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Monocular pattern alternation: Effects of mean luminance and contrast

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Monocular pattern alternation refers to the changes over time in the apparent contrast of the components of a pattern formed by superimposing two sinusoidal gratings. In Experiment 1, alternation rate was measured as a function of the orientation, spatial frequency, and mean luminance of the pattern. Experiment 2 determined pattern alternation rate as a function of orientation, spatial frequency, and contrast. For both experiments, alternation was greater for patterns whose components were horizontal and vertical than for patterns whose components were obliquely oriented. These differences were more pronounced at intermediate than at high and low spatial frequencies. With decreases in mean luminance, there was a decline in both the rate of alternation and the differences in rate due to orientation. There was no significant effect of contrast upon alternation rate. Experiment 3 determined the effects of viewing time upon pattern alternation. For both horizontal-vertical and oblique patterns, the frequency of alternation increased with time up to 100-200 sec and then leveled off. However, the rate of increase with time was greater for horizontal-vertical patterns. These results were discussed in terms of the antagonistic interaction between channels tuned to spatial frequency and orientation.

Under monocular viewing, a pattern composed of two sinusoidal gratings alternates so that over time there are changes in the component that is dominant in apparent contrast and in the one that is reduced. This phenomenon is called monocular pattern alternation. Alternation is found when the components have the same spatial frequency but differ in relative orientation by at least 10°-15° (Kitterle & Thomas, 1980) or have the same orientation and differ in spatial frequency by an octave (Furchner & Ginsburg, 1978). Psychophysical studies using an adaptational paradigm have suggested the existence of mechanisms or channels sensitive to orientation and spatial frequency. Because the band width of channels selectively sensitive to orientation is ±10°-15° and the spatial frequency selectivity is ±1 octave, it has been suggested that monocular pattern alternation reflects interactions between channels tuned to spatial frequency and orientation (e.g., Campbell, Gilinsky, Howell, Riggs, & Atkinson, 1973).

The orientation of the components of the pattern influence alternation rate. Kitterle, Kaye, and Nixon (1974) found that alternation rate was less for patterns in which the components were oblique left and right than for patterns in which one component was horizontal and the other vertical. This finding is consistent with other research that indicates that lateral interactions are weaker between oblique channels than between those responsive to the horizontal and vertical meridians (Essock, 1982; Kitterle, 1973).

In a more recent study, Georgeson and Phillips (1980) determined the influence of relative versus absolute orientation upon pattern reversal rate. The components were 4 cycles/deg (cpd) sinusoidal gratings. They were oriented symmetrically about a coordinate system with either a vertical or an oblique axis, and the angle between the components was varied. Based upon results of Kitterle et al. (1974), Georgeson and Phillips (1980) expected that there would be more rivalry when the angular separation between the components was large for gratings varied about an oblique axis than there would be for gratings varied about a vertical axis that had small angular separations between the components. This is because in the oblique axis condition the components in the horizontal and vertical meridians are at large angular separations. On the other hand, in the vertical axis condition the components in the oblique meridians are at small angular separations.

Georgeson and Phillips (1980) did not find any difference in the rate of alternation between these two conditions. They have argued, primarily from threshold data (e.g., Campbell, Kulikowski, & Levinson, 1966), that these results are to be expected. Differences in sensitivity between vertically and obliquely oriented gratings tend to be greatest at high spatial frequencies and to decrease with corresponding decreases in spatial frequency. There is virtually no effect of orientation at spatial frequencies at or below 4 cpd (see also Berkley, Kitterle, & Watkins, 1975). Nevertheless, other suprathreshold data have shown orientation effects in which it can be inferred that lateral interactions are weaker in the oblique orientations with large targets and at medium spatial frequencies (Bowker & Mandler, 1981; Kitterle, 1973). In addition, other research (Kitterle & Thomas, 1980) indicates that at higher spatial frequencies the effect of orientation on alternation rate is not found. The discrepancy between the results of Kitterle et al. (1974) and Georgeson and Phil-

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lips (1980) has led us to reexamine the influence of orientation and spatial frequency upon pattern alternation.

Mean luminance and contrast have been shown to influence the magnitude of the oblique effect (Berkley et al., 1975; Kitterle, Leguire, & Riley, 1975). Consequently, the present study was undertaken to determine the effects of mean luminance (Experiment 1) and contrast (Experiment 2) upon alternation rate. In both experiments, the spatial frequency of the components was also varied.

