Colour Specificity in the Motion After Effect

Sanjay G. Manohar

The Psychological Laboratory, University of Cambridge

Abstract

Introduction

It has always been an unresolved issue as to what extent motion detectors are colour selective.

There are three possible ways in which colour and motion information could interact: firstly there is the case for neuronal selectivity for particular combinations of motion and colour triggers, secondly there may be some associative (learning) mechanisms that link certain movement percepts with colour percepts, and thirdly there may be some higher-level cognitive process activated by combinations of motion and colour. While contingent after effects may fall into the second (Siegel & Allan, 1985, but see Humphrey et al., 1998), there is evidence (Lu et al., 1999) that isoluminant colour selectivity in the MAE is cognitive, requiring attention.

The paradigm is to create a stimulus that is isoluminant, allowing comparison of luminance and chrominance stimuli. Early evidence counted against any contribution of colour information to motion perception: Ramachandran (1978) showed that random-dot kinematograms are not perceived as moving when dots are isoluminant red and green. Since then, many experiments have found this conclusion wanting, and lead to Braddick's (1980) proposal that isoluminant motion detection is a form of higher-order motion detected by mechanisms outside V1.

Krauskopf and Farrell (1990) have compared the perception of gratings moving in different directions with plaids made up of the gratings superimposed. The plaid is either perceived as coherent, with a single direction of motion, or as two superimposed moving gratings. He found that if the two gratings were isoluminant then the gratings were always seen to cohere, unless the colour modulations were aligned along different opponent channels, i.e. one grating was S-cone constant, and the other was (M+L)-cone constant. The result suggests that the detection of motion direction uses input from independent red-green and blue-yellow channels.

There is evidence that the colour-opponent coding at the level of post-receptoral adaptation (Webster & Mollon, 1991) and of motion nulling (Webster & Mollon, 1997) is not confined to two independent cardinal axes, unlike in the LGN. This would suggest that chromatic information is involves different inputs to those of motion detection.

There is a large body of evidence to support the idea that spatial chromatic channels have longer time-constants than spatial luminance channels. The flicker fusion frequency for changing coloured isoluminant boundaries is lower than for luminance varying stimuli. The contribution of pure colour contrast stimuli to motion perception are limited to long time separations and lower spatial densities than luminance stimuli (Baker et al., 1998), declining to half-amplitude at 3-6 Hz (Lu et al., 1999). They interpret this to be a manifestation of the 'third-order' nature of isoluminant motion: isoluminant changes are slower to be detected than chromatic ones.

One prediction of this hypothesis is that the colour-specific component of MAE will be reduced for higher motion speeds. This is because colour specificity would require contributions from separate colour channels to the motion subsystem, and due to longer time constants these channels would be less effective at higher motion speeds.

Technique

On the front of motion and colour, the results of MAE studies have been equivocal. Lovegrove (1972) found that adaptation to red or green moving bars caused greater after effects in stationary test bars of the same colour than in those of the other colour. The selectivity was also confined to monocular presentation. This selectivity effect was not found by Day and Wade (1979) in a very similar study. Lovegrove (1980) found that the criterion for selectivity was duration of the delay left between adapting and test stimuli: when 15 s, the after-effect was colour specific. The stimuli in this case were luminance modulated (red-black and green-black) square-wave gratings. The case was made for two components to the MAE: one that depends on luminance alone but had a short duration, and a colour selective component which has a longer duration.

Aims

In this study the intention is to measure colour selectivity of the MAE. The use of isoluminant gratings which are either S-cone or (M+L)-cone constant will determine whether, at the level of chromatic motion adaptation, there is opponent coding of colour. Evidence for opponent colour coding would be that, when the adapt colour is the same as the test colour, there is a larger MAE than when they are different.

The effect of adapting speed on this colour selectivity will be measured. This would help determine how the colour-selective component's time constant differs from that of the non colour-selective component. The rationale is that a temporal frequency of 3-6 Hz corresponds, for a grating of 1.29 cycles per degree, to a speed of 2.3-4.7 degrees per second. If the stimuli elicit MAE via the chromatic motion system, we would expect any colour specificity in the effect to vanish at higher speeds of grating..

