Strong influence of test patterns on the perception of motion aftereffect and position

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In a completely linear system, the behavior of a square wave pattern can be predicted by its sinusoidal components. However, we observed a complete breakdown of the linear system prediction in the perception of the motion aftereffect (MAE). The duration of the MAE was measured following a one-minute adaptation to a rotating radial grating. Three different luminance patterns were used for both the adaptation and test stimulus: (1) sine wave, (2) square wave, and (3) complex grating with the same Fourier amplitude spectrum as the square wave, but with randomized phases. The sine wave stimulus generated the highest magnitude MAE, followed by the random-phase complex grating, and lastly the square wave grating. To test whether the square wave grating is a weak adaptor or a weak test for the MAE, we performed a cross adaptation experiment in which the sine wave, square wave, and complex gratings were paired in seven ways. Results show that the strength of the MAE critically depended on the test pattern. Regardless of the adaptor, MAE strength is in a decreasing order with the test pattern as sine wave grating, complex grating, and square wave grating. Further experiments ruled out the possibility that differential MAEs between these conditions are due to different peak contrasts in these patterns. Additionally, the MAE from a square wave grating as the test pattern is not accompanied by a significant concurrent shift in the apparent position. Linear system theory cannot predict the magnitude of the MAE using complex gratings. The spatial features of a test stimulus, such as position reliability or luminance uniformity, strongly influence the magnitude of MAE. Sharp edges and local luminance uniformity can greatly reduce MAE.

Keywords: motion aftereffect, spatial pattern, linear system, adaptation, position

Introduction

The motion aftereffect (MAE) refers to the change in motion perception following prolonged observation of a regularly moving stimulus. Typically, the MAE involves the apparent motion of a stationary stimulus in the opposite direction to a previously observed one, but it can also result in a change in the apparent velocity of a moving stimulus (Mather, Verstraten, & Anstis, 1998).

Sine wave gratings gained their popularity after Blakemore and Campbell (1969) introduced the idea of the visual system as a set of "spatial-frequency channels." These so-called "spatial-frequency channels" were suggested to form the basis of a visual Fourier analysis of the retinal image (Robson, 1975). Sine wave gratings have been widely used in visual detection and discrimination tasks (see Wilson & Wilkinson's review, 1997), and it is a natural extension to use them in studies of MAE. Meanwhile, the square wave grating has also been frequently used in MAE studies for its spatial simplicity. With the Fourier transform, the square-wave can be decomposed into a series of sinusoid harmonic components.

The MAE is a very robust phenomenon in the sense that after motion adaptation, almost any static pattern will be seen as moving. Because any spatial pattern can be decomposed into its Fourier components, the generality of the MAE implies that the motion adaptation occurs on the underlying channels tuned to different spatial frequencies, not on the specific adapting pattern per se.

Some very general underlying assumptions of the MAE (Mather et al., 1998) are that when we "adapt" to a pattern, we assume that some mechanisms, neurons, or synapses in the visual pathways are excited, stimulated, or activated. In addition, it is assumed that the greater the excitation, stimulation, or activation during adaptation, the greater the mechanisms, neurons, or synapses are adapted, fatigued, or habituated, resulting in a stronger MAE (Priebe & Lisberger, 2002). Because the multiple sinusoid components in a square wave grating can stimulate a range of spatial-frequency channels in the visual system simultaneously, one may want to predict that the MAE produced by square wave grating will be stronger than that produced by a sine wave grating, especially given that there is evidence showing that some MAE signals can be linearly combined (Mather & Moulden, 1980; Verstraten, Fredericksen, & van de Grind, 1994). In these studies, subjects adapted to two motions simultaneously. The MAE direction was predicted by the vector sum of the adaptation components. Is it the case that the MAE magnitude produced by square wave grating

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can be predicted from those produced by its Fourier components?

