Influence of the spatial periodicity of moving gratings on motion response

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The present experiments examine the suprathreshold response of the motion or direction-selective portion of the human visual system by means of the motion aftereffect (MAE). The MAE was measured as a function of the contrast and spatial frequency of moving sinusoidal gratings. For spatial frequencies less than 1 cy/deg, the MAE speed was found to increase linearly with log contrast up to 80%. For spatial frequencies greater than 1 cy/deg, the rate of increase of the MAE speed with log contrast was not found to be linear over the entire range of contrast. The nonlinearity was greatest for the 8 and 10 cy/deg gratings, which showed very little increase in MAE speed with contrast above 25%. We conclude that the direction-specific mechanisms in human vision show a more limited contrast response to the high spatial frequencies than does the visual system as a whole.

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Fig. 1. Initial MAE speed as a function of the contrast of the moving grating for 1 cy/deg (○), 4 cy/deg (△), and 8 cy/deg (□) for Subject P. H. The data for the 1 and the 8 cy/deg gratings were normalized by the factors given in the caption of Fig. 2.

its normal baseline response (adaptation). When the stimulus motion was stopped, the response dropped abruptly to zero and then slowly recovered to its maintained level of discharge. The MAE is believed to result from an imbalance in discharge among cells sensitive to various directions of motion during the recovery phase.5-8 A stronger MAE would be due to a greater imbalance, which in turn implies a greater response of the direction-specific system during adaptation. We therefore assume that the magnitude of the MAE can be used as a measure of the response of the direction-specific motion system.

Sekuler and Pantle8 used the MAE to determine the recovery rate and the dependence on stimulus velocity of direction-specific cells. Pantle6 measured the MAE as a function of the velocity (temporal frequency) for 3 and 6 cy/deg gratings. He concluded that the magnitude of the MAE has a broad maximum for a temporal frequency near 5 Hz for both 3 and 6 cy/deg gratings. To achieve this optimal temporal frequency of 5 Hz, the grating velocity must be changed accordingly for each spatial frequency.

Keck et al.10 examined the dependence of the MAE on the contrast of 4 cy/deg moving gratings. Their results showed that for low contrasts, the MAE magnitude increased rapidly with grating contrast. However, for contrasts greater than five to six times threshold, further increases in the MAE magnitude with contrast occurred at a greatly reduced rate. This is in agreement with the results of Pantle and Sekuler4 and Pantle et al.5 obtained from direction-selective adaptation experiments.

In the present experiments we measured the MAE as a function of the contrast and spatial frequency of moving gratings. At each spatial frequency the velocity of the adapting grating was adjusted to result in a temporal frequency of 5 Hz. The magnitude of the MAE was determined by two psychophysical methods: magnitude estimation and tracking. The gratings subtended a visual angle of 7.6° × 5.9°.

Experimental method

Grating display. The gratings used for this study were generated electronically on the face of a Tektronix 5103 (F31 phosphor) oscilloscope. The manual intensity control of the oscilloscope was positioned so that the luminance of the screen was
directly proportional to the DC voltage applied to the external z-axis input. An amplifier was used to sum the AC and DC voltage applied to the z-axis.

Because the luminance of the screen was a linear function of the applied z-axis voltage, the contrast was the peak amplitude of the AC voltage divided by the DC voltage (up to 80% contrast). This was confirmed by optical measurements of the contrast.

The gratings were made to drift across the screen by continuously phase-delaying the signal applied to the trigger relative to the z-axis signal. This was accomplished by rotating a synchroresolver with a motor. The grating speed was determined by the angular speed of the synchroresolver.

The experiments took place in a room that was dark except for the light emitted by the oscilloscope screen. For all measurements, the subject viewed the display binocularly from a chair situated so that the viewing distance was 1 m. A headrest was mounted on the chair to maintain a constant viewing distance. At 1 m the screen subtended a visual angle of 7.6° horizontally and 5.9° vertically. A small black dot situated in the center of the display served as a fixation point for the subjects. The average luminance of the screen was 0.7 millilamberts.

Subjects. The subjects were three John Carroll University students. P. H. and F. M. were experienced psychophysical observers. T. B. was familiarized with the procedures used and was given some practice in observing prior to being used as a subject. All three subjects were myopic and wore corrective lenses.

Procedure. Before each run, the subject dark-adapted for 10 min. He was then presented with a set of trials. Each trial consisted of the following: a 30 sec presentation of a moving grating at the desired contrast, a 3 sec uniform field, and then a stationary test grating (same spatial frequency as the moving grating) at four times threshold contrast (the MAE varies with the test contrast). For both the adapt and test phase, the subject was instructed to maintain fixation on the small black dot located at the center of the display. The MAE generated with the test grating was measured either by magnitude estimation or tracking. During a particular run, only one method was used.

When using the method of magnitude estimation, the subject was asked to estimate the backward speed of the MAE within 2 sec after the stationary grating was turned on. The first two trials were with a 4 cy/deg grating (14% contrast) which was referred to as the standard. The subject was told that the MAE arising from the standard...
had a speed of 50 and that all other MAEs were to be estimated relative to this standard speed.

