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Invisible motion contributes to simultaneous motion contrast

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ABSTRACT

The purpose of the present study was two-fold. First we examined whether visible motion appearance was altered by the spatial interaction between invisible and visible motion. We addressed this issue by means of simultaneous motion contrast, in which a horizontal test grating with a counterphase luminance modulation was seen to have the opposite motion direction to a peripheral inducer grating with unidirectional upward or downward motion. Using a mirror stereoscope, observers viewed the inducer and test gratings with one eye, and continuous flashes of colorful squares forming an annulus shape with the other eye. The continuous flashes rendered the inducer subjectively invisible. The observers' task was to report whether the test grating moved upward or downward. Consequently, simultaneous motion contrast was observed even when the inducer was invisible (Experiment 1). Second, we examined whether the observers could correctly respond to the direction of invisible motion: It was impossible (Experiment 2).

1. Introduction

'Invisible' stimuli occasionally impact on the processing of 'visible' stimuli. For example, observers can perceive a contrast-modulation flicker of the grating with high spatial frequency of more than 60 cycles per degree (cpd), in spite of their being unable to discriminate the orientation of the grating (MacLeod & He, 1993). In a similar vein, He and MacLeod (2001) reported that orientation-specific aftereffects occurred after observers adapted to the grating, the orientation of which was unresolvable due to the high spatial frequency. The unresolvable orientation of the grating also affects apparent motion perception and serves as a spatial cue (Rajimehr, 2004). In addition, perceptual adaptation to an invisible flicker due to high temporal frequency has been reported (Shady, MacLeod, & Fisher, 2004). These results indicate that unresolvable orientation and flicker information is retained during visual processing, and can interplay with successive visible stimuli. Consistent with this idea, Jiang, Zhou, and He (2007) observed the brain activities that correlated with the invisible chromatic flicker with a high temporal frequency of more than 25 Hz.

In addition to stimuli that are invisible due to the limitation of spatiotemporal resolution of visual processing, stimuli that are invisible due to subjective disappearance phenomena have been used to assess the effect of invisible visual information on conscious visual processing. For example, by employing motion-induced blindness (MIB: Bonneh, Cooperman, & Sagi, 2001), previous studies have reported an orientation-specific aftereffect of the invisible grating (Montaser-Kouhsari, Moradi, Zandvakili, & Esteky, 2004), and the robust formation of a negative afterimage (Hofstoetter, Koch, & Kiper, 2004). By using visual crowding (Bouma, 1970; Toet & Levi, 1992), studies have shown the orientation-selective aftereffect of invisible illusory lines (Montaser-Kouhsari & Rajimehr, 2005; Rajimehr, Montaser-Kouhsari, & Afraz, 2003) and the motion aftereffects of several types of motion stimuli, such as invisible apparent motion (Rajimehr, Vaziri-Pashkam, Afraz, & Esteky, 2004),

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invisible first order motion[1] (Whitney, 2005) and invisible second-order motion[2] (Harp, Bressler, & Whitney, 2007; Whitney & Bressler, 2007). Furthermore, by employing binocular rivalry (Alais & Blake, 2005), previous studies have reported contrast aftereffects and spatial frequency aftereffects (Blake & Fox, 1975), the McCollough effect (White, Petry, Riggs, & Miller, 1978), and a motion aftereffect (Blake, Tadin, Sobel, Raissian, & Chong, 2006; Lehmkuhle & Fox, 1975; O'Shea & Crassini, 1981), but no facial aftereffect (Moradi, Koch, & Shimojo, 2005). On the basis of these findings, many studies have proposed that the 'invisible' visual stimuli are still processed in the visual system, and cause perceptual aftereffects.

