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The motion aftereffect of transparent motion: Two temporal channels account for perceived direction

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Abstract

Adaptation to orthogonal transparent patterns drifting at the same speed produces a unidirectional motion aftereffect (MAE) whose direction is opposite the average adaptation direction. If the patterns move at different speeds, MAE direction can be predicted by an inverse vector average, using the observer's motion sensitivity to each individual pattern as vector magnitudes. These weights are well approximated by the duration of each pattern's MAE, as measured with static test patterns. However, previous efforts to use the inverse-vector-average rule with dynamic test patterns have failed. Generally, these studies have used spatially and temporally broadband test stimuli. Here, in order to gain insight into the possible contribution of temporal channels, we filtered our test pattern in the temporal domain to produce five ideal, octave-width pass-bands. MAE *durations* were measured for single-component stimuli drifting at various adaptation speeds and tested at a range of temporal frequencies. Then, two components with orthogonal directions and different speeds were combined and the *direction* of the resulting MAE was measured. The key findings are that: (i) for a given adaptation speed, the duration of a single component's MAE is dependent on test temporal frequency; (ii) the direction of MAEs produced by transparent motion (i.e., bivectorial adaptation) also varies strongly as a function test temporal frequency (by up to 90° for some speed pairings); and (iii) the inverse-vector-average rule predicts the direction of the transparent MAE provided the MAE durations used to weight the vector combination were obtained from stimuli matched in adaptation speed and test temporal frequency. These results are discussed in terms of the number and shape of temporal channels in our visual system.

Keywords: Transparent motion; Motion aftereffect; Adaptation; Temporal channels; Speed; Temporal frequency

1. Introduction

The motion aftereffect (MAE) is the term given to the illusory motion perceived in a test pattern following prolonged exposure to a moving pattern (Anstis, Verstraten, & Mather, 1998; Mather, Verstraten, & Anstis, 1998). Typically, the test pattern is stationary and the direction of the illusory movement is opposite that of the adapting movement. Explanations of the MAE are usually couched in terms of adaptation of direction-selective cortical units following a sustained period of activation (Barlow & Hill, 1963; Huk, Ress, & Heeger, 2002; Mather, 1980; Sutherland, 1961). This produces an imbalance in the population of these units such that the direction opposite adaptation is temporarily dominant.

There is a class of motion stimuli that do not produce MAEs in the direction opposite that of adaptation. These are transparent-motion stimuli, produced by superimposing (or rapidly interleaving) two arrays of random dots drifting in differing directions. During

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adaptation, the percept elicited is of two transparent sheets of dots translating independently. As with single-component movement, adaptation to transparent motion also produces a MAE but, curiously, it does not result in two transparent MAEs, one opposite each of the two component motions seen during adaptation. Rather, the MAE of transparent motion is univectorial with a direction opposite the average direction of the adapting motions (Mather, 1980).

Verstraten and colleagues tested the vector-average proposal by adapting to two orthogonal motions and varying their relative speeds. When the adapting components had the same speed, the MAE reflected the average direction. However, when the adapting components differed in speed, the MAE direction deviated from a simple directional average and exhibited a speed-dependent bias. This suggested that the transparent MAE might reflect a true vector average, with the weight of each component in the directional average determined by the motion system's sensitivity to that component's speed. To quantify this, MAE durations were measured for each of the component directions at a range of speeds, and these too were found to depend on adaptation speed. Taking these MAE durations as indicative of the underlying motion sensitivity to a given direction and speed, they can serve as magnitudes for each component's direction, effectively creating motion vectors. For a range of relative speeds, it was found that the speed-dependent deviations from a simple directional average in the transparent MAE were well predicted by an inverse-vector-average rule (Verstraten, Fredericksen, & van De Grind, 1994).

A novel means of eliciting the MAE was introduced first by Mather (1980) and developed by Hiris and Blake (Blake & Hiris, 1993; Hiris & Blake, 1992). Instead of using a static test pattern, they introduced a dynamic test pattern containing an array of dots which jumped about randomly and incoherently. Locally, this stimulus contains a broad range of directions and speeds but (globally) contains no net motion. The rationale for using this stimulus was that a dynamic test stimulus would better drive the motion system during MAE testing to more effectively reveal its adapted state. In a study employing dynamic MAE test stimuli, it was found that MAE directions following transparent motion adaptation differed depending on whether the test stimulus was static or dynamic (Verstraten, van der Smagt, Fredericksen, & van de Grind, 1999). While the MAE directions elicited by static test patterns were predictable using the inverse-vector-average rule (with component MAE durations as weights), those elicited by dynamic test patterns were not (Verstraten and colleagues, unpublished experiments). Their conclusion was that there must be different systems underlying static and dynamic MAEs.

In another study, support was found for two pattern-MAE systems when the durations of MAEs produced by single-component adaptation were measured on static and on dynamic test patterns. The key difference concerned the speed tuning of MAE duration: The strongest dynamic MAEs were elicited by fast adaptation speeds whereas the strongest static MAEs were produced by much slower speeds (Verstraten, van der Smagt, & van de Grind, 1998). Further support for the claim that static and dynamic MAEs are produced in different systems came from a study that showed that it was possible for transparent motion adaptation to produce transparent, bivectorial MAEs (van der Smagt, Verstraten, & van de Grind, 1999). They achieved this by interleaving static and dynamic components in the same test pattern, which presumably tapped separate and independent systems to yield a transparent, bivectorial MAE. Recently, van de Grind and his colleagues collected more evidence for separate mechanisms showing that low and high speeds do not rival when binocularly fused (van de Grind, van Hof, van der Smagt, & Verstraten, 2001).

In the present paper, our goal is to understand why the direction of the dynamically tested transparent MAE cannot be predicted by the inverse-vector-average rule. As a starting point, it is known that dynamic stimuli are processed through temporal channels sensitive to particular ranges of temporal modulation. Psychophysical work on this matter suggests that there are at least two temporal channels (Anderson & Burr, 1985; Fredericksen & Hess, 1998; Hammett & Smith, 1992; Hess & Snowden, 1992; Mandler & Makous, 1984), which can be characterised as a broad low-pass channel and a higher band-pass channel. We reason that adaptation to transparent motion with components of differing speeds would differentially activate the temporal channels. A slow vector would primarily drive the low-frequency temporal channel, whereas a fast vector would primarily drive the high-frequency channel. When the MAE is tested with a broad-band dynamic test pattern, such as those used by Blake and Hiris (1993), the MAE direction would presumably reflect similar contributions from both these channels. However, in this paper, by using dynamic random-dot test patterns temporally filtered into narrow pass-bands, it should be possible to tap preferentially into one temporal channel more than the other. Thus, following adaptation to transparent motion containing both a fast and a slow component, slowly modulating test patterns should elicit a MAE direction opposite the slow component, and quickly modulating test patterns should elicit a MAE direction opposite the fast component. Intermediate test modulations would tap both temporal channels, producing intermediate MAE directions.

The purpose of the present paper is to test these claims and, more specifically, to determine whether the inverse-vector-average rule can accurately predict the direction of transparent MAEs in dynamic test patterns.