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A MOTION AFTEREFFECT FROM AN ISOLUMINANT STIMULUS

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Abstract—We investigate whether a motion aftereffect (MAE) can be induced by an isoluminant stimulus which contains colour contrast but no luminance contrast. We created a red/green chromatic stimulus, composed of a red and green monochromatic grating added in antiphase, and corrected for the chromatic aberrations of the eye. We varied the ratio of the red to green luminances in the stimulus and found that there is no luminance ratio at which the MAE disappears. The results suggest that isoluminant stimuli can induce a MAE which is as great and sometimes greater than that induced by luminance contrast.

Motion aftereffect Isoluminance Chromatic gratings

INTRODUCTION

Many studies of the mechanisms underlying motion perception have employed stimuli consisting of a sequence of exposures of a visual pattern presented at successively displaced positions. Such stimuli elicit a sensation of smooth apparent motion, provided the spatial displacement and interstimulus interval (ISI) between exposures are appropriate. There is now a large body of evidence to support the idea that there are two types of apparent motion mechanism: a "short-range process" which is effective only for relatively small spatial displacements and short ISIs, and a "long-range process" which is able to utilize much larger displacements and ISIs (Braddick, 1974; Anstis, 1980). The short-range process is generally believed to reflect low-level neural mechanisms, and probably underlies the perception of most instances of "real", continuous motion (Gregory and Harris, 1984).

Another long-standing approach to the study of mechanisms in motion perception has been the motion aftereffect: following prolonged viewing of stimuli moving in one direction, static objects at the corresponding retinal location appear to be in motion in the opposite direction (Wohlgemuth, 1911; see Sekuler, 1978 for review). The motion aftereffect (MAE) is believed to reflect the adaptation of local direction-selective neural mechanisms (Barlow and Hill, 1963; Petersen *et al.*, 1981). Consistent with this idea, apparent motion stimuli are reported to produce a motion aftereffect only for small displacements and ISIs (Banks and Kane, 1972), indicating that only the short-range process can support a motion aftereffect. Indeed, the ability to produce a motion aftereffect is regarded as one of the characteristics distinguishing short-range from long-range apparent motion (Anstis, 1980).

Another property which seems to distinguish the two types of apparent motion mechanism is that the short-range process fails or is impaired for stimuli which are isoluminant: these are patterns containing different colours whose luminances have been equated (Ramachandran and Gregory, 1978; Anstis and Cavanagh, 1983). Furthermore, it has been suggested that motion perception in general is degraded, sometimes severely, at isoluminance (Morland, 1982; Cavanagh *et al.*, 1984).

Taken together, these findings made it seem likely that the motion aftereffect would fail at isoluminance. To test this prediction, we produced a red-green sinusoidal grating varying only in colour with all achromatic contrast removed. A quantitative method of removing achromatic contrast was used. Both types of chromatic aberration were carefully corrected for in order to remove any luminance artifacts. A motion aftereffect was tested for with a drifting chromatic grating as the adapting stimulus and the same stationary chromatic grating as the test stimulus. These results were compared to the size of the MAE generated by using monochromatic luminance gratings as both adapting and test stimuli. We also tested for the transfer of the MAE between luminance adapting gratings and chromatic test gratings and vice versa.

METHODS

The stimulus

A red/green sinusoidal chromatic grating was produced by displaying two gratings, each on Joyce display screens with white (P4) phosphors. These were viewed through narrow band interference filters

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to produce their colour (Fig. 1). Interference filters with peak transmissions at 526 and 602 nm were chosen as these wavelengths are at the peaks of the human opponent colour spectral sensitivity function (Sperling and Harwerth, 1971). The two monochromatic gratings, presented 180° out of phase, were combined optically to form the composite chromatic grating. The chromatic grating patch was circular and subtended 6.3° in diameter. The remainder of the display screen was masked off. A fixation mark appeared at the centre of the chromatic grating. Viewing was monocular with a natural pupil and at 82 cm from each display screen.

The contrast of either component grating was defined by the usual formula

$$C = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

where I_{max} and I_{min} are the peak and trough luminance values respectively. Output contrast was calibrated with a UDT (United Detector Technology) lightmeter. The contrasts of the two component gratings were yoked together so that, although their respective mean luminances may differ, $C(526) = C(602)$ at all luminances. Henceforth these contrasts are used to describe both the monochromatic and the chromatic gratings. All mean luminances were measured with a calibrated SEI spot photometer. A 6809 Motorola microprocessor was used on-line to control the stimulus production and presentation.