EXPERIMENT 1: MEAN LUMINANCE

Method

Observers. Thirty introductory psychology students participated in this experiment. They were naive about the purpose of the experiment and served for course credit. Each observer had uncorrected 20/20 acuity, as determined by a Snellen chart. The stimulus display was viewed monocularily by the sighting dominant or preferred eye, as determined by the procedure outlined by Coren, Porac, and Ward (1978).

Apparatus. A four-channel projection system was used to present the stimuli. One channel (Channel 1) provided a uniform adapting field, which was on during the times that the stimuli were not presented. Channels 2 and 3 were used to present each component of the pattern. These channels could be rotated to present the components of the grating in various orientations. Channel 4 provided a uniform field, which, in combination with Channels 2 and 3, equaled the mean luminance of Channel 1. Thus, adaptation level remained constant when the blank field and the pattern were switched. Light in Channels 2 and 3 was polarized orthogonally to that in Channel 4. By rotating an analyzer placed in front of the observer's eye, grating contrast could be changed independently of mean luminance. The mean luminance of the patterns could be changed independently of its contrast by placing neutral density filters in all channels. In Experiment 1 there were three mean luminance levels: 92.2, 21.6, and 8.6 cd/m^2, as measured with an SEI photometer. The contrast of the gratings (maximum luminance − minimum luminance/maximum luminance + minimum luminance) was held constant at .10.

The stimuli were calibrated photographic transparencies of sinusoidal gratings produced by Stromeyer and Lange (Stromeyer, Lange, & Ganz, 1973). At a viewing distance of 509.97 cm, the spatial frequencies of the gratings were 1.00, 2.25, 4.00, 8.00, and 11.00 cpd. The stimulus configuration of the two crossed gratings was circular and subtended 4.5° in diameter. The observer viewed the stimulus pattern through an aperature in an otherwise flat black screen. A headrest allowed the observer to position himself comfortably. Three event counter/timers (Hunter Klockounters, Model 120A Series D) were used to record the frequency and the duration of a keypress. The response keys were attached to the chair used by the observer.

Procedure. Each observer was assigned randomly to one of three independent groups, which differed in mean luminance of the pattern they were to view. All groups judged monocular pattern alternation for patterns in which the two components were either obliquely oriented, that is, one grating at 45° and the other at 135° (O-O condition), or horizontally and vertically oriented (H-V condition) with one grating at 0° and the other at 90°. For each orientation condition, there were six randomly presented spatial frequencies. Observers made two judgments of alternation for each stimulus condition, resulting in a total of 20 observations per data point.

An experimental session began with 5 min of adaptation to the mean luminance. During this period, the instructions were read to the observer, who was told to press a response key to indicate the dominant aspect of the pattern (i.e., the component that had the greatest contrast) at a given moment. For example, for the H-V and O-O conditions, pressing the middle key indicated that the composite condition dominated, whereas pressing either the left or the right key indicated that one of the components of the grating dominated. For some observers in the H-V condition, the left key was used to indicate the dominance of the horizontal component and the rightmost key was used to indicate the dominance of the vertical component. For the others, this was the reverse. Similarly, in the O-O condition, the leftmost key corresponded to dominance of the 45° component and the rightmost key corresponded to dominance of the 135° component for some of the observers, whereas the meaning of the keys was reversed for the other observers. The dependent measure of this experiment was the total number of keypresses for a given condition. This number corresponds to the number of alternations or fluctuations in contrast of the components of the pattern for that condition.

After the adaptation period, Channel 1 was turned off and the test patterns were presented for 60 sec. At the end of the viewing period, there was a 15-sec intertrial interval, during which the stimulus channels were turned off and the adapting channel reilluminated. In this way, the adaptive state of the observer was held constant for the entire duration of the experiment. The design of the experiment involved three levels of mean luminance as a between-observers factor and two conditions of orientation and six spatial frequencies as within-observers factors.

Results

The results of this experiment were analyzed in terms of the number of alternations (i.e., the frequency or number of times a response key was pressed).

In Figure 1 A-C, the number of responses are plotted as a function of spatial frequency for the 92.2, 21.6, and 8.6 cd/m^2 mean luminance conditions, respectively. This dependent measure represents the total number of responses to each of the keys (e.g., number of responses to horizontal + number of responses to vertical + number of responses to composite). The results for the H-V patterns are shown as circles, and those for the O-O patterns, as squares.

