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The oblique effect with colour defined motion throughout the visual field

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Abstract

We assessed the extent of the oblique effect (OE) and the meridional orientation effect (MOE) for a chromatic motion task using red/green gratings throughout an 80° visual field. Four different stimulus orientations were tested. Generally, sensitivity to chromatic motion decreased with increasing eccentricity regardless of the visual field meridian. Also, sensitivity was highest for horizontal or vertical gratings, thus supporting the presence of an OE rather than of a MOE. The strength of the OE varied between subjects, but was present from the fovea to 20° of eccentricity. At 40° of eccentricity, chromatic motion was always perceived but the grating orientation did not consistently influence chromatic motion sensitivity. The present study confirmed our previous results on chromatic motion sensitivity and isoluminance ratios throughout the visual field. In addition, our data show that the chromatic system can exhibit OEs at lower spatial frequencies than is observed for the achromatic system.

Keywords: Color; Isoluminance; Motion; Oblique effect; Peripheral chromatic motion

1. Introduction

The oblique effect (OE) (Berkley, Kitterle & Watkins, 1975; Rovamo, Virsu, Laurinen & Hyvärinen, 1982; Matin, Rubsamen & Vannata, 1987); for a general review see Appelle, 1972, refers to the observed reduction in sensitivity to oblique stimuli. The OE has been reported in central vision for the detection of achromatic gratings (Campbell, Kulikowski & Levinson, 1966; Mansfield, 1974; Caelli, Brettel, Rentschler & Hilz, 1983; Heeley, Buchanan-Smith & Heywood, 1993) and for the detection of isoluminant stimuli (Reisbeck & Gegenfurtner, 1996). The latter study showed that the magnitude of the effect was equivalent for isochromatic gratings and isoluminant gratings once they were equated for cone contrast by the root-mean-square method. Murasugi and Cavanagh (1988) tested the strength of the OE by contrasting chromatic and achromatic detection thresholds. They tested four grating orientations and obtained the OE, as well as an anisotropy between horizontal and vertical gratings. Sensitivity was higher for vertical gratings than horizontal when they tested with chromatic stimuli, whereas no difference was apparent between vertical and horizontal gratings with achromatic stimuli. OEs for achromatic motion sensitivity have also been reported (Heeley & Buchanan-Smith, 1992; Yo & Wilson, 1992; Coletta, Segu & Tiana, 1993). In these studies, sensitivity was higher for horizontal or vertical paths than for oblique paths.

Investigations of the OE using achromatic gratings have also been carried out in the peripheral visual field, where the OE disappeared between 15 and 25° of retinal eccentricity (Rovamo et al., 1982; Lundh, Lennerstrand & Derefelt, 1983; Temme, Malcus & Noell, 1985). However, an orientation effect was observed, which depended on the orientation of the stimuli and the visual field meridian tested rather than for the orientation of the stimulus alone as in the classic OE. These authors demonstrated that detection thresholds were lower when the gratings were parallel to the meridian (horizontal grating on the horizontal meridian; vertical grating on the vertical meridian), and this was also true for the 45 and 135° meridia. This

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effect is referred to as the meridional orientation effect (MOE). Rovamo et al. (1982) also reported that contrast sensitivity was worst when the gratings were presented orthogonal to the visual field axes (e.g. vertical gratings on the horizontal axis, horizontal gratings on the vertical axes).

Further research in the peripheral visual field (Cormack, Blake & Hiris, 1992; Galvin, Williams & Coletta, 1996) and parafoveal visual field (Coletta et al., 1993) reported OEs for achromatic motion sensitivity. In the periphery, subjects were able to correctly identify the direction of motion when the stimulus was moving vertically or horizontally, but could not do so for gratings displaced along a 45° angular path for example. In the parafovea, subjects identified the direction of motion, but performance decreased rapidly as the spatial frequency of the grating was increased (Coletta et al., 1993).

