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Surround-contingent motion aftereffect

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ABSTRACT

We investigated whether motion aftereffects (MAE) can be contingent on surroundings. Random dots moving leftward and rightward were presented in alternation. Moving dots were surrounded by an open circle or an open square. After prolonged exposure to these stimuli, MAE were found to be contingent upon the surrounding frames: dots moving in a random direction appeared moving leftward when surrounded by the frame that was presented in conjunction with rightward motion. The effect lasted for 24 h and was observed when adapter and test stimuli were presented not only retinotopically, but also at the same spatiotopic position. Furthermore, the effect was observed even when the adapter and test stimuli were presented at different retinotopic and spatiotopic positions as long as they were presented in the same hemi-field. These results indicate that MAE would be influenced not only by the stimulus features, but also by their surroundings, and they suggest that the surround-contingent MAE might be mediated in the higher stage of the motion processing pathway.

1. Introduction

Prolonged exposure to paired presentation of two different sensory features causes an aftereffect that is contingent on one of the features. For example, after viewing repeated alternations of red vertical and green horizontal gratings, an achromatic vertical grating looks greenish, whereas an achromatic horizontal grating looks reddish (McCollough, 1965). In contingent aftereffects, many types of sensory features can be paired including color-contingent orientation (Held & Shattuck, 1971) and motion (Favreau, Emerson, & Corballis, 1972) aftereffects, spatial frequency-contingent (May & Matterson, 1976) and motion-contingent color aftereffects (Hepler, 1968), and disparity-contingent motion aftereffects (Anstis & Harris, 1974). It is well known that contingent aftereffects last for a long time: color contingent motion aftereffects last for 24 h (Favreau et al., 1972; Hepler, 1968) or a few days (Mayhew & Anstis, 1972).

The paired sensory features belong to one stimulus in the studies on contingent aftereffects. The color of the grating is contingent upon the orientation of the same grating. However, the perception of a visual object is largely influenced not only by the stimulus features belonging to the object itself but also by its surroundings. For instance, the perceived brightness and color of an object depend upon its surroundings (Albright & Stoner, 2002). The perceived shape (Kaufman, 1979) and moving velocity and direction (Loomis & Nakayama, 1973; Nawrot & Sekuler, 1990) of an object are also influenced by its surroundings. It is possible that the aftereffects are also affected by spatial contexts. It was recently shown that the tilt aftereffects could be contingent on the features of the surrounding frames, and that these effects lasted for 24 h (Nakashima & Sugita, 2014). It has been reported that the motion aftereffects (MAE) are contingent on the color of the surroundings (Durgin, 1996; Potts & Harris, 1975). Therefore, in this study, we examined whether the MAE were affected by spatial contexts and found that the MAE could be contingent on the shape of the surrounding frames and the effects persisted at least for 24 h.

Motion and form information is strongly linked in the brain: some neurons in the visual cortex are selective for both motion and orientation (Albright, 1984; Maunsell & Van Essen, 1983) and distinct pathways of motion and form mutually interact (Beck & Neumann, 2010). Recent psychophysical studies have demonstrated that motion and form perception interact. The strength of the MAE is modulated by orientation signals presented with motion stimuli, and the motion–orientation interaction is considered to occur at the higher level of motion processing where local motion is integrated (Mather, Pavan, Bellacosa, & Casco, 2012) or optic flow is extracted (Pavan, Marotti, & Mather, 2013). The frame shape-contingent MAE examined in the present study demonstrates another type of motion-form interaction where motion and shape signals interact.

It has been argued that some aftereffects are remapped across a saccade to keep the adapting location aligned in the external world (Melcher, 2005, 2007; Zimmermann, Morrone, Fink, & Burr, 2013),

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although the aftereffects are the strongest in the retinotopic reference frame. The MAE were found to occur in the spatiotopic reference frame (Ezzati, Golzar, & Afraz, 2008). However, it has been also reported that the MAE are retinotopic but not spatiotopic (Knapen, Rolfs, & Cavanagh, 2009; Wenderoth & Wiese, 2008). The results of fMRI studies have been also inconsistent. One study claimed that the area hMT encodes motion signals not only in the retinotopic but also in the spatiotopic position (d'Avossa et al., 2007); however, it has also been reported that only retinotopic representation is observed in the MT (Gardner, Merriam, Movshon, & Heeger, 2008). To examine the reference frame of the contingent MAE, we conducted experiments with four reference frame conditions where the location of adapter and test stimuli were: the same in a retinotopic frame of reference (retinotopic), the same in a spatiotopic frame of reference (spatiotopic), the same in both frames of reference (full), and different in both frames of reference (unmatched).

2. Experiment 1

2.1. Methods

2.1.1. Participants

Twelve participants (20–25 years old) took part in the experiment, all of whom had normal or corrected-to-normal vision. The participants, except the authors, were naive to the purpose of the experiments. The experiment was performed in accordance with the Declaration of Helsinki. Informed consent was obtained from all participants.