There are three features readily apparent in this figure. First, the rate of alternation decreases significantly with decreases in mean luminance [$F(2,27) = 9.72$, $p < .001$]. Second, The rate of alternation is a function of both the spatial frequency and the orientation of the pattern. Spatial frequency and orientation significantly interact to influence the rate of alternation [$F(5,135) = 3.72$, $p < .005$]. The effect of orientation is greater at intermediate than at high or low spatial frequencies. In addition, alternation rate varied in a significant quadratic manner for the H-V condition [$F(1,29) = 25.90$, $p < .001$] and for the O-O condition [$F(1,29) = 17.33$, $p < .001$]. Finally, there is a second-order interaction between mean luminance, spatial frequency, and orientation [$F(10,135) = 1.91$, $p < .05$]. The interaction between spatial frequency and orientation found at the two higher mean luminance levels is not present at the lowest mean luminance. It should be noted that the effects of orientation are reflected in a greater number of responses to both the composite and component categories of the H-V composite and than to the composite and component categories of the O-O pattern.

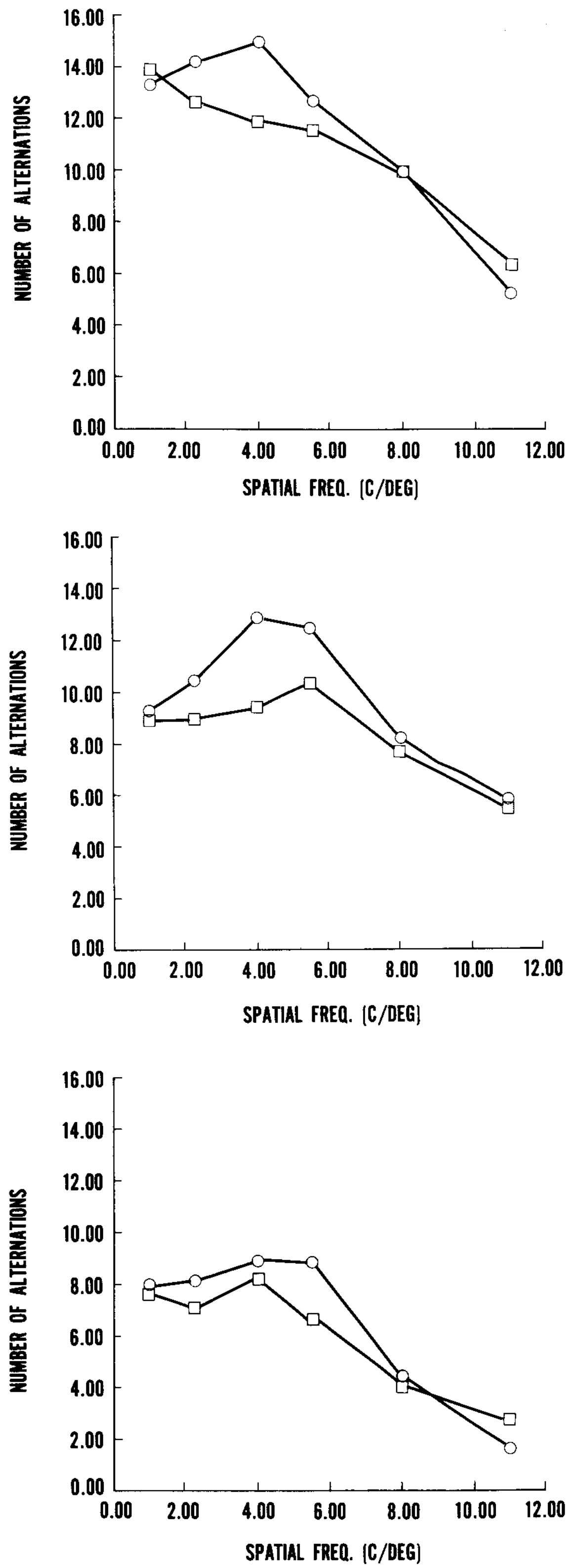

Figure 1. (A-C) Results of Experiment 1. Alternation rate is plotted as a function of spatial frequency for the 92.2, 21.6, and 8.6 cd/m² mean luminance conditions. Circles show the results obtained with an H-V pattern and squares with an O-O pattern. Contrast level was 10%.

