■講演要旨（VISION Vol. 20, No. 2, 72–76, 2008）

Color and Luminance Interactions in the Visual Perception of Motion and Depth

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Many studies have suggested that color and luminance are separately mediated by different processing streams in the early visual system and that the two information cues play different roles in the perception of motion, depth and shape. One major suggestion in these studies is that luminance information is the main contributor to motion and depth detection. Although color information was not considered as an important cue, recent studies have shown that color signals contribute to the detection of motion and depth as well. To sort out the relative contributions of both information cues and to shed light on the visual mechanism behind motion and depth detection in general, we have investigated how color information is processed in the presence of luminance information.

1. Introduction

Livingstone and Hubel (1987, 1988)[1,2] reviewed numerous studies showing that color does not provide essential information for the perception of motion and depth. However, recent studies have suggested that color signals do contribute to both perceptions (Simmons & Kingdom, 1994[3], 1995[4], 1997[5], 2002[6]; Cropper & Derrington, 1996[7]; Yoshizawa et al., 2000[8]; Mullen et al., 2003[9]; Michna et al., 2007[10]).

Since the reviews of Livingstone and Hubel (1987, 1988)[1,2], many studies have reported the deficiencies of chromatic processing of motion. For instance, Cavanagh, Tyler and Favreau (1984)[11], as well as Mullen and Boulton (1992)[12], demonstrated that isoluminant drifting gratings appear to move relatively slowly. Failure to discriminate the drift direction of gratings close to detection threshold has also been shown (e.g., Lindsey & Teller, 1990[13]; Metha & Mullen, 1998[14]). Despite these demonstrations, however, it has become clear that color vision still retains substantial motion processing capabilities, and recent research efforts using a wide range of different stimuli and approaches, have been directed at documenting and understanding these (e.g., Yoshizawa et al., 2000[8], 2003[15]; Mullen et al., 2003[9]; Michna et al., 2007[10]).

In line with the study on motion perception, early studies suggested degradation of stereopsis at isoluminance (e.g., Gregory, 1979[16]; Kovács & Julesz, 1992[17]). Gregory (1979)[16] showed that random dot stereo depth did not occur when there was color contrast, but no brightness difference between the dots and their background. Simmons and Kingdom (1994)[3] found that the disparity tuning of both chromatic and luminance mechanisms was similar, yet for stereoscopic depth identification a higher chromatic contrast threshold was found as compared to the luminance threshold.

Most studies on the relationship between color vision and stereopsis have concentrated on either the nature of stereopsis at isoluminance or whether chromatic information can assist in solving the correspondence problem. A series of studies on the first of these themes has attempted to establish the existence of a chromatic stereopsis mechanism and to characterize its properties (Simmons & Kingdom, 1994[3], 1995[4], 1997[5]; Kingdom & Simmons, 1996[18]; Kingdom, Simmons, & Rainville, 1999[19]). The conclusion from these studies is that there exists a rudimentary chromatic stereopsis mechanism which is less contrast sensitive, has a more limited disparity range, poorer stereoacuity and poorer ability to encode stereoscopically defined shape than its luminance counterpart.

2. Psychophysics

To explore the contradictory results on the relative contributions of luminance and color information on motion and depth perception, we investigated the characteristics of mechanisms mediating motion discrimination of isoluminant red-green, S-cone isolating and luminance stimuli with the masking effect paradigm (see details in Yoshizawa et al., 2000[8]; 2003[15], Mullen et al., 2003[9]; Michna et al., 2007[10]). We also examined the characteristics of mechanisms mediating disparity detection of S-cone isolating and luminance stimuli.

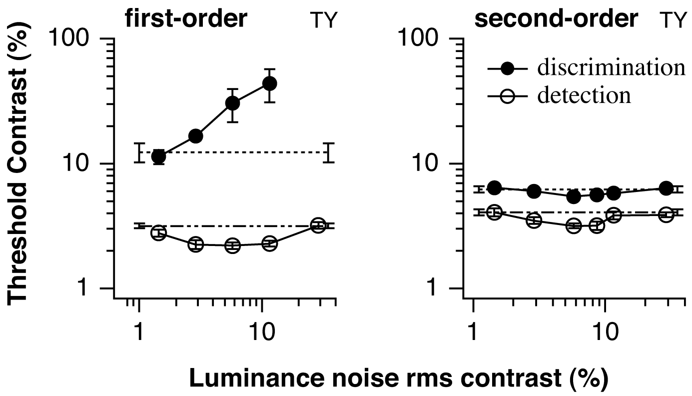
2.1 Motion

We used various levels of masking-noise contrast and investigated its effects on detection and direction discrimination thresholds for linear and nonlinear motion mechanisms, both with chromatic and luminance stimuli. We also investigated the effects of dynamic chromatic noise on our stimuli. As with the luminance noise, we measured the effects of variable contrast noise on detection and direction discrimination thresholds for chromatic and luminance stimuli under the linear and nonlinear motion conditions. **Fig. 1** shows the direction discrimination thresholds (filled symbols) and the detection thresholds (open symbols), as functions of the contrast of the masking noise.

