Influence of motion on chromatic detection

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Abstract

Intense scrutiny has been focused on whether chromatic stimuli contribute to motion perception. The present study considers a related but different question: how does motion affect chromatic detection? Detection thresholds were measured for a disk that underwent a brief (13.3 ms) chromatic change in the L/(L+M) chromatic direction. The disk’s presentation sequence and speed (0–16 deg/s) were manipulated. In the coherent presentation sequence, the disk moved smoothly along a circular path centered on the fixation point. In the random presentation sequence, the disk appeared randomly at positions along the circular path. In both types of sequences, the disk underwent a brief chromatic change midway through the temporal presentation sequence. Threshold was elevated in the coherent condition compared to the random condition, and threshold decreased with an increase in speed. The threshold elevation observed in the coherent presentation sequence can be accounted for by temporal integration. The decrease in threshold with an increase in speed can be accounted for by spatial integration. The results, therefore, can be explained by spatiotemporal integration, without invoking a neural mechanism specialized for motion.

Keywords: Motion perception, Chromatic detection

Introduction

Many investigations of motion perception at or near isoluminance assess whether purely chromatic information can mediate motion (e.g. Cavanagh et al., 1984; Dobkins & Albright, 1993; Culham & Cavanagh, 1994; Lu et al., 1999). While early reports suggest the motion system is “color-blind” (e.g. Ramachandran & Gregory, 1978; Livingstone & Hubel, 1987), other studies show that purely chromatic signals give rise to the percept of motion (e.g. Cavanagh & Anstis, 1991; Gegenfurtner & Hawken, 1996; Thiele et al., 2001). This paper considers a related but different issue: does motion affect chromatic detection? Most natural scenes include moving objects, so it is important to know whether color perception is affected by motion.

The study tests whether color perception is affected by motion and, if so, distinguishes two explanations for the influence of motion. The first posits that chromatic detection is facilitated by a specific motion-sensitive mechanism. The second explanation is that stimulus motion affects a neural mechanism not specialized for the perception of motion. Instead, chromatic detection of moving stimuli may be accounted for by spatial and temporal integration alone.

Materials and methods

Apparatus and calibration

Stimuli were displayed on a 17-inch calibrated color monitor (NEC FE750, 832 by 624 pixels, 75 Hz noninterlaced) controlled by a Macintosh G4 computer with a Radius Thunder 30/1600 auxiliary video board (10 bits per gun). The spectral power distribution of the R, G, and B guns was measured with an Optronics 750. The stimuli were specified in a cone-based chromaticity space (MacLeod & Boynton, 1979) modified slightly so the unit of $s = S/(L+M)$ is normalized to 1.0 for equal-energy white (EEW). In this space, the $x$-axis represents relative L- to M-cone stimulation $[l = L/(L+M)]$, and the $y$-axis represents relative S-cone stimulation $[s = S/(L+M)]$. The luminance output of each gun was linearized with lookup tables. Absolute luminance and the stability of the calibration were measured frequently with a Minolta LS-100 photometer.

Stimuli and procedure

Detection thresholds were measured using a two temporal interval forced-choice task. A moving disk (0.5 deg in diameter) underwent a brief (13.3 ms) chromatic change during one randomly selected interval. Seventy-nine-percent detection thresholds were estimated with a three-up one-down staircase procedure (two interleaved staircases were run simultaneously). Each staircase ran for 12 reversals; only the last six reversals were used for the threshold estimate. A final threshold was obtained from three separate measurements made on separate days.

The presentation sequence and speed (0–16 deg/s) of the disk were manipulated. In the coherent presentation sequence, the disk moved along a circular trajectory, 2 deg in diameter, and appeared to move smoothly between adjacent positions. In the random motion presentation sequence, the disk appeared along the same circular trajectory, but was presented in random positions so it appeared to jump from one location to the next. In all conditions, the duration of the entire temporal sequence was fixed (200 ms).
Because of the fixed temporal aspect of the sequences, the various speeds were achieved by varying the disk’s spatial displacement from frame to frame. Specifically, the disk was presented for 15 frames of 13.3 ms each, and the chromatic change was always presented on the eighth frame (Fig. 1). While “speed” is a good description of the spatial manipulation for the coherent sequence, it is inappropriate for the random sequence. The spatial manipulation is therefore expressed in terms of the disk’s total spatial displacement for a particular condition. For example, in the 2-deg/s condition, the disk was presented on an arc subtending 0.4 deg of visual angle while in the 16-deg/s condition the disk was presented on a 3.2-deg arc. Table 1 lists the speed, spatial displacement, and the angular displacement for each sequence.