Discussion

The present experiment verifies the earlier results of Kitterle et al. (1974), showing that at intermediate spatial frequencies pattern alternation is greater for patterns whose components are in the H and V orientations than for patterns whose components are in the oblique axes. This finding contrasts with threshold data, which show the effects of orientation on visual sensitivity to be greater at high spatial frequencies (e.g., Berkley et al., 1975). Although we did not find any effect of orientation on reversal rate at higher spatial frequencies in the present results, they have been reported elsewhere (Kitterle et al., 1974). However, Kitterle et al. (1974) used a contrast level of 60%, which was considerably greater than that used in the present experiment.

The pattern of the results that have been obtained in this experiment is at variance with that of Georgeson and Phillips (1980). We are not sure of the critical variables that contribute to these differences, but note that the mean luminance of their study, 140 cd/m² was higher than ours. Perhaps orientation effects diminish at higher luminance levels.

In the following experiment, the effects of pattern contrast, orientation, and spatial frequency upon alternation rate are examined.

EXPERIMENT 2: EFFECTS OF CONTRAST

Campbell and Howell (1972) found that frequency of monocular pattern alternation remains constant down to contrast threshold. A similar set of results was obtained by Atkinson, Campbell, Fiorentini, and Maffei (1973). However, Atkinson et al. (1973) based their conclusion upon the results obtained with a 1-cpd grating. It is not clear that this applies to all spatial frequencies. One purpose of this experiment was to determine the effects of contrast on pattern alternation for patterns composed of different spatial frequencies. A second purpose of this experiment was to determine the effects of contrast, spatial frequency, and orientation upon monocular pattern alternation.

Method

Subjects. Thirty observers who were not subjects in Experiment 1 participated in this experiment. The requirements for participation were the same as in the previous experiment.

Apparatus and Procedure. In this experiment, the mean luminance of the pattern was 92.2 log cd/m², but the contrast of the display was varied. The values used were .10, .062, and .020. Ten subjects were assigned randomly to each of the three contrast conditions. Otherwise, the apparatus and procedure were essentially the same as in Experiment 1.

Results

The data were analyzed by means of a one-between-(contrast) and two-within-subjects (orientation and spatial frequency) analysis of variance. The results summarized in Figures 2A-2C show pattern alternation as a function of spatial frequency for each of the three contrast levels. The circles and squares represent, respectively,