2.1.2. Stimuli

Two-dimensional visual stimuli were presented on a 24-inch CRT display (800×600 pixel resolution, refresh rate of 60 Hz) with a viewing distance of 1 m. A global motion display containing 200 white dots (112.4 cd/m^2) was presented as adapter and test stimuli on a uniform black background (0.1 cd/m^2). Each dot (0.03° in diameter) moved within an invisible circular window (4.6° in diameter). The velocity and life time of each dot were 6.6°/s and 166.7 ms, respectively.

2.1.3. Procedure

The participants were asked to keep looking at a red fixation (24.53 cd/m^2 and 0.2° in diameter) in a dark room. In the adaptation phase, the fixation was presented at the center of the screen and the adapter stimuli, where all dots moved rightward and leftward, were presented in alternation (Fig. 1A). The center of the adapter stimulus was 2.9° to the right from the fixation. The duration of each adapter stimulus was 5000 ms. For half the participants, a square frame (4.3° in inner side and 4.9° in outer side) was always presented in conjunction with the rightward motion and a circle frame (4.8° in inner diameter and 5.4° in outer diameter) with the leftward motion. For the remaining half, the relationship was reversed. The frames were presented 100 ms before the stimuli. The alternate presentation of the adapter stimuli lasted for 90 s and repeated 10 times with a short rest (less than 20 s). Thus, total adaptation time was at least 15 min.

In the test phase, the adapter stimulus disappeared and the fixation appeared. After 500 ms, the test stimulus was presented at 2.9° to the right from the fixation, the duration of which was 900 ms (Fig. 1A). In a rightward frame condition, the test stimulus was presented in conjunction with the frame that was accompanied with the rightward moving adapter in the adaptation condition. In a leftward frame condition, the test stimulus was presented with the frame that was accompanied with the leftward moving adapter. A no-frame condition was also included. The coherence of dots in the test stimulus was from −30% to 30% in a step of 6%. The amount of coherence and the condition were randomized from trial to trial. The participants judged whether the stimulus moved rightward or leftward. Ten responses were obtained for each condition. The test phase was conducted before and after adaptation with the same procedure.

In the above condition, the test stimulus was presented not only in the identical retinal location but also in the same screen location (full condition). To examine the reference frame of the surround-contingent aftereffects, participants were given another six sessions in another retinal position as well as in another screen position (Fig. 1B). In the retinotopic condition, the fixation was presented at 4.3° left from the screen center and the test stimulus was presented at 2.9° to the right from the fixation, so that the adapter- and test stimuli were presented at the same retinal location but at different screen locations. The spatiotopic condition was tested for two different fixation points. In one spatiotopic condition, the fixation was presented at 1.4° to the left from the screen center and the test stimulus was presented at 4.3° to the right from the fixation. In the other spatiotopic condition, the fixation was presented at 5.8° to the right from the screen center and the test stimulus was presented at 2.9° to the left from the fixation. The adapter- and test stimuli were presented in the same hemi-field in the first spatiotopic condition, whereas they were presented in different hemi-fields in the second spatiotopic condition. Three unmatched conditions were also tested, where the adapter- and test stimuli were presented at different retinal and screen locations. The fixation was presented at 5.8° to the left from the screen center and the test stimulus was presented at 4.3° to the right from the fixation in the first unmatched condition. In contrast, the fixation was presented at 2.9° to the right from the screen center and the test stimulus was presented at 4.3° to the right from the fixation in the second unmatched condition. In these two conditions, the adapter- and test stimuli were presented in the same hemi-field. In the third unmatched condition, the fixation was presented at 2.9° to the right from the screen center and the test stimulus was presented at 2.9° to the left from the fixation, where the adapter- and test stimuli were presented in different hemi-fields. When the test phase started and the fixation moved to a new location, participants were required to move their eyes to the new fixation point as soon as possible. A random order of reference frame conditions was assigned to each participant.

To examine the persistence of the aftereffect, the test session was also conducted 24 h after the adaptation. Only the full condition was examined, because the strongest effect has been observed in the full condition.

2.2. Results

The proportions of rightward motion response were plotted against the dots coherence of the test stimuli. To determine a point of subjective stationarity (PSS), we calculated the 50% point (the point of subjective equality) by fitting a cumulative normal-distribution function to each participant's data using the maximum likelihood estimation. Before the exposure to the adapter stimuli, surrounding frames did not affect the PSS. However, the frames affected the PSS after adaptation (Fig. 2). The judgments of the test stimuli shifted to the leftward motion when presented in conjunction with the frame that was accompanied with the adapter stimulus moving rightward compared with when presented with no frame. In contrast, it shifted to the rightward motion when presented in conjunction with the frame that was accompanied with the adapter stimulus moving leftward compared with when presented with no frame.

To evaluate the effect of adaptation, the PSS shift was calculated by subtracting the PSS for the no-frame condition from that for