There is clear evidence that the central visual field is more specialised for colour analysis (Mullen, 1991; Stromeyer, Lee & Eskew, 1992), whereas the peripheral visual field appears to be specialised for detecting objects in motion (Previc, 1990). Nonetheless, previous investigations have demonstrated that motion can be perceived with the chromatic system in central vision (Cavanagh, Tyler & Favreau, 1984; Gorea & Papathomas, 1989; Cavanagh & Anstis, 1991; Cropper & Derrington, 1996). Motion sensitivity of the chromatic system has been tested in the inferior visual field, extending to 24° of eccentricity (Metha, Vingrys & Badcock, 1994), and we recently demonstrated that chromatic motion could be perceived up to 40° of eccentricity (Bilodeau & Faubert, 1997).

The present study was devised to answer the following questions:

1. Do we get OEs with suprathreshold colour defined motion stimuli;
2. Do we get OEs and/or MOEs throughout the visual field.

We answered these questions by comparing sensitivity for four different grating orientations in an 80° visual field, which was divided into eight meridia.

2. Methods

2.1. Subjects

Five subjects participated in this study. Three subjects completed all the experimental conditions, two being trained psychophysical observers (JF and LB) and one naive subject (KP). Two additional subjects were tested in central vision only, one trained psychophysical observer (VD) and one naive observer (YV). All subjects had normal or corrected to normal vision, and they all had normal colour vision. Subjects used their preferred eye.

2.2. Apparatus and stimuli

Viewing distance was fixed at 57 cm using a chin rest. The stimuli were presented on a standard 13 in. RGB Apple monitor and generated by a Macintosh IIfx computer. The radiometric characteristics of the RGB guns and the white used on the monitor have been described previously by Faubert (1994, 1995). The maximum luminance possible for red, green, and blue were 19, 57.5, and 9.3 cd/m^2, respectively. The average luminance of the stimuli and the testing screen was 19 cd/m^2. The background of the monitor consisted of random black and white dots each measuring 4 pixels (1 pixel = 2.4 min of arc). The stimulus was a circle filled with red-green (R/G) sine wave gratings. The stimulus configurations for the two tasks, isoluminance and chromatic motion, were the same for a given condition. The following eight meridia were tested: temporal (0°), superior-temporal (45°), superior (90°), superior-nasal (135°), nasal (180°), inferior-nasal (225°), inferior (270°), inferior-temporal (315°). Different eccentricities were tested by having the subjects fixate at different locations around the monitor. A central position (0° of eccentricity) was assessed and on each meridian, four eccentricities were assessed: 5, 10, 20, and 40° from the centre. The stimulus diameter was increased with eccentricity (8, 10, 12.5, 16, and 20°, respectively) to roughly compensate for the cone density function changes with eccentricity and to allow a direct comparison with our previous study(Bilodeau & Faubert, 1997). All stimuli contained four cycles of red-green bars. Therefore, the spatial frequencies used were 0.5, 0.4, 0.32, 0.25, and 0.2 cpd, respectively. For each fixation point, four different stimulus orientations were tested. The gratings were presented horizontally, vertically, right oblique i.e. with 45° of clockwise rotation from vertical (RO), and left oblique i.e. with 45° of counter-clockwise rotation from vertical (LO).

The stimulus used for the isoluminance task consisted of a light-red/dark-green grating superimposed on a dark-red/light-green grating (Cavanagh, Anstis & MacLeod, 1987). The waveforms of the colour gratings are given as:

$$R_{(x,t)} = 0.5*L_R*\{[1 + m*\sin(2\pi f_S x)*\sin(2\pi f_T t)] + [1 + \cos(2\pi f_S x)*\cos(2\pi f_T t)]\} \quad (1)$$

$$G_{(x,t)} = 0.5*L_G*\{[(1 + m*\sin(2\pi f_S x)*\sin(2\pi f_T t)) + [1 - \cos(2\pi f_S x)]*\cos(2\pi f_T t)]\} \quad (2)$$