However, the advent of "spatial-frequency channels" analysis may be partly responsible for the general neglect of nonlinear interactions in the visual system. Recent work has demonstrated that early visual channels interact through a variety of nonlinear pooling mechanisms. Such nonlinear interactions perform important computations in texture perception, stereopsis, and motion and form vision (Wilson & Wilkinson, 1997). It is possible that nonlinear interactions exist in the generation of MAE, which in turn will lead to a failure of predicting MAE of a complex grating from its sinusoidal components. Actually, some studies have demonstrated the effects of cross-channel interaction on visual aftereffects (Levinson & Sekuler, 1975; Magnussen & Kurtenbach, 1980).

To test whether MAE can be predicted based on a linear model, we measured the strength of MAE to a number of different spatial patterns. In particular, in Experiment 1, we tested whether changing the relative phases of sine wave components in a pattern will alter the perceived MAE. Given that we did find a contribution from spatial phase in Experiment 1, we further tested whether the pattern influence occurs during the adaptation or testing phase in Experiment 2. Nishida and Johnston (1999) showed that motion aftereffect could alter the perceived position of a visual target. In Experiment 3, we also test if spatial pattern can influence the perception of illusory position shift following motion adaptation.

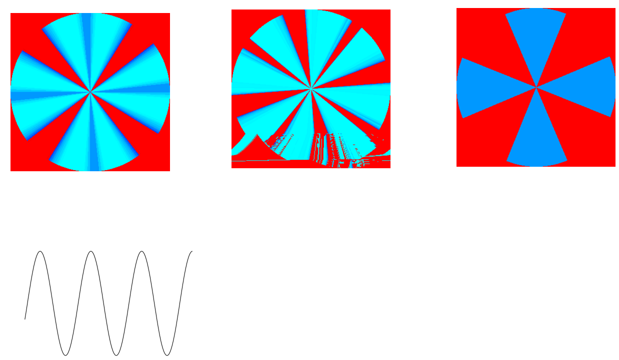
Experiment 1: Does spatial phase matter in MAE?

The purpose of this experiment is to compare the MAE magnitudes generated by sine wave and square wave gratings. We also measured the MAE from a complex grating that shares the same amplitude spectrum with the square wave grating, but with scrambled phases. Because randomizing the phases of sine wave components could make the peak contrast of a complex grating higher than a square wave, and some studies (Keck, Palella, & Pantle, 1976; Nishida, Ashida, & Sato, 1997) have shown that increasing adaptation contrast increases the MAE, it was necessary to do a control experiment to test whether differences in peak contrast are responsible for the different MAE between the complex and square wave gratings observed in Experiment 1.

Method

Apparatus and stimuli

All experiments were conducted on a PC controlling a SONY 19-inch Trinitron high-resolution monitor (1280 × 1024) set at 100-Hz refresh rate. Stimuli were radial gratings of three types of waveforms: sine wave (SIN), square-wave components with scrambled phases (SCR), and square wave (SQU). The diameter of each stimulus was 8.2 deg. The fundamental frequency for all three stimuli was 4 cycles per revolution at 50% contrast. The mean luminance of the stimuli is 40 cd/m^2. SCR was generated by randomly scrambling the phase spectrum of SQU with the constraint that the maximal and minimal luminance values in SCR are within the luminance range of the monitor. The stimuli and their luminance profiles are shown in Figure 1.



Results

As shown in Figure 2, for all observers, the most robust result is that the MAE generated by SQU is surprisingly weak (~10 s), and the SIN generated the longest MAE (> 30 s). The duration of MAE from SCR lies between the other two (20-30 s). The difference of MAE duration between any pair of stimuli types reached statistical significance ($p < .01$).

For the control experiment directly comparing the MAE from SCR and SQU, all four subjects judged the MAE from SCR stronger than that from SQU in all 40 trials. This result shows that when the peak contrast of SQU was increased to exceed that of the SCR, the SCR still generated a stronger MAE.

It should be noted that equating the peak contrast between SIN and SQU did not make the amplitude of the fundamental frequency equal. We found equating the amplitudes of their fundamental frequencies had a negligible effect on our results.

