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Interocular grouping without awareness

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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]

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[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).