On the other hand, whether spatial interaction between invisible and visible stimuli affects the appearance of visible stimuli is still a subject of debate. Clifford and Harris (2005) showed that simultaneous orientation contrast[3] occurred even when the surround orientation, as an inducer, was invisible due to backward masking. Pearson and Clifford (2005) also showed that the surround orientation suppressed by binocular rivalry contributed to simultaneous orientation contrast. On the other hand, the visual phantom perception[4] in the static display (Gyoba, 1983) disappeared when surrounding inducers were invisible due to flash suppression or binocular rivalry (Meng, Ferneyhough, & Tong, 2007). Thus, it was the important task for vision researchers to specify what kinds of spatial interaction occurred between invisible and visible stimuli.

The purpose of the present study was two-fold. First, we investigated whether simultaneous motion contrast occurred even when the inducer motion was invisible. Simultaneous motion contrast refers to the phenomenon by which ambiguous motion in the central patch is perceived to have the opposite direction to the motion in the surrounding inducer (see for example Nishida, Edwards, & Sato, 1997). Simultaneous motion contrast is deeply related to the center-surround spatial interaction in the motion processing mechanism (Murakami & Shimojo, 1993; Tadin, Lappin, Gilroy, & Blake, 2003). Thus, by investigating whether invisible inducer motion could alter the perceived motion direction in the test patch, we could directly confirm the effects of spatial interaction between invisible and visible motion on the appearance of visible motion.

The second purpose of our study was to additionally examine whether the invisible motion could affect guess-based decisions for motion direction in a direct way. In a study by Clifford and Harris (2005), the invisible grating orientation induced simultaneous orientation contrast, but did not contribute to the direct discrimination of the invisible grating orientation. That is, the orientation of invisible gratings affected the appearance of visible grating in an indirect way, but it did not contribute to guess-based decisions for the orientation of invisible grating in a direct way. They discussed that the neural activity strength for the inducer orientation generating the simultaneous orientation contrast is insufficient to generate a conscious representation of the inducer orientation. The present study also confirmed whether the invisible inducer motion that altered the appearance of visible test motion also contributed to guess-based discriminations of invisible motion direction in a direct way.

2. Experiment 1

In Experiment 1a, we examined whether invisible inducer motion can contribute to simultaneous motion contrast. We rendered inducer motion invisible by means of continuous flash suppression (CFS: Tsuchiya & Koch, 2005). We also tested whether there was a difference in the magnitude of simultaneous motion contrast depending on the inducer's visibility. Furthermore, in Experiment 1b, we checked whether simultaneous motion contrast occurred in the dichoptic presentation. Walker and Powell (1974) showed that spatial interaction of velocity processing was observed only in the monocular presentation. Thus, by investigating simultaneous motion contrast in monocular and dichoptic presentations we could specify the pathway (monocular vs. binocular) that was suppressed by continuous flashes.

2.1. Methods

2.1.1. Observers

In Experiment 1a, five observers, including the two authors, participated in the experiment. In Experiment 1b, the two authors and three naive observers participated in this experiment. Apart from the authors, no observers participated in Experiment 1a. They reported that they had normal or corrected-to-normal visual acuity. Apart from the authors, the observers were naive as to the purpose of the experiment. The observers received ¥800 for their participation.

2.1.2. Apparatus

Stimuli were presented on a 17-inch CRT monitor (HF703U; Iiyama, Japan). The resolution of the monitor was 1024 $\times$ 768 pixels and the refresh rate was 100 Hz. The presentation of stimuli and collection of data were controlled by a computer (Mac pro; Apple). Using a photometer (3298F; Yokogawa, Japan), we performed gamma correction for the luminance emitted from the monitor. The observers viewed stimuli through a mirror stereoscope (Screenscope, Stereoaids, Australia).

[1] A kind of motion that is defined by luminance features, and processed in a linear spatiotemporal filter.
[2] A kind of motion that is defined by non-luminance feature such as texture, contrast, and flicker, processed in a filter-rectify-filter system.
[3] A perceptual phenomenon where the orientation of a central patch is perceived as tilted in the orientation opposed to a surround background.
[4] A perceptual phenomenon where perceptual filling-in occurs between two separated low-contrast gratings.