Movement-selective mechanisms in human vision sensitive to high spatial frequencies

C. F. Stromeyer III and J. C. Madsen
Division of Applied Sciences, Harvard University, Cambridge, Massachusetts 02138

Stanley Klein
Division of Biology, California Institute of Technology, Pasadena, California 91125
Joint Science Department, Claremont College, Claremont, California 91711

Y. Y. Zeevi
Department of Electrical Engineering, Technion-Israel Institute of Technology, Haifa, Israel
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Evidence for motion-selective mechanisms sensitive to high spatial frequencies (e.g., 15 c/deg) was obtained via direction-specific adaptation and measurements of the threshold ratios for moving and counterphase flickering gratings.

I. INTRODUCTION

A flickering line has two visual thresholds: at one threshold flicker is apparent; at the second threshold, spatial structure is apparent.[1,2] Keesey[1] suggests that the two thresholds reflect "flicker- and spatial-contrast-detection mechanisms," respectively. Several investigators[1–3] have studied the properties of flicker or movement mechanisms (transient mechanisms) and pattern mechanisms (sustained mechanisms) using these subjective criteria of seeing flicker or pattern.

The present experiments examine whether there are motion-selective mechanisms sensitive to high spatial frequencies. Two methods are used which do not rely on subjective criteria of seeing flicker or pattern. First, the threshold of a compound grating composed of two oppositely moving matched sinusoids is compared to the threshold of one of the

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TABLE I. Thresholds (in percent contrast) and ±1.0 S.E. for grating of 6 c/deg moving rightward or in sinusoidal counterphase flicker at rate in left column. Observers CFS and (YYZ). Right column: threshold ratio of counterphase and moving gratings.

Hz	Counterphase	Moving	Ratio
2	0.50 ± 0.01	0.42 ± 0.01	1.19
	(0.60 ± 0.01)	(0.43 ± 0.01)	(1.40)
4	0.60 ± 0.02	0.44 ± 0.01	1.36
6	0.82 ± 0.02	0.50 ± 0.01	1.64
8	1.02 ± 0.02	0.53 ± 0.01	1.92
	(0.93 ± 0.02)	(0.48 ± 0.04)	(1.94)

components. For spatial frequencies below ~ 7 c/deg, Levinson and Sekuler[4] showed the composite pattern reached threshold when either of its components reached threshold. This finding suggests the two components are detected by unidirectional motion mechanisms. In the present experiments, the two oppositely moving sinusoids are of the same contrast and move at the same rate, thus forming a stationary, counterphase flickering grating. This pattern was used extensively by Levinson and Sekuler. The second method is direction-selective adaptation. Sekuler and Ganz[5] showed that adapting to a grating moving in one direction raises the threshold more for a subsequently seen grating moving in the same direction than in the opposite direction. This effect has typically been demonstrated using spatially coarse patterns.[5-8] In the present experiments, considerably higher spatial frequencies are used for both methods. The experiments suggest that *motion-selective* mechanisms are used to detect patterns of relatively high spatial frequencies that move quite rapidly.

II. METHODS

Vertical sine-wave gratings were displayed on a Tektronix 602 oscilloscope (P-4 phosphor). The patterns were generated with synchro-resolvers and Wavetek 186 function generators. The x-axis sweep repeated every 4.7 m. The field was 4.6° wide and 4.3° high with a dark surround. However, for the results shown in Fig. 4 the field was 4° in diameter. For the first experiments (with gratings of 6 c/deg) the mean luminance of the field was 52 cd/m^2; later it was 19 cd/m^2. The velocity of the moving gratings is specified by the corresponding temporal frequency (Hz) which is equal to the product of the velocity and spatial frequency.