R was the red luminance, G was the green luminance, L_R corresponded to the red mean luminance, L_G was the green mean luminance, x was the horizontal position, t was time, m was the contrast of the luminance grating, f_S was the spatial frequency of the gratings, and f_T was the temporal frequency of the gratings. A

yellow/dark-yellow (luminance) grating was superimposed on the counterphased colour gratings differing by 90° of spatial and temporal phase. Any chromatic variations in the colour gratings was accompanied by the same variation in the colours of the luminance grating; therefore, the colours remained identical for the two gratings. The luminance grating was 90° out of phase with the colour grating, which added to the luminance contrast of the colour grating allowed the grating to drift (Cavanagh et al., 1987). If the red luminance was higher than the green, rightward motion was be perceived. If green luminance was higher than the red, leftward motion was perceived. If the luminance components were equal, a flicker was perceived. Combining Equations (1) and (2) gave the total spatial and temporal luminance variation, ($L_{(x,t)}$):

$$\begin{aligned} L_{(x,t)} &= R_{(x,t)} + G_{(x,t)} \\ &= L_R + L_G + 0.5*[m*(L_R + L_G) + L_R - L_G] \\ &\quad *\cos[2\pi(f_S x - f_T t)] \\ &\quad + 0.5*[m*(L_R + L_G) + L_G - L_R]*\cos[2\pi(f_S x - f_T t)] \end{aligned} \tag{3}$$

To get an isoluminance measure the subjects adjusted the luminance contrast of the green waveform until the bars produced a counterphase flicker. The chromatic contrast of the red and green was preset at 60% of the phosphors' maximum. The luminance contrast of the luminance grating was set at 10%, which gave a good range of visible motion and in turn helped the subjects to set isoluminance.

The stimulus used for the colour motion task consisted of the previously established isoluminant grating which remained spatially counterphased but temporally in phase, and an isochromatic grating (yellow/dark-yellow) of the same size drifting in the opposite direction. The strength of the motion corresponded to the contrast of the isochromatic grating necessary to null the drift.

2.3. Procedure

The first task was to adjust the luminance contrast of the gratings until the observer could no longer identify a clear motion direction (subjects perceived the bars as counterphase flickering). Subjects were asked to make five consecutive adjustments for each condition. The average of these five measures ($L_R - L_G$) was considered as the R–G isoluminance value for that condition.

Immediately after completing the isoluminance task for a given condition, the subject adjusted the luminance contrast of the isochromatic grating, which was drifting in the opposite direction to the isoluminant grating, until he/she could no longer perceive a clear motion direction (the bars appeared as counterphase flickering). The average of five consecutive adjustments was treated as the relative contribution of the chromatic system to the perception of motion.

For any given eccentricity, four different stimulus orientations were presented, along eight visual field meridia for a total number of 132 conditions. For each condition, five isoluminance adjustments and five motion nulling adjustments were made, for a total of 1320 trials for the entire experiment.

3. Results

3.1. Isoluminance

The isoluminance values consisted of $L_R - L_G$. A negative value indicated that red contrast was lower than green at isoluminance, a positive value indicated a higher red contrast to match the green contrast, whereas a null value (0) indicated that the red and green contrasts were physically equal. An $8 \times 4 \times 4$ (meridian, eccentricity, and stimulus orientation) analysis of variance (ANOVA) was performed on the isoluminance values. We obtained a significant interaction between eccentricity and stimulus orientation ($F(9, 256) = 4.577$, $P < 0.0001$) as well as a meridian effect ($F(7, 256) = 4.911$, $P < 0.0001$). Isoluminance values averaged across grating orientations are represented for each subject in Fig. 1a–c.

Our previous study (Bilodeau & Faubert, 1997) had demonstrated a discrepancy in R–G values between the inferior and superior axes, where more red contrast was necessary to set isoluminance along the superior axis than along the inferior axis as eccentricity increased. We averaged the data of the present experiment for the upper field (including superior–temporal, superior, and superior–nasal axes) and for the lower field (including the inferior-temporal, inferior, and inferior-nasal axes) and plotted the mean values as a function of eccentricity in Fig. 1d. Consistent with our previous observations, we found that more red contrast was necessary to set R–G isoluminance conditions in the upper visual field.