Method

Subjects

Four subjects were tested, two of whom were volunteers from college, and two experimenters. EJBC and JPT were naïve, and SGM and JDM were not.

Apparatus

The stimuli were presented on a 21" Sony Trinitron monitor controlled by a Cambridge VSG graphics adapter. The display was 800 x 600 pixels at 60 Hz and 16 bits per gun – this was mapped on an 8-bit palette. Stimuli and protocol were programmed in Pascal. Subjects were seated 1 m from the screen, on which gratings were presented over the full rectangular visual area measuring 0.337 x *** m. Viewing was *monocular* and under dim illumination. During adaptation, a central fixation spot was present. A neutral-colour rectangular 1" border of was present around the stimulus.

Stimuli

All stimuli consisted of sinusoidally modulated isoluminant gratings, spatial frequency 1.29 cycles per degree. The chromaticity gratings were either constant for S-cone ('red') or L+M-cone ('blue') catches, and chromaticity varied from a white point of $x = 0.3127$, $y = 0.3291$, CIE coordinates. The contrast was normalised across the two colours by measuring motion detection contrast threshold, and scaling the contrast linearly to equate these thresholds. The effective speeds of the gratings were finely controlled with 256-step palette dithering.

Protocol

The adapting grating was presented initially for 15 seconds, with 7 second top-up between test stimuli. The test stimuli were presented for 1 s immediately after the adapting grating, after which the screen was blanked. In a single trial the adapting speed was constant, but test stimulus speed was varied by staircase procedure, using a 2AFC on the perceived direction of motion of the test grating. Thus the null speed was narrowed down to an interval of 0.036 degrees per second, and the midpoints of these intervals were logged.

Trials were performed in at four different adapting speeds 0.43, 2.37, 4.30 and 6.23 degrees per second, and with the four permutations of adapting and testing colour: (adapt-test) red-red, red-blue, blue-red and blue-blue. The 16 conditions were presented in a pseudorandomised and counterbalanced order, and with *direction of motion randomised* from trial to trial. This formed blocks of 32 trials. Subjects were instructed to report the average direction of motion of the test grating over the 1 s presentation; they were given one preliminary block of 8 trials for familiarisation with the apparatus and protocol. A respite of 2 minutes was allowed every 4 trials, and on average a block of 32 trials lasted about an hour. Subjects were tested on two consecutive days, on one eye each day, 32 trials per eye. Results were logged by computer.

Results

Comments

1. Subject EJBC often perceived movement but was not aware of its direction.

2. Subject JPT complained that the test grating sometimes moved in both directions at once, and also claimed that
3. Sometimes the bars themselves could not be seen distinctly but their direction of motion could be perceived.
4. Subjects also noted that during the course of an hour, it became harder to see the gratings, and also harder to perceive the motion.
5. Subjects felt they could see the test patterns better immediately after the 2-minute rests.

Data analysis

A three-way ANOVA was performed on the data to investigate the contribution of speed, of testing with a different colour to that adapted to, and of subject. The contribution of adapting speed was significant ($p<0.001$) but the contribution of same/different colour was not ($p**$).
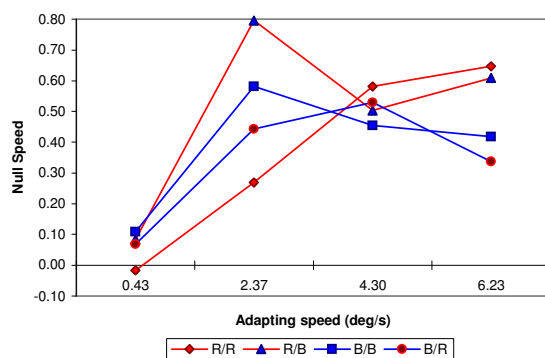

Figure 1: Compiled averaged results showing the effect of colour on the null-speed—adapting-speed relationship. The line colour represents the adapting-grating colour, and the marker colour represents the test-grating colour. Red (R) represents a constant S-cone/(L+M-cone) grating; Blue (B) represents a constant L-cone/M-cone catch grating.