In the presence of the luminance noise, the direction discrimination threshold for the linear chromatic motion monotonically increased, but that for the nonlinear chromatic motion did not. Both of the detection threshold for the linear and nonlinear chromatic stimuli showed no effect of the luminance noise contrast. The chromatic noise neither deteriorated linear nor nonlinear chromatic motion perception. However, the detection thresholds for both types of stimuli increased as the noise contrast increased. We also reported similar results for the S-cone isolating stimulus (Michna et al., 2007)[10]. These results indicate that the linear isoluminant motion stimuli are mediated by the luminance channel and that the nonlinear ones are mediated by the genuinely chromatic channels. That is, chromatic channels contribute to motion perception, and several mechanisms handle different chromatic motion stimuli.

2.2 Stereopsis

In the same manner as in Simmons and Kingdom (2002)[6], we measured stereoacuity (1/disparity threshold) of S-cone isolating and luminance stimuli as a function of the respective stimulus contrasts, as shown in **Fig. 2**. Note that the data were not normalized to the detection threshold. Consequently, performance is not strictly comparable between chromatic and achromatic performance at the same contrast level. This transformation would simply shift the chromatic and achromatic data relative to one another along the log-contrast axis.



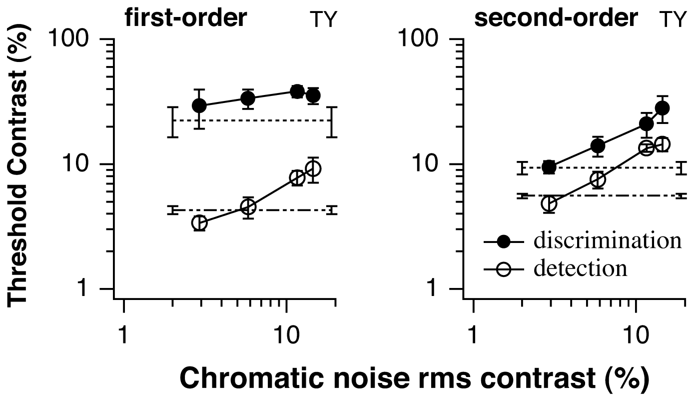


Fig. 1. Contrast thresholds for the direction discrimination of motion (filled circles) and stimulus detection (open circles) as a function of luminance noise contrast (to panels) and of chromatic noise contrast (bottom panels). Dashed- and dot-dashed lines represent the direction discrimination threshold and the detection threshold in the absence of noise, respectively. Left panels show the results for the first-order stimulus and right panels are for the second-order stimulus. Redrawn from Yoshizawa et al., 2000.

The stereoacuity for both the S-cone isolating (filled symbols) and luminance stimuli (open symbols) improved as the stimulus contrast increased. This indicates that the disparity tuning of both S-cone isolating chromatic and luminance mechanisms was similar, but more contrast was required for the chromatic patterns to evoke a sensation of stereoscopic depth. This finding is consistent with the results of Simmons and Kingdom (2002)[6] in which stereoacuity for red-green isoluminant and luminance binocular stimuli was tested.

3. Summary

We demonstrated that in our stimuli both the chromatic opponent channels played a substantial role in motion processing. In chromatic motion perception, several mechanisms handle different chromatic motion stimuli: the luminance mechanism deals with the linear isoluminant motion stimuli and genuine chromatic mechanisms deal with for the nonlinear ones. We also found that the disparity tuning of both S-cone isolating and luminance

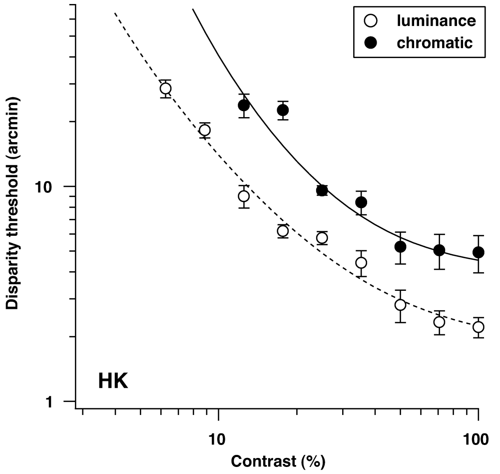


Fig. 2. Disparity thresholds in arcmin as a function of contrast. Filled circles and open circles represent the disparity threshold for chromatic Gabors and luminance Gabors, respectively.

mechanisms was similar, but more contrast was required for the chromatic patterns to evoke a sensation of stereoscopic depth. This finding is consistent with a series of studies by Kingdom and his colleagues (Simmons & Kingdom, 1994[3)], 1995[4)], 1997[5)], 2002[6)]; Kingdom & Simmons, 1996[18)]; Kingdom et al., 1999[19)]). Taking all our findings into account, chromatic signals do play important roles to produce the perception of both motion and depth, although in a somehow different manner than luminance signals contribute to these perceptions.

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