3.2. Motion

The higher the equivalent contrast, the stronger the chromatic input to motion. An $8 \times 4 \times 4$ (meridian, eccentricity, and stimulus orientation) ANOVA was performed on the chromatic motion sensitivity expressed as equivalent contrast. Two main effects were found: the eccentricity factor significantly influenced the data ($F(3, 256) = 55.627$, $P < 0.0001$), and the stimulus orientation factor ($F(3, 256) = 13.028$, $P < 0.0001$) significantly influenced the data thus suggesting an OE. The two main effects are represented in Fig. 2a. In

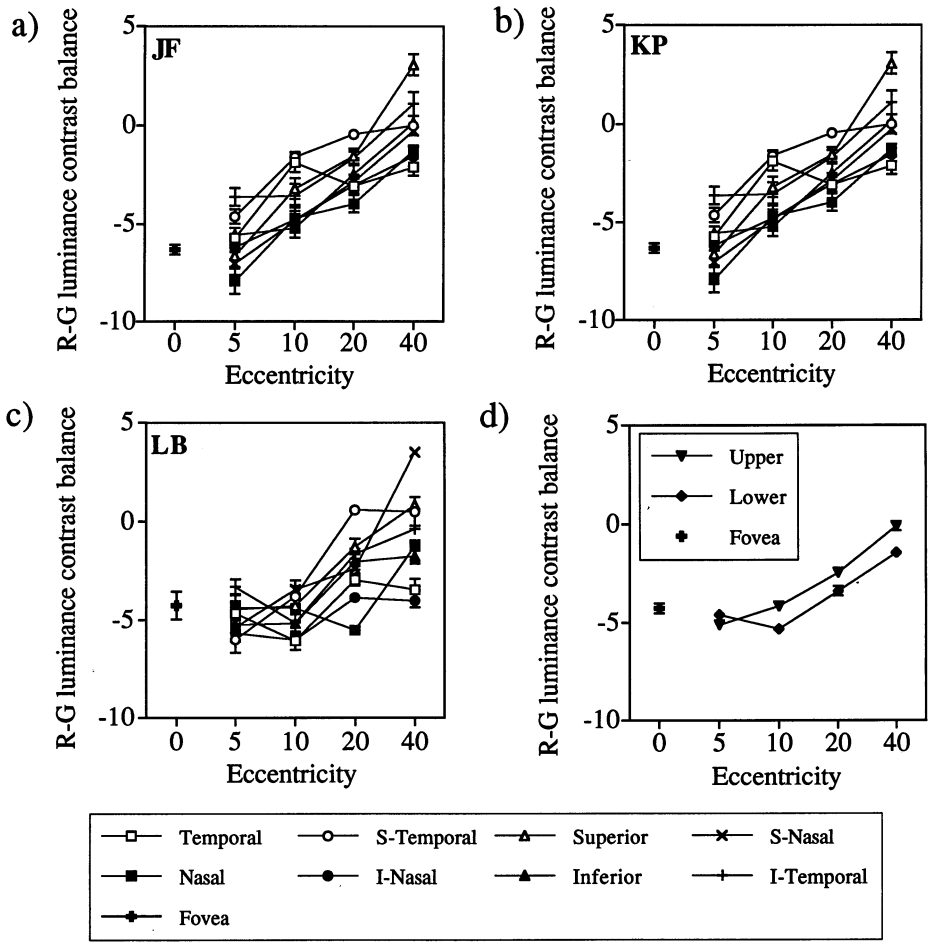

Fig. 1. Isoluminance values averaged across stimulus orientations and plotted as a function of eccentricity. (a)–(c) represent individual data. (d) Isoluminance values averaged separately for the upper (the values obtained on the superior-temporal, superior, and superior-nasal meridia) and for the lower field (the values obtained on the inferior-temporal, inferior, and inferior-nasal meridia). Error bars represent the standard error of the mean.