Discussion

Viewing isoluminant gratings causes adaptation to particular colour-opponent channels. We are therefore likely to find a similarly-coloured test grating harder to perceive than a different-colour one. Comment 3 may count as evidence for this. Thus subjects will have decreased sensitivity to gratings of the same colour as the adapting grating. If the grating is perceived less strongly, it may force the motion system to use

MAE speed preferentially to actual speed (Wohlgemuth, 1911, noted that MAE can be felt in the absence of any visual input during test phase.)

It is known that test gratings of lower contrast produce a larger MAE. When testing with the same colour as the adapting grating, it is likely that the decreased effective contrast of the test grating may increase the null speed of the MAE.

Luminance contamination

Troscianko (1994) deprecated the use of isoluminant test stimuli to measure properties specific to the chromatic subsystem. This is because of the difficulty in preparing a stimulus which produces a constant photon-catch in a particular cone type. The problem is that luminance is a much more powerful stimulus for motion perception; luminance changes of less than 1% are sufficient to induce a strong MAE. Even if the stimulus were truly isoluminant, there are possibilities that temporal phase lags between colours, variability in the equiluminant point for different units, and distortions caused by optics could all lead to effective luminance cues by which to detect the motion (Cavanagh & Anstis, 1991).

The alternative proposed by Troscianko was to add luminance noise to the motion stimulus, which would mask luminance contamination, and so only the chromatic MAE is measured. The technique was not used in this experiment.

The 'isoluminant' stimuli in this experiment were no doubt partly contaminated with luminance variation. However, this variation would be small against the relatively high background luminance. Moreover, the variation would not contribute to the interaction between adapting and test grating colour, since the comparison is made both ways. It is the effect of speed upon this interaction that is of importance in this experiment.

A major difficulty for the subjects was the decrease in visibility of the gratings as

References

Krauskopf & Farrell, *Nature*, **348**, 328 (1990)

Lovegrove, W.J., Over, R., Broerse, J., Colour specificity in the motion after-effect, *Nature*, **238**, 334 (1972)

Lovegrove, W.J., *Perception & Psychophysics*, **25**, 111

Lovegrove, W.J., *Perception & Psychophysics*, **27**, 33 & 585

Day, R.H. & Wade, N.J., Absence of colour specificity in the movement after-effect, *Perception & Psychophysics* (1979)

Wade, N. J., A selective history of the study of motion aftereffects, *Perception*, **23**: (10), 1111 (1994)

Troscianko, T., Contribution of colour to the motion aftereffect and motion perception, *Perception* **23**, 1221 (1994)

Mather, G., Verstraten, F.A.J., Anstis, S.M., *The Motion After Effect*, ISBN 0-262-13343-1 (1998)

Ramachandran, V.S., *Nature*, **275**, 55 (1978)

Siegel, S., Allan, L.G., Overshadowing and blocking of the orientation-contingent color aftereffect - Evidence for a conditioning mechanism, *Learning and Motivation*, **16**: (2), 125-138 (1985)

Cavanagh, P., Anstis, S., The contribution of color to motion in normal and color-deficient observers, *Vision Research*, **31**: (12), 2109 (1991)

Webster, M.A., Mollon, J.D., Motion minima for different directions in color space, *Vision Research*, **37**: (11), 1479 (1997)

Baker, C.L., Boulton, J.C., Mullen, K.T., A nonlinear chromatic motion mechanism, *Vision Research*, **38**: (2), 291 (1998)

Humphrey, G.K., Herbert, A.M., Hazlewood, S., Stewart, J.A.D., The indirect McCollough effect: An examination of an associative account, *Perception & Psychophysics,* **60**: (7) 1188-1196 (1998)

Lu, Z.L., Lesmes, L.A., Sperling, G., The mechanism of isoluminant chromatic motion perception, *Proceedings of the National Academy of Sciences USA*, **96**: (14), 8289 (1999)

Wohlgemuth, A., The after-effect of seen movement, British Journal of Psychology: Monograph Supplement (1911)