The observer started at a tiny fixation point in the center of the field while making *all* threshold judgments. For the results in Table I, the threshold contrast was set by the method of adjustment. The remaining measurements were made with a signal detection method, described elsewhere.[9,10] Each run consisted of 100 trials. For the experiments comparing the threshold of a moving grating to a counterphase grating, the test pattern's contrast was selected at random with equal probability at one of four contrast values (including blanks). The observer pressed a button to present the test pattern. For the experiments on direction-specific adaptation

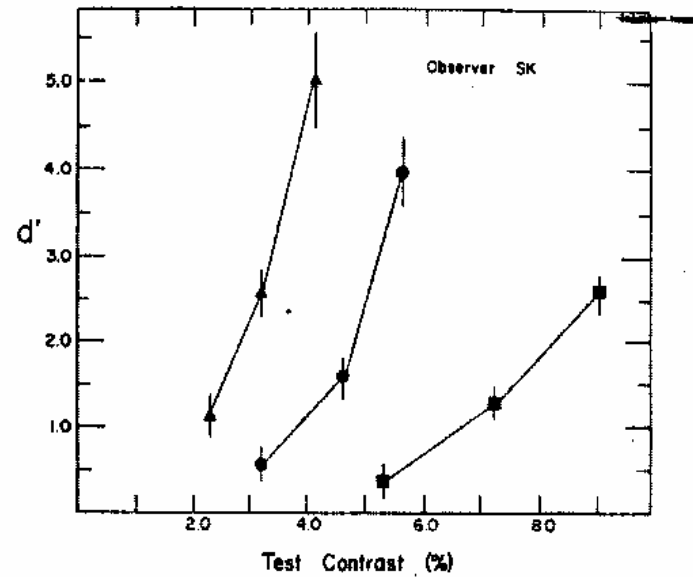

FIG. 2. Detectability of 15 c/deg gratings that were stationary (triangles), moved rightward at 10 Hz (circles), or flickered in counterphase at 10 Hz (squares). Patterns were exposed for 400 ms. Each curve is based on two runs.

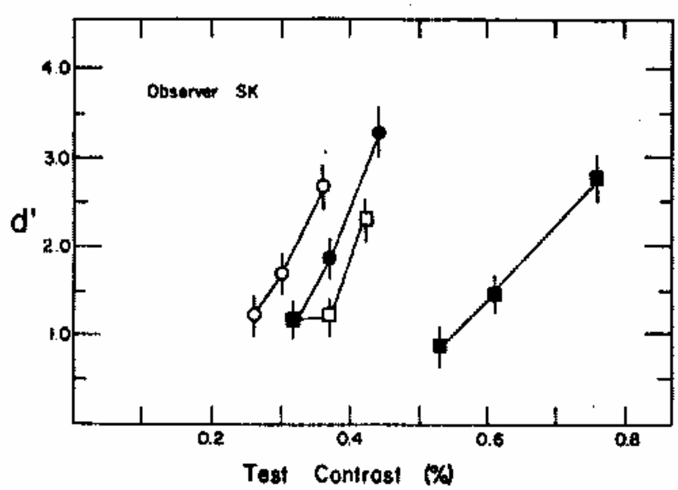

FIG. 1. Detectability d', and ±1 S.E. for gratings of 6 c/deg that moved rightward at 2.7 (open circles) or 8.0 Hz (closed circles) or flickered in counterphase at 2.7 (open squares) or 8.0 Hz (closed squares). Patterns were exposed for 750 ms. Each curve is based on two runs.