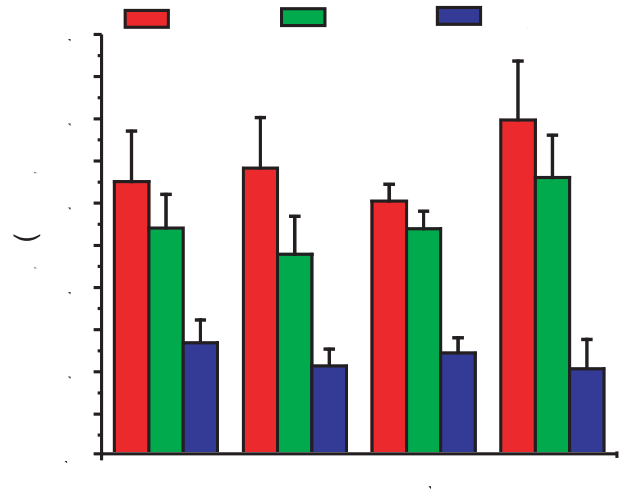


Figure 2. Average MAE durations for three types of stimuli from four observers (n = 12). Vertical bars denote 1 *SD*.

Experiment 2: Adapting versus test stimulus: cross adaptation between different patterns

Experiment 1 demonstrated that the square wave grating produced much weaker MAE than the complex and sine wave gratings. Why was the MAE from the square wave grating so weak? The MAE duration reported in Experiment 1 for square wave grating probably overestimates the actual strength of the square wave MAE. All subjects reported that they could hardly perceive any significant illusory rotation of the square wave grating after adaptation, but saw only weak "vibration" of the borders between bright and dark regions. To further explore whether the lack of strong MAE from square wave grating is because square wave grating is a poor adaptor or a poor test pattern for MAE, we performed a cross adaptation experiment pairing complex (SCR), square wave (SQU), and sine wave (SIN) gratings across each other.

Method

There were seven experimental conditions, depicted in the insets in Figure 3, consisting of adaptation – test pairs as following: (1) sine wave – sine wave, (2) square wave – sine wave, (3) complex – complex, (4) square wave – complex, (5) sine wave – square wave, (6) complex – square wave, and (7) square wave – square wave. In the complex-complex condition, the adapter and test were identical. The experimental procedure was the same as that of Experiment 1. One experienced (FF) and three naïve observers (WL, JZ, and JW) participated in this experiment.

Results

The duration of MAE highly depended on the test pattern, but not adaptor (see Figure 3). As the test pattern, the sine wave grating generated the longest MAE (close to 30 s), the complex grating generated shorter MAE (low 20 s), and the square wave grating generated the shortest MAE (~10 s). The difference of MAE duration among different test patterns was significant ($p < .01$). Somewhat surprisingly, for each test pattern, there was no significant difference between different adaptors.

