objective awareness check response (line orientation judgment) were analyzed (34.7% and 39.1% of the Grouping and Control conditions).

In the Grouping condition, the existence of interocular grouping was supported by that the proportion of Same-object-target trials was significantly higher than chance level (61.4%, $t(15) = 2.31$, $p = .04$, $\sigma_{\bar{x}} = 0.06$, 95% CI = [58.5, 64.3]; Fig. 5) with a medium effect size (Cohen's $d = 1.93$) in a paired t-test. In another paired t-test, there was no evidence for interocular grouping in the trials of the Control condition since the proportion of the Same-object-target trials (55.5%, $\sigma_{\bar{x}} = 0.06$, 95% CI = [52.3, 58.4]) was not different from chance level ($t(15) = 1.33$, $p = .21$).

Our results showed that, with an additional objective awareness check, the rate of 'seen' trials increased and the remaining trials available for analysis decreased. Perhaps, the inclusion of binocular viewing condition that was intended to serve as a reference of "seeing the lines" might somehow lowered the participants' criterion in their decision of report seeing the lines. Furthermore, the requirement of objective awareness check might have excluded some trials that were unseen but with correct orientation judgment. Nevertheless, with objective awareness check, we consistently observed that interocular grouping actually occurred unconsciously.

4. General discussion

Through these three experiments, we demonstrated that complementary parts of two objects presented separately in front of each eye could be grouped without all of their parts being visible, as suggested by the object-based advantage. In Experiment 1, presentation of complementary contours in both eyes formed perceptual objects in the Grouping condition as reflected by the TOJ of concurrent targets. In Experiment 2, the potential confounding of binocular inputs that may explain the difference between the Grouping and Control conditions in Experiment 1 was excluded by employing similar stimuli that resulted in different grouped shapes in the two conditions. In Experiment 3, an objective awareness check was added along with a binocular viewing condition to reduce uncertainty, and the results replicated that of previous two experiments. Furthermore, while the object-based advantage was observed in all three experiments, the results were based on the trials that participants were not aware of the content in the suppressed eye. Base on the results of awareness checks that the configuration of the grouped objects remained unaware to the participants, it is inferred that interocular grouping between stimuli presented to the both eyes occurred unconsciously[3].

By using CFS to establish a stable suppression, this study, to our knowledge, is the first one that demonstrated how interocular grouping occurs unconsciously. While the to-be-grouped objects were presented in separate eyes, the flashing Mondrian patterns in the dominant eye induced stable suppression of the non-dominant eye for examining unconscious interocular grouping. It further suggests that, compared to CFS used in this study, the seemingly absent processing in BR might be due to insufficient suppression time to keep stimuli invisible (cf. Lo & Yeh, 2008). However, further studies are needed to verify this assumption.

Although we did not address the bases for competition in BR directly, our results actually shed light on the dynamics of interocular presentation of the stimuli. Our finding makes it explicit that interocular grouping and interocular suppression coexist in such a way that consciousness might not be needed. In the work of Kovács et al. (1996) where interocular grouping was indicated by subjective report, the interocular grouping existed as a failure of interocular suppression (i.e., BR). With an objective measure using the TOJ task, we illustrated that these two seemingly exclusive phenomena coexist: while interocular suppression occurs at an early stage, the suppression does not prevent the stimuli from undergoing interocular grouping unconsciously. Such conclusion is consistent with the finding of Stuit, Paffen, van der Smagt, and Verstraten (2014) that spatially separate but congruent features (i.e., both in parallel or continual) can be grouped at low-level processing stages during binocular rivalry. Hence, our research findings did not support the conscious grouping hypothesis that was hinted in previous research (Lee & Blake, 2004). Nevertheless, the exact nature of patch-based rivalry requires further exploration.

A relevant work of Wang et al. (2012) also indicated that perceptual grouping can occur without the involvement of consciousness. In their work, a Kanizsa triangle and its variations (triangles of misaligned Pacman) were suppressed using CFS. The time that the stimuli broke into consciousness was measured. The results showed that the Kanizsa triangle broke suppression sooner than its variations. While release from suppression is commonly used for measuring unconscious processing, we argue that one of the two key implicit assumptions of this measurement might be invalid. The first assumption is that differential times for breaking into consciousness are taken as an index of differential processing (i.e., the stimuli that is reported to be seen earlier is assumed to be prioritized than the other one). Second, it is assumed that the processing of stimuli is completed *before* the stimuli break into consciousness. While the first assumption might be correct, there

[3] Although the object configuration was formed unconsciously since the participants were not aware of the suppressed content, it was possible that the formation of the configuration might be helped with the conscious perception of the part of the to-be-grouped object. While specific contributions of the conscious perception should be examined in future studies, this study emphasized that the object configuration can exist and exert influence unconsciously.

is no way to know whether the second one is true or not because there is no objective measurement of the end product of processing (e.g., completed object) other than subjective detection of seeing 'any part' (instead of all parts) of the end product—a common practice when measuring release from suppression during CFS. Thus, while assuming that the stimuli were well processed before breaking into consciousness, it might be that the stimuli were brought into consciousness as separate parts (or Pacman) and grouped with each other when breaking into the realm of consciousness. Therefore, unless the grouped triangle in Wang, Weng and He's study (2012) remained in unconsciousness and exerted behavioral influence other than subjective report, as we showed here, there is no way to tell whether that grouping occurred at a conscious or unconscious stage. In line with this reasoning, the results we demonstrated in this study (that the object configuration remained unknown to the participants after grouping) could be used to support interocular grouping occurring unconsciously, or equivalently, without the need for all of its constituent parts to be visible.

Although attentional effect (i.e. object-based advantage) served only as a dependent variable to illustrate whether or not interocular grouping could occur unconsciously in this study, attention itself has been viewed to be close to consciousness. In the discussion of dissociation between attention and consciousness (Koch & Tsuchiya, 2006), it is very difficult to attain a situation in which attention is totally absent while consciousness is present. The current study provided, as a side track, an instance of dissociation between attention and consciousness because our results revealed that, while attention operated on the interocularly grouped object, the portion of the object that was visible to the participants did not expand accordingly. It also suggests that consciousness emerges for the grouped object differently from the way attention does. Moreover, the reliance of stimulus strength for attention and consciousness differs. While 20% of contrast for suppressed stimuli is sufficient for attention to operate on grouped objects, it is insufficient to evoke awareness—a finding in line with dissociation between consciousness and feature-based attention (Schmidt & Schmidt, 2010) or object-based attention (Norman, Heywood, & Kentridge, 2013).

In conclusion, using CFS, this study provides the first evidence that interocular grouping occurs without awareness. That is, grouping occurs between visible and invisible stimuli and the resulting object configuration remains unknown to the participants.

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