general, the relative contribution of the chromatic system to motion significantly decreased with increasing eccentricity, regardless of the visual field meridian. The data are plotted as a function of eccentricity for each stimulus orientation for each observer in Fig. 2b–2d. The influence of the eccentricity factor was present for each observer, whereas the orientation effect fluctuated between observers. Subject JF showed a clear OE from the fovea to 20° of eccentricity, and a weaker one at 40°. Subject LB showed a clear OE from the fovea to 10° of eccentricity, and at 20° of retinal eccentricity the effect was weaker. At the fovea subject KP was more sensitive to obliques than horizontal or vertical gratings, whereas she showed a clear OE only at 10° of eccentricity. Because of the reversed pattern at the fovea fixation for observer KP, we tested two more subjects for all the orientations at the fovea and compared their results with the other observers (see Fig. 3). Observer VD showed a marked OE where his sensitivity to chromatic motion was highest for vertical and horizontal orientations and lowest for the two obliques, whereas observer YV showed a weaker OE but showed a similar pattern of sensitivity (higher equivalent contrasts were necessary to null the motion for horizontal and vertical stimuli).

A one-way ANOVA (orientation factor) was performed on the equivalent contrast measures obtained at the fovea. We obtained an OE ($F(3, 9) = 16.141$, $P < 0.001$) where the highest sensitivity was obtained for horizontal/vertical stimuli as compared to the two obliques.

4. Discussion

The results of this experiment show OEs, as assessed with the chromatic motion task, at the fovea and in the peripheral visual field. At 40° of eccentricity, the grating orientation did not influence the motion sensitivity of the chromatic system. Furthermore, the motion sensitivity did not differ as a function of the meridian tested. This suggests a dissociation of the OE from the

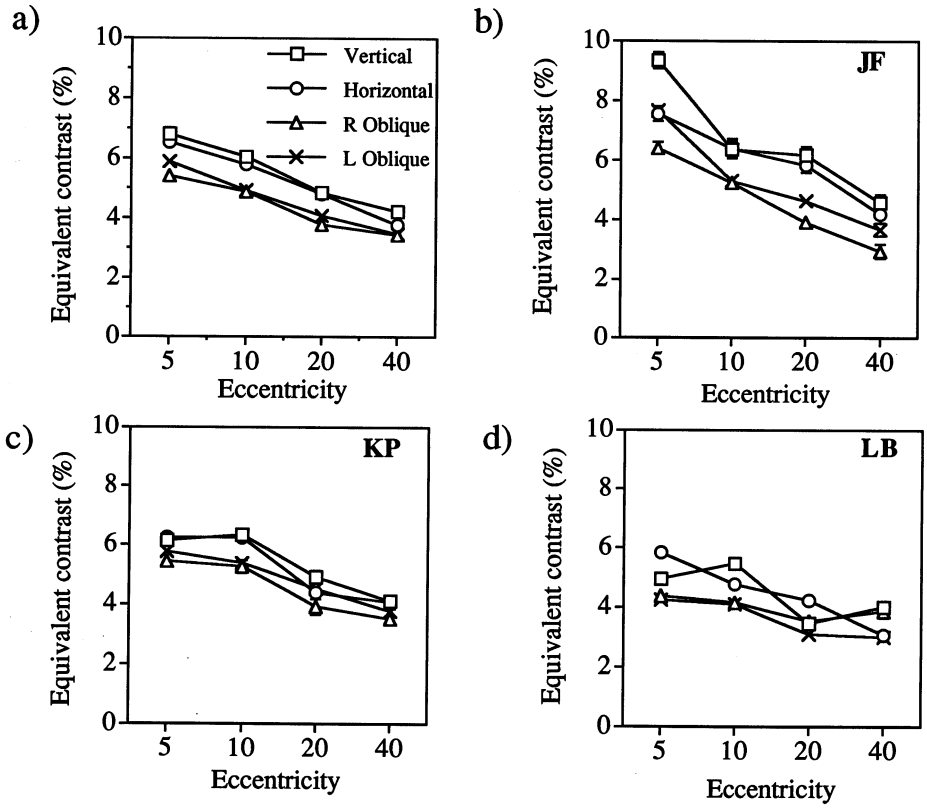

Fig. 2. Average equivalent contrast measures as a function of eccentricity. The values are grouped for each stimulus orientation. (a) group means; (b) (c) and (d) are individual measures. Error bars represent the standard error of the mean.

MOE for chromatic motion, in contrast to the findings of Rovamo et al. (1982) who observed MOEs for achromatic grating acuity.