In both random and coherent sequences, the disk underwent a 13.3-ms chromatic change midway through the temporal presentation. The chromatic change occurred along the l chromatic dimension and was a deviation from \( l = 0.665 \), either as an l increment (in a reddish direction) or as an l decrement (in a greenish direction).

As a control, the chromatic change was also presented as a single 13.3-ms pulse. The single 13.3-ms pulse was presented at a random spatial location anywhere along the circular trajectory.

An experimental session began with 3 min of dark adaptation followed by 3 min of light adaptation to the EEW background \((l, s, Y) \text{ of } 0.665, 1.00, 20 \text{ cd/m}^2\). Observers were instructed to determine which of two temporal intervals contained the chromatic change while remaining fixated on a small dot at the center of the monitor. Detection thresholds for l increments and l decrements were measured in the same sessions, in separate staircases. A session lasted about 20 min.

Isoluminance was determined for each observer using the method of minimum motion (Anstis & Cavanagh, 1983). Each observer, therefore, saw slightly different chromaticities based on their estimated isoluminance point. S-cone isolation was confirmed using the minimally distinct-border technique (Tansley & Boynton, 1978).

**Observers**

Three observers took part in the study. Two were naïve and one is the author, PM. All had normal or corrected acuity (20/20) and normal color vision as assessed with the Ishihara plates and Raleigh matching. All observers completed practice sessions to familiarize themselves with the task before data collection was initiated. Each subject gave informed consent before beginning the experiments, which were approved by an Institutional Review Board at the University of Chicago.

**Table 1. The speed, spatial displacement (deg of visual angle), and angular displacement (deg) for the motion sequences tested**

<table>
<thead>
<tr>
<th>Speed (deg/s)</th>
<th>Spatial displacement (deg)</th>
<th>Angular displacement (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>0.4</td>
<td>22.9</td>
</tr>
<tr>
<td>4</td>
<td>0.8</td>
<td>45.8</td>
</tr>
<tr>
<td>8</td>
<td>1.6</td>
<td>91.7</td>
</tr>
<tr>
<td>16</td>
<td>3.2</td>
<td>183.4</td>
</tr>
</tbody>
</table>

**Results**

**Luminance-increment disk**

In this experiment, the disk \((l, s, Y) \text{ of } 0.665, 1.00, 30 \text{ cd/m}^2\) was a luminance increment from the EEW background \((l, s, Y) \text{ of } 0.665, 1.00, 20 \text{ cd/m}^2\). Chromatic threshold was measured along l, either as an increment or decrement from \( l = 0.665 \). Absolute detection thresholds, averaged over increments and decrements, are plotted as a function of spatial displacement in Fig. 2. The error bars are standard errors based on results from 3 days. Open and solid circles are the thresholds for the coherent and random presentation sequences, respectively. Detectability of the chromatic change alone, as a single 13.3-ms pulse, also was measured (squares). Compared to the stationary case (0 deg), the pulse threshold was lower for every observer. A stationary threshold (0 deg), as well as thresholds for the smallest spatial displacements, were higher than achievable by the monitor gamut for observer JW. This stationary comparison shows that the threshold to detect a chromatic change is lower when it is simultaneously presented with a luminance pedestal compared to when the luminance pedestal is extended temporally both before and after the presentation of the chromatic change, as in the 0-deg condition. These measurements are qualitatively consistent with previous work (Cole et al., 1990; Eskew et al., 1994).

For both types of sequences, detection thresholds significantly decreased with spatial displacement for two observers [JW: \( F(2,24) = 7.53, P < 0.05; \text{ ML: } F(3,32) = 3.05, P < 0.05; \text{ PM: } F(3,32) = 0.43, P = 0.73 \)]. Thresholds were significantly lower for the random compared to the coherent sequence for two observers [JW: \( F(1,24) = 2.41, P = 0.13; \text{ ML: } F(1,32) = 10.32, P < 0.05; \text{ PM: } F(1,32) = 4.37, P < 0.05 \)].