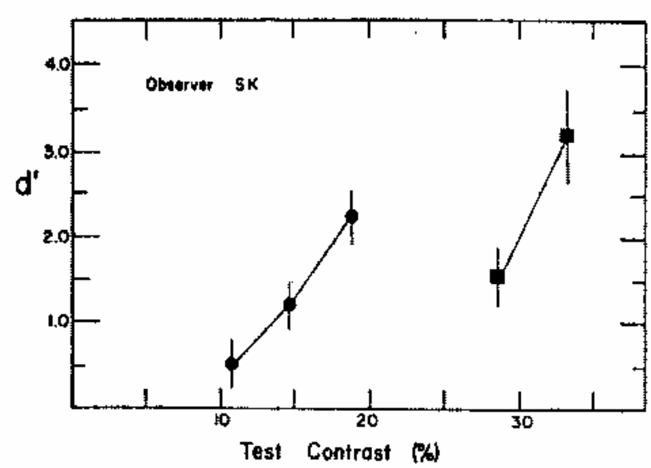

FIG. 3. Detectability of 15 c/deg gratings that moved rightward at 20 Hz (circles) or flickered in counterphase at 20 Hz (squares). Patterns were exposed for 400 ms. The curve for the moving grating is based on one run; each point for the counterphase gratings is based on one run.

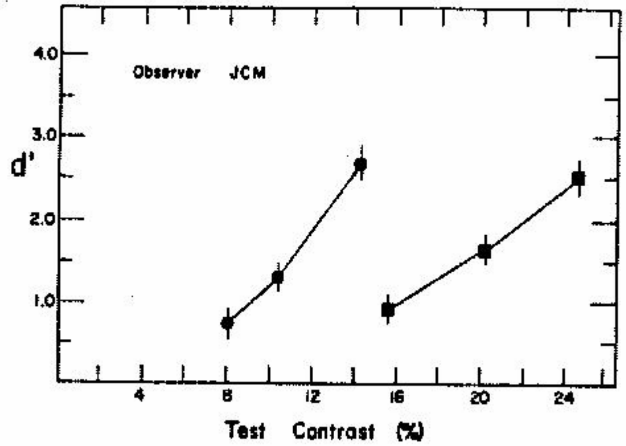

FIG. 4. Detectability of 15 c/deg gratings that moved rightward at 15 Hz (circles) or flickered in counterphase at 15 Hz (squares). Patterns were exposed for 400 ms. Each curve is based on three runs.

the test pattern was randomly chosen to be either a blank or a grating moving rightward or leftward. The adapting pattern during a run moved in only one direction (right or left) for 10 s intervals, which alternated with blank intervals of 3 s during which the observer presented the test pattern for 400 ms.

III. RESULTS

Table I shows the threshold values obtained for counterphase and rightward-moving gratings of 6 c/deg. The modulation rates are given in the left column. The right column shows the threshold ratios of counterphase and moving gratings. The ratios approach two only at the higher modulation rates. This result was replicated using the signal detection method (Fig. 1). The visibility of the moving gratings is quite similar at rates of 2.7 and 8.0 Hz. (Perhaps movement mechanisms are used to detect both moving patterns.) However, there is a large difference in the visibility of the counterphase gratings at the two rates. (There may be a shift from form to movement mechanisms when the modulation rate is increased.) The results thus suggest that rapid temporal rates should be used to isolate movement mechanisms at high spatial frequencies.

Figure 2 shows the detectability of gratings of 15 c/deg that were presented for 400 ms. The gratings were either stationary, moving rightward at 10 Hz, or in counterphase flicker at 10 Hz. For equal detectability, the counterphase gratings had slightly less than twice the contrast of the moving gratings. Figure 3 shows similar results for a 20 Hz rate. Figure 4 shows results for a second observer obtained with a 15 Hz rate. The threshold ratio of approximately 2 for counterphase and moving gratings suggests the gratings are detected by unidirectional motion mechanisms.

Direction-specific adaptation was observed with patterns of 15 c/deg that moved at 10 Hz. The solid symbols in Fig. 5 show the detectability of the gratings *prior* to selective adaptation (observers adapted to a blank field). Circles and square are used for observers CFS and JCM, respectively. For one run, the adapting grating (40% contrast) moved leftward, for a second run, it moved rightward. Results for leftward- and rightward-moving *test* patterns are shown separately, although both patterns were used in each run. The points labeled R and L show detectability of the test gratings while adapting to leftward- and rightward-moving patterns, respectively. Test patterns that moved in a direction opposite from the adapting patterns often appeared to be clearly and swiftly moving, whereas test patterns moving in the same direction as the adapting pattern were hardly visible.