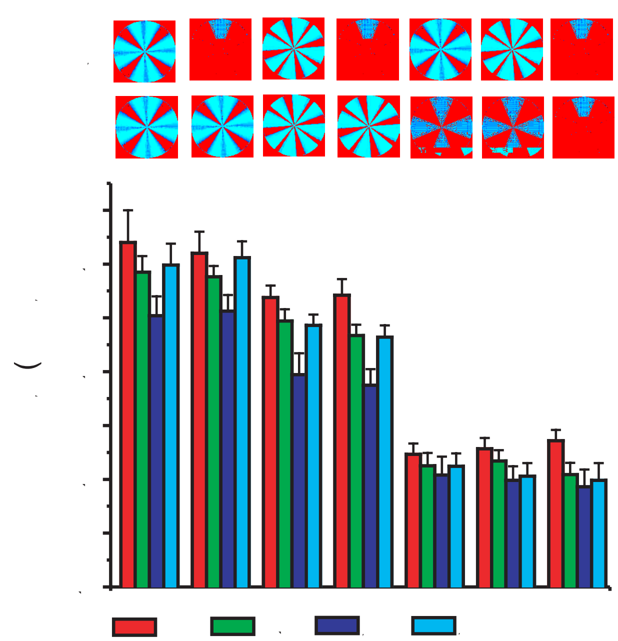


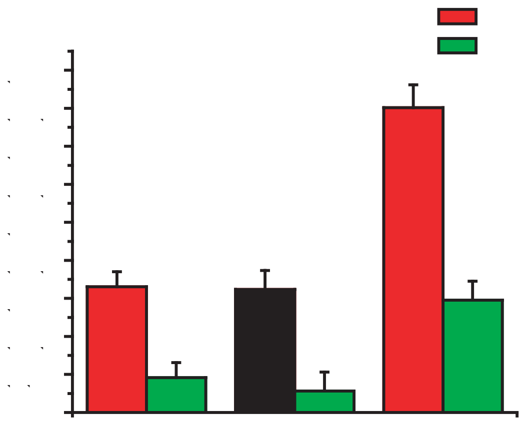
Figure 3. The results of Experiment 2. Average MAE durations for four experimental conditions from four observers (n = 12). Vertical bars denote 1 *SD*.

Control experiment

A possible explanation for weak MAE from SQU as test pattern is that subjects used different criteria for judging when the different patterns are (and are not) in motion. For example, if it were in some sense "harder to see" a particular pattern moving, then that would tend to shorten the measured MAE duration, even though the effect had nothing to do with that pattern's susceptibility to adaptation per se. We did a simple control experiment to measure (unadapted) minimum motion thresholds of two subjects (FF and WL) for the three different patterns. The experimental procedure was very similar to that used by Tadin, Lappin, Gilroy, and Blake (2003). We measured the threshold exposure duration required for human observers to accurately identify the motion direction of a horizontally drifting vertical linear grating (SIN, SQU, and SCR). The stimuli extended 8.2×8.2 deg^2. The fundamental frequency for all three stimuli was 0.31 c/deg at 50% contrast, which was the average frequency of radial pattern used in Experiments 1 and 2. Other experimental conditions were the same as those used in Experiments 1 and 2. On each trial, a drifting patch was presented foveally and observers indicated the perceived direction (left or right) by a key press.

Results

As shown in Figure 5, spatial pattern played an important role in the MAE-induced position change. For the sine wave grating, all three subjects needed a significantly larger (about 3 times larger) spatial shift between the two gratings to perceive them as aligned, compared with the square wave grating (p < .01). A potential explanation of this phenomenon is that the square wave grating provides a strong position cue to prevent the illusory position shift.



Discussion

We found that the square wave grating produced much weaker MAE than the sine wave and complex gratings. Cross adaptation between these patterns showed that the square wave grating was not a weaker adaptor for the motion system. The weak MAE was only observed when square wave grating was used as the test stimulus.

Why does square wave grating as a test pattern generate very weak MAE? We suggest that two properties of the square wave pattern may contribute to this result: position reliability and local luminance uniformity. Intuitively, if a test stimulus provides reliable cues on spatial position, then it will be difficult to generate illusory motion. The square wave grating, with the black and white boundaries sharply localized, presumably provides such reliable position cues. Similarly, the reliable positions cues can prevent the illusory position shift of the test pattern. This point was supported by a parallel study (Fu, Shen, & Dan, 2001). In their experiment, motion-induced perceptual extrapolation of both first- and second-order targets depended critically on spatial blurring of the targets. For example, the perceptual displacement of a sharp-edged target was near zero; however, for a target with Gaussian profile, its displacement was very significant. The influence of visual motion on perceived position has been well acknowledged (see a review by Whitney, 2002). The current study highlights the reverse influence, that the reliability of position cues strongly affects the strength of perceived illusory motion. It supports the intricate relationship between representations of an object's (or pattern's) location and its motion, possibly supported by the interactions between MT and V1 neurons (Ramachandran & Anstis, 1990; De Valois & De Valois, 1991; Whitney & Cavangh, 2000; Pascual-Leone & Walsh, 2001; Murray, Kersten, Olshausen, Schrater, & Woods, 2002). With this explanation, it is not surprising to find that the MAE from a square wave grating as a test pattern is not accompanied by a concurrent shift in the apparent position.

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