The correction of chromatic aberrations

The two types of chromatic aberration of the eye, the chromatic difference of focus and the chromatic difference of magnification, are likely to produce luminance artifacts in a stimulus containing colour

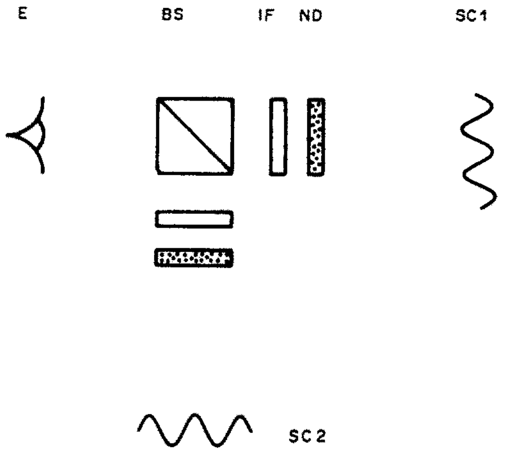

Fig. 1. A diagram of the apparatus used to create the monochromatic and chromatic grating stimuli. SC1, SC2, display screens Nos 1 and 2; E, eye of observer; ND, neutral density filter; BS, beam splitter; IF, interference filter. Interference filters with peak wavelength transmissions at 602 and 526 nm were used to produce a red/green chromatic grating.

differences and will potentially affect the results obtained. The chromatic difference of focus was corrected by placing a negative lens in the path of the shorter wavelength of the grating pair (526 nm) before the component gratings are combined by the beam splitter. The magnitude of the correction required was measured directly, using a method which has been described elsewhere (Mullen, 1985). This indicated that a correction of −0.5 D was required to correct for the difference of focus of the green grating in the red/green pair.

The chromatic difference of magnification of the eye was corrected by making independent adjustments of the spatial frequency of one of the component gratings. Magnification differences are easily detected by displaying the two component gratings as square waves; overlap of adjacent bars produces a bright strip of a different colour which can be removed by adjusting the X-gain on the appropriate display screen. When these corrections for chromatic aberrations have been made, the gratings are displayed sinusoidally in space to produce a red/green chromatic grating.

The procedure

The subject viewed a 1.5 c/deg adapting grating drifting at 2.5 c/sec (3.75 deg/sec) for 7 sec. A stationary test grating of the same spatial frequency was then immediately presented. Subjects were asked to rate on a 5 point scale the strength of any motion aftereffect they saw; non-integral ratings were allowed. At least 15 sec elapsed between each trial. Four subjects were used; two were the authors (K.T.M., C.L.B.) and two were naive as to the purpose of the experiment (R.M.C., J.S.P.). All subjects wore their usual correcting lenses and performed normally on the Farnsworth-Munsell 100 hue test and the Ishihara test for colour blindness. Subjects were allowed several practice trials before beginning the experiment in order to become familiar with the use of the rating scale.

RESULTS

In the experiment the magnitude of the subject's motion aftereffect was measured at and close to isoluminance. A quantitative method of producing the isoluminant stimulus was used. The ratio of the mean luminances of the red and green component gratings was varied over a wide range. The luminance ratio is expressed as the percentage of red light in the red/green mixture. The extreme points in the range correspond to a red or green monochromatic stimulus (at 100 and 0% red, respectively) which has luminance contrast but no colour contrast, and in between must lie an isoluminant point (around 50% red) which has colour contrast and no luminance contrast. Overall there is no net change in the mean luminance of the composite stimulus; although the red/green ratio varies, the summed red and green luminances were arranged to be constant at 15 cd/m^{-2}. The motion aftereffect was measured at seven percentages in this range, clustered in the central region and at either end. Six trials were run at each percentage with the total of 42 trials for each subject presented in a pseudo random order. Both the test and adapting stimuli were presented at the same red/green ratio, and both were presented at a high contrast of 50% (see the Methods for the definition of contrast).

The results for four subjects are shown in Fig. 2. The abscissa shows the mean MAE ratings and error bars denote -1 standard deviations. The results show that a motion aftereffect is induced at all percentages tested and that the MAE in the middle region is as great as, and for some subjects greater than, the effect induced by luminance gratings at 0 and 100% red. Thus a MAE can be induced by chromatic stimuli at and close to isoluminance as well as by luminance contrast.

A lower contrast test grating is likely to be more effective at revealing a luminance MAE (Keck *et al.*, 1976), and so the experiment was repeated with the same high contrast (50%) adapting grating and a lower contrast (16%) test grating. Subjects reported that the MAEs for the chromatic stimuli at 43–57% red were hard to judge since these low contrast stationary test stimuli tended to fade before the MAE could be noted. However subjects were instructed to ignore the fading if possible or to make the rating when fading did not occur, and again their ratings indicate that the MAE is induced by colour contrast alone.