IV. DISCUSSION

For gratings of 6 and 15 c/deg, the threshold ratio of counterphase and moving gratings approached 2 when the modulation rate was above 8 or 10 Hz. This suggests that the gratings are detected by directionally selective motion mechanisms (Introduction). At low modulation rates, the ratio was considerably less than 2. Such patterns may be largely detected by nondirectional, sustained mechanisms that are equally sensitive to moving and counterphase gratings of equivalent contrast. Kulikowski and Tolhurst[3] observed that at 0.8 c/deg, lower contrast was needed to see "flicker" than "pattern" when the modulation rate of counterphase flick-

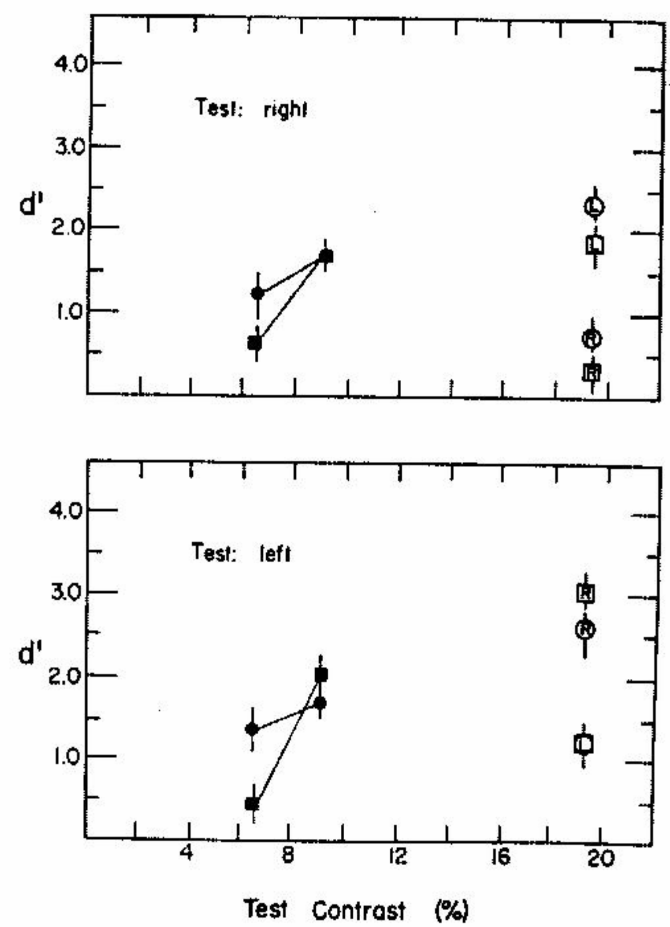

FIG. 5. Detectability of 15 c/deg test gratings moving rightward or leftward at 10 Hz. Each direction of movement is represented in separate panels, although rightward- and leftward-moving test gratings were presented in each run. Solid symbols show *d'* prior to exposure to the adapting pattern. Circles and squares are used for observations CFS and JCM, respectively. The symbols R and L show *d'* while adapting, respectively, to a rightward- or leftward-moving grating that was similar to the test gratings but of 40% contrast. Test patterns were exposed for 400 ms.

ering gratings was as low as 2 Hz, whereas at 12 c/deg, the flicker rate had to be increased to 6 Hz for flicker to be seen at a lower contrast than pattern. Both sets of results suggest that at low modulation rates, the sustained mechanisms may be more sensitive; and at high modulation rates, the motion mechanisms may be more sensitive.

The existence of direction-specific adaptation observed with gratings of 15 c/deg further suggests that the thresholds of rapidly moving, fine gratings may be determined by direction-selective mechanisms that respond to high spatial frequencies. Although the observed adaptation was direction-specific, a leftward- or a rightward-moving adapting pattern considerably affected the visibility of test patterns moving in *both* directions. This is a generally observed property of direction-specific adaptation.[4,7,8]

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