When using the tracking method to measure the MAE, the subject moved a lever at the same speed as the test grating appeared to be moving. The lever was the wiper of a linear potentiometer. Its position was recorded on a strip chart recorder with a speed of 15 cm/min. The slope of the resulting curve was proportional to the lever speed. Tangents to the first 2 sec of the recorded curves were drawn to obtain the initial MAE speed.

The contrast of each moving (adapting) grating was the independent variable tested for each spatial frequency. The contrasts tested ranged from 0.6% to 80%. The range of spatial frequencies tested was 0.26 to 10 cy/deg, with only one spatial frequency utilized per run. The speed of the moving grating of each spatial frequency was such that it produced a 5 Hz temporal frequency at any point on the oscilloscope face.

A run consisted of the following: two standards (defined to have an MAE speed of 50 for magnitude estimation); two familiarization trials which served as practice for the subject; a set of trials, one at each contrast tested, presented in random order; a standard, the speed of which was estimated (or tracked) by the subject; a second complete set of trials, also presented in random order; and a final standard trial. There was a 90 sec delay between trials during which the subject looked away from the display. Each run took approximately 1½ hr, with the actual time depending on the number of contrasts presented.

Results

Fig. 1 shows representative results for Subject P. H. The initial MAE speed resulting from the adaptation to moving gratings is shown as a function of the contrast of the moving grating for three different spatial frequencies. Each point is the geometric mean of four speed estimates obtained during two separate runs by the method of magnitude estimation.

The straight lines are obtained by least-squares fits to the data. The data is divided into a high-contrast and a low-contrast segment, each with its own straight-line fit. A choice was made by inspection as to which data point should be used for the break point between the high-contrast segment and the low-contrast segment. If the resulting lines indicated that a poor choice had been made, the procedure was repeated until a good fit.
Fig. 4. Initial MAE speed as a function of the contrast of the moving grating for Subject T. B., who is using the method of tracking. The spatial frequency is indicated in cycles per degree next to each curve. These data were not normalized. The mean value of the standard errors for Subject T. B. was 0.50.

Fig. 2 shows the normalized MAE speed at all the measured spatial frequencies for Subject P. H. Similar curves are shown for Subject F. M. in Fig. 3. And the curves in Fig. 4 are fits to data obtained from Subject T. B. by the tracking method rather than the magnitude estimation method. Note that dashed curves are used for spatial frequencies less than 1 cy/deg and that the labels next to each curve refer to the spatial frequency.

The families of curves presented in Figs. 2 to 4 for the three subjects showed the following similar trends. (1) The threshold contrast for obtaining an MAE was at a minimum at an intermediate spatial frequency (about 1 cy/deg); it increased for both higher and lower spatial frequencies. (2) For spatial frequencies less than 1 cy/deg the MAE speed increased linearly with the logarithm of the grating contrast above threshold. (3) For higher spatial frequencies the MAE speed did not increase linearly with log contrast over the entire contrast range. For contrasts greater than about six times threshold, the rate of increase of the MAE speed was reduced. This was most pronounced at the highest spatial frequencies where we began to see a saturation of the MAE speed.

Discussion

The MAE results from the fatiguing of that portion of the visual system which detects the motion of a stimulus. The present experiments examine the response of this direction-specific system as a function of the stimulus contrast and spatial frequency.

First, consider the minimum contrast re-
required to obtain a response of this system at a particular spatial frequency. An approximate value of this minimum contrast could be obtained from our data by extrapolating the MAE speed curves to zero; the intercepts would represent the threshold contrasts required for obtaining an MAE. The reciprocal of the threshold contrast values for T. B. (from Fig. 4) are plotted as a function of the spatial frequency in Fig. 5 (triangles). These values ought to be compared with the more conventional measurement of a threshold contrast for the detection of a moving grating, with motion direction used as the detection criterion. We have measured these threshold contrasts for Subject T. B., and their reciprocals are also plotted in Fig. 5 (circles). Note that the sensitivity is greater for the latter measurements. This is a reasonable result, since the MAE is a fatiguing effect, and one might expect that the threshold for obtaining it would be somewhat higher than that required for detecting the grating motion.

However, the striking similarity between the two curves supports the notion that the cell population which mediates the detection of a moving grating is also responsible for the MAE.

Next, consider the response above threshold. For low spatial frequencies, less than 1 cy/deg, the MAE speed was found to increase linearly with log contrast up to 80% contrast. However, for spatial frequencies greater than 1 cy/deg the increase of the MAE speed with log contrast was not found to be linear over the entire range of contrast. The nonlinearity is especially pronounced for the highest spatial frequencies, 8 and 10 cy/deg. For these spatial frequencies there is very little increase in MAE speed above 25% contrast. Thus, for high spatial frequencies, the MAE speed shows a limited or compressed contrast response. These results are in agreement with published data available for some spatial frequencies.\(^4\) 5\(^\text{st}10\)

The MAE measurements which we have...
reported in this paper must be attributed to the direction-specific mechanisms in human vision. We have found that this subset of cells has a more limited contrast response to high spatial frequencies than does the visual system as a whole. Although the transient cell populations have been shown not to respond well to high spatial frequencies, there is no convincing evidence that all direction-specific cells fall solely within the transient system. It remains to be shown whether those direction-specific cells which respond to high spatial frequencies can be classed as either transient or sustained.

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REFERENCES