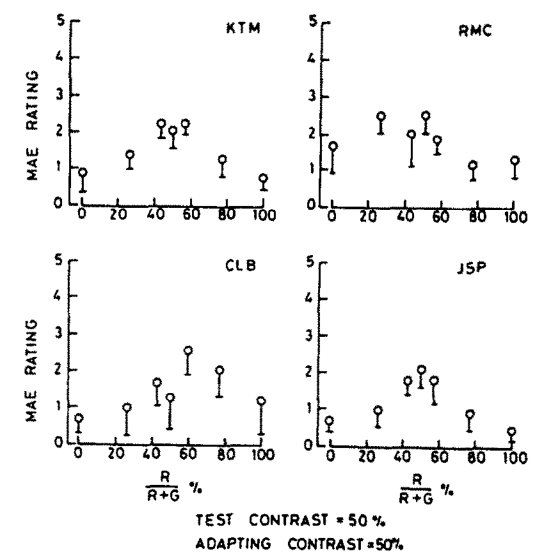

Fig. 2. Mean motion aftereffect (MAE) ratings for four subjects (K.T.M., C.L.B., R.M.C., J.S.P.) plotted as a function of the percentage of red (R) light in the red-green mixture (R + G). The adapting stimulus, composed like the test stimulus of a red and green monochromatic sinusoidal grating added in antiphase, drifted at 2.5 c/sec. The test and adapting grating contrasts were both 50%. Error bars denote -1 SD.

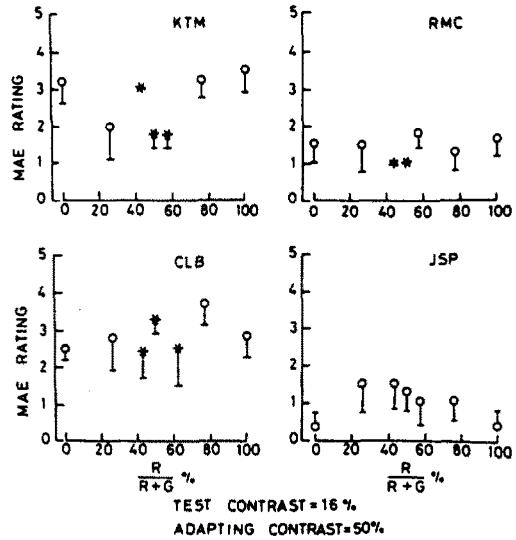

Fig. 3. Mean MAE ratings for four subjects plotted as for Fig. 2. The test contrast was 16% and the adapting contrast 50%. Data points represented by an asterisk indicate that the subject reported fading of the test stimulus. See text for further details.

The results (Fig. 3) show that the average MAEs are of a similar magnitude at all the percentages tested, suggesting that the chromatic and luminance MAEs do not differ significantly under these viewing conditions.

All four subjects reported a MAE when observing a luminance test grating, after adapting to the chromatic (50% red) grating, both presented at 50% contrast. They could also report a MAE when observing the chromatic test grating after adapting the luminance grating. The MAE observed when using a chromatic test grating was generally greater, regardless of whether adaptation had been to a monochromatic or isoluminant chromatic grating.

DISCUSSION

Our results demonstrate a motion aftereffect at all red/green ratios tested, indicating that there exists no match point for its failure. Thus a motion aftereffect can be produced by stimuli at and close to isoluminance. These results are unlikely to be contaminated by luminance artifacts produced by chromatic aberrations, since our methods allowed the correction of both the chromatic difference of focus and the chromatic difference of magnification (see Methods).

Consequently we conclude that at least one of the assumptions leading to the expectation that the motion aftereffect would fail at isoluminance must be mistaken. For example, Ramachandran and Gregory (1978) indicated that long-range apparent motion was still operative at isoluminance—it might be that the long-range process can support a motion aftereffect, but failed to do so in the experiments of Banks and Kane (1972) due to an inappropriate choice of stimulus parameters such as the contrast of the adapting and test stimuli. Alternatively the short-range mechanism might be able to operate at isoluminance, in some limited fashion not revealed in the experiments of Ramachandran and Gregory (1978) and Anstis and Cavanagh (1983), which is sufficient to support a motion aftereffect in our stimulus situation. More specifically, the Ramachandran and Gregory (1978) result might be interpretated to mean that there is a failure of the segregation process rather than a failure of short-range motion. A more general possibility is that there may exist important aspects of mechanisms responsive to continuous motion, not yet successfully isolated with apparent motion stimuli, which complicate comparisons between the two. (While our stimulus consisted of discrete frames, the very high refresh rate, multi-frame presentation, and very small spatial displacements from one frame to the next make it essentially a "continuous" rather than an apparent motion stimulus.)

These possibilities would be best pursued by the use of isoluminant stimuli which can be either random dots or gratings and which can appear either in apparent motion or are continuously drifting. A substantial difficulty is that a random dot pattern is likely to be particularly difficulty to render isoluminant and free of luminance artifacts, due to its significant content of high spatial frequencies. In any case, the preliminary conclusions that motion-detecting mechanism fail or function poorly at isoluminance, implied by the reports of Ramachandran and Gregory (1978) and Anstis and Cavanagh (1983), must be reconsidered. More generally our results suggest that the neural substrate mediating the MAE is sensitive to the movement of both colour and luminance contours.

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