**Isoluminant disk**

Detection thresholds were measured using a disk that was equal in luminance to the achromatic background \((l, s, Y) \text{ of } 0.665, 1.00, 20 \text{ cd/m}^2\). The disk appeared lime \((l, s, Y) \text{ of } 0.665, 0.17, 20 \text{ cd/m}^2\) and, as before, the chromatic change occurred along l, as either an increment or decrement from \( l = 0.665 \), at a luminance of

![Fig. 1. Chromatic detection thresholds were measured for a chromatic change that appeared as part of a sequence. The disk was presented for 15 frames of 13.3 ms each, and the chromatic change was always presented in the eighth frame.](image-url)
The influence of motion on chromatic detection

20 cd/m². Average absolute $l$ detection thresholds averaged over increments and decrements are plotted as a function of spatial displacement in Fig. 3. The format is the same as in Fig. 2. Stationary thresholds (0 deg) were above the extremes of the monitor gamut for all observers. Hence, the threshold to detect a chromatic change in a 13.3-ms pulse was again significantly lower than the threshold for 0 deg.

For both coherent and random sequences, detection threshold decreased significantly with spatial displacement for observers ML and PM [ML: $F(3,32) = 13.32$, $P < 0.05$; PM: $F(3,32) = 8.43$, $P < 0.05$]. In general, threshold was lower for the random than for the coherent presentation sequence although this reached statistical significant for only observer ML [ML: $F(1,32) = 9.43$, $P < 0.05$].

Discussion

Chromatic detection was investigated with a moving disk. The measurements showed that chromatic detection was affected by

Fig. 2. Chromatic detection thresholds were measured for a disk moving smoothly (open circles) or randomly (solid circles) along a circular trajectory. The disk was a luminance increment from the background and the chromatic change occurred along $l$, either as an increment or decrement from $l = 0.665$. Absolute $l$ detection thresholds for a pulsed chromatic change (solid squares) were lower than for the stationary (0-deg) condition. Generally, thresholds decreased with angular displacement and were lower for the random compared to the coherent sequence.

Fig. 3. Chromatic detection thresholds were measured for a disk that was equal in luminance to the background. Thresholds for the pulse (solid squares) were lower than for the stationary (0-deg) condition (these thresholds could not be measured with the limited gamut of the experimental monitor). Thresholds generally decreased with angular displacement and were lower for the random compared to the coherent sequence.
both the spatial displacement of the moving disk and the presentation sequence (coherent vs. random). Chromatic detection generally improved with spatial displacement and was better when the disk was presented in a random sequence rather than as a coherent sequence. What can account for these results?

Some explanations can be ruled out. While a specific motion-sensitive chromatic mechanism can accommodate the increase in sensitivity with speed, such a mechanism cannot explain lower detection thresholds in the random presentation sequence than the coherent sequence. Further, the measurements are not consistent with an explanation based on spatial uncertainty because the spatial location of the chromatic change is less certain in the random presentation sequence compared to the coherent motion sequence.

The measurements can be accounted for by spatial and temporal integration. First, the difference between coherent and random presentation showed the importance of the temporal aspect of the sequence. In both sequences, the spatial presentation of the disk with the chromatic change was identical. The difference in threshold for the two sequences must be due to the temporal characteristic of the presentations. In the coherent sequence, the chromatic change always was immediately preceded and followed by a disk in an adjacent location. This stimulation in close temporal and spatial proximity can plausibly mask the chromatic change.

Temporal integration can explain the difference in chromatic detection threshold between the pulse and the 0-deg condition. Chromatic detection was significantly better in the pulse condition, when the luminance (Experiment 1) or chromatic (Experiment 2) pedestal was temporally coincident with the chromatic change. When the pedestal was temporally extended both before and after the presentation of the chromatic change (as in the 0-deg condition), thresholds were elevated. Temporal integration of neural signals longer than the 13.3-ms chromatic change would raise threshold with the temporally extended pedestal (Cole et al., 1990; Eskew et al., 1994; Stromeyer et al., 1998).

Finally, spatial integration can account for the general decrease in threshold with spatial displacement. For both sequences, the spatial overlap of the disk from frame to frame decreased with spatial displacement. If signals were pooled over some spatial region, then threshold for the chromatic change would increase with spatial displacement, as shown by the measurements here.

In sum, threshold to detect a chromatic change increased when the change was embedded in a coherent motion sequence rather than in a random sequence. This can be accounted for by spatial and temporal aspects of the stimulus and neural integration, without invoking a specialized chromatic-motion mechanism.

Acknowledgments

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References