4.1. The spatial component

Murasugi and Cavanagh (1988) have reported a vertical anisotropy that takes place at the fovea with a contrast detection task using isoluminant and isochromatic gratings presented at four different orientations. However, the vertical anisotropy was present for only two of the five subjects. The spatial frequency of the gratings we used for foveal targets was much lower (0.5 cd) than what Murasugi and Cavanagh (1988) used (2 cd), and the different spatial components might account for the difference among these findings, although we both obtained an OE.

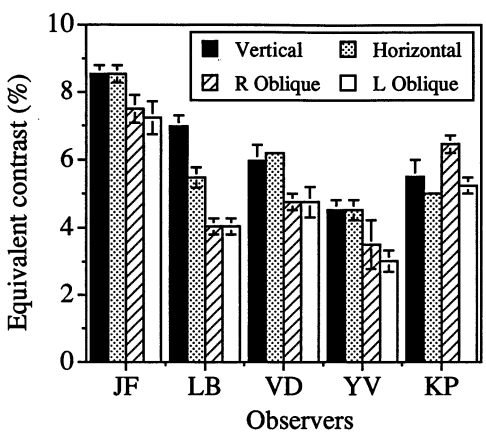

Fig. 3. Equivalent contrast measures of various stimulus orientations at the central fixation (0°) for the five observers. Error bars represent the standard error of the mean.

Coletta et al. (1993) argued that many of the motion studies that failed to obtain the OE used either very low spatial frequencies or broadband stimuli. Reisbeck and Gegenfurtner (1996) have demonstrated that the magnitude of the OEs obtained with static isoluminant stimuli were analogous to the OE reported with achromatic gratings, as long as the threshold measures were equivalent. Reisbeck and Gegenfurtner (1996) further argued that the processing of orientation might be the same for chromatic and achromatic gratings for identical spatial frequencies. In the present experiment, the stimuli used were defined by colour and low spatial frequency components. Nonetheless, an OE was observed for drifting isoluminant stimuli presented at the fovea where the spatial frequency was 0.5 cd, which was the highest frequency that was used (nearly ten times lower than in Coletta et al., 1993). Scaling the stimuli to roughly compensate for the cone density changes with eccentricity must have influenced the present findings.

4.2. The eccentricity factor

Cormack et al. (1992) and Coletta et al. (1993) have found that the identification or discrimination of direction was impaired in the peripheral visual field for achromatic stimuli moving in oblique directions (e.g. 45 or 135°). Coletta et al. (1993) added that performance was even more impaired if the spatial frequency was increased. The present study used decreasing spatial frequency gratings as retinal eccentricity increased, and an OE is observed at 20° of eccentricity, where the spatial frequency of the gratings was rather low (0.25 cd). However, there was no evidence of an OE at 40° of eccentricity. Did we reach an eccentricity at which there are no longer OEs, or is there either a critical stimulus size or spatial frequency for which OEs are no longer present?

4.3. The visual field axis

Motion sensitivity did not vary for the different meridia. Therefore the findings for static achromatic gratings of Rovamo et al. (1982) and Temme et al. (1985) were not observed with drifting chromatic gratings. They had previously shown that detection thresholds were lower when the stimulus orientation was parallel to the axis and thresholds were highest when the stimulus orientation was orthogonal to the axis. In contrast, the present results for the chromatic motion task demonstrated the highest sensitivity for horizontally or vertically oriented gratings, regardless of the meridian. If the MOE had been present, the highest sensitivity would have been obtained for conditions where the stimuli were parallel to a given meridian. The data on the oblique axes (superior-temporal, superior-nasal, inferior-temporal, and inferior-nasal) did not show such a tendency. Therefore, the OE rather than a MOE is confirmed throughout the visual field for a chromatic motion task.

In summary, the present study confirmed our previous results on chromatic motion sensitivity and isoluminance values throughout the visual field (Bilodeau & Faubert, 1997). In addition, an OE was found from the fovea to the peripheral visual field, regardless of the meridian, for chromatic motion. We found no evidence of a MOE. Finally, our data show that the chromatic system can exhibit OEs at lower spatial frequencies than are observed for the achromatic system.

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