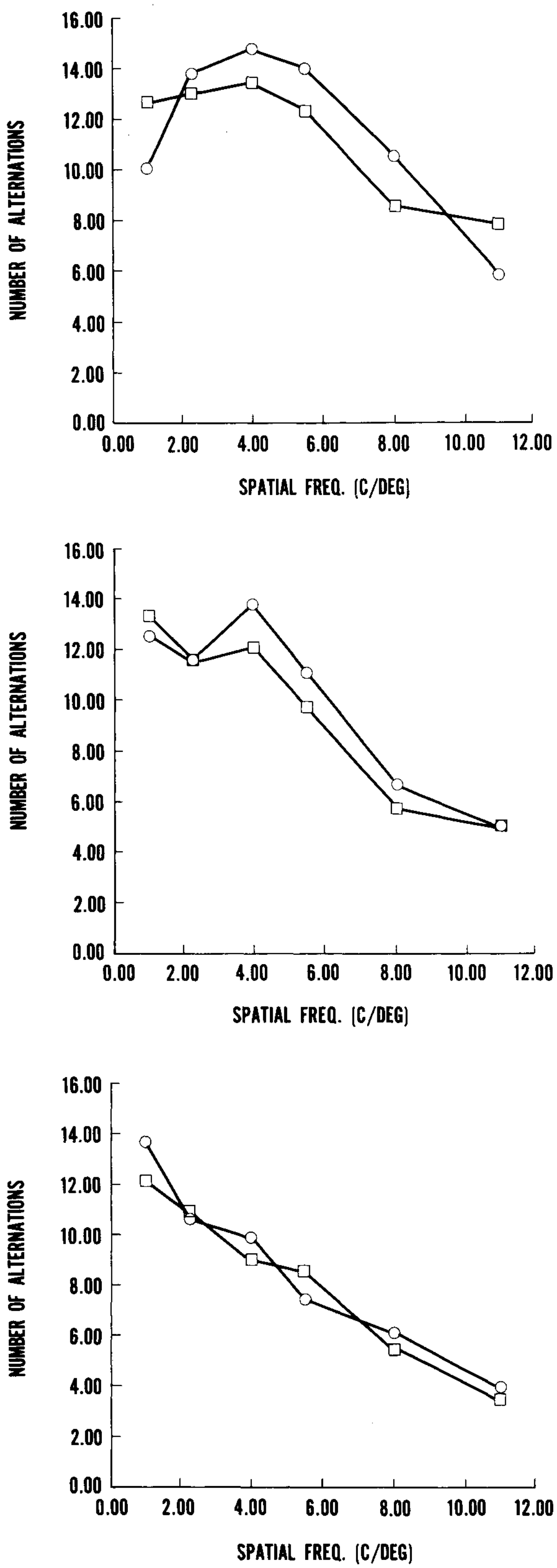

Figure 2. (A-C) Results of Experiment 2. Number of reversals is plotted as a function of spatial frequency for H-V (circles) and O-O (Squares) patterns. Top figure show the results for a contrast of 10%, middle for 6.2%, and bottom, 2%. Mean luminance was 92.2 cd/m².

the H-V condition and the O-O condition. There does not appear to be very much difference in the data obtained under the three different contrast conditions. This is confirmed by the results of the analysis of variance, which indicated that the main effect of contrast and the first- and second-order interactions of spatial frequency and orientation with contrast were not significant. There was, however, a significant spatial frequency × orientation interaction $[F(5,135) = 6.22, p < .005]$ with greater reversals in contrast for H-V than for O-O patterns. Spatial frequency was also significant $[F(5,135) = 24.51, p < .001]$. Thus, the results of this experiment verify earlier studies and show that contrast has no effect upon pattern alternation rate. In addition, the present results provide additional support for the conclusion that, at intermediate spatial frequencies, patterns with H-V components alternate more than those with O-O components.

Discussion

The failure to find any influence of contrast upon monocular pattern alternation is consistent with other studies and extends their conclusions to other spatial frequencies (Atkinson et al., 1973; Campbell & Howell, 1972). Furthermore, the results of this experiment provide additional support for the earlier conclusions of Kitterle et al. (1974) that the effects of pattern orientation on reversal rate is confined to intermediate spatial frequencies.

The present results do not appear to support an eye-movement/afterimage model of alternation (Georgeson & Phillips, 1980). Briefly, this model suggests that pattern alternation is the result of random eye movements that superimpose the afterimages of the components upon their real images. The degree to which these two are in or out of phase accounts for the alternation of apparent contrast. If reversals did depend upon afterimages, one would expect a decrease in reversal rate with decreases in contrast (Corwin, Volpe, & Tyler, 1976). Furthermore, the finding by Campbell et al. (1973) showing that alternation rate is similar for stationary and rotating patterns seriously casts doubt upon the afterimage hypothesis. Finally, the finding that rivalry is obtained when the stimulus pattern is an afterimage of a grid (Crassini & Broerse, 1982; Sindermann & Luddeke, 1972) weakens the eye-movement/afterimage theory (Georgeson & Phillips, 1980).

EXPERIMENT 3: A PRELIMINARY MODEL

Crassini and Broerse (1982) have suggested that because monocular pattern alternation can occur in the absence of eye movements (Crassini & Broerse, 1982) and when negative afterimages are minimized (Mapperson, Bowling, & Lovegrove, 1982), a more parsimonious explanation is in terms of antagonistic neural interactions between orientation channels (Campbell & Howell, 1972; Campbell et al., 1973; Kitterle et al., 1974; Thomas, 1977). The results of the present experiments and those of Kitterle et al. (1974) can be understood in terms of this model if it is assumed that lateral interactions depend upon target orientation. There are two ways in which this could occur. Either the temporal properties of the oblique channels differ from the horizontal and vertical channels, as suggested by Furchner and Young (1975), or the strength of lateral interactions are weaker in the oblique meridians (Kitterle, 1973; Rentschler & Fiorentini, 1974) Although no specific model of pattern alternation has been elaborated, alternations over time in apparent contrast are thought to reflect interactions between orientation-selective neural populations that alternatively adapt and recover over time. Erke and Graser (1972) have proposed a model to account for reversibility of perceived motion which may be useful in understanding the mechanisms underlying pattern alternation.

The Erke-Graser model is based on the mutual inhibition of antagonistic neural populations. In the model, the neural population that responds to one component of the pattern may be more activated than that responding to the other component. This mechanism, or channel, would, because it has the higher discharge rate, inhibit the activity of the population of neurons responding to the other orientation. However, neural adaptation would cause the activity of the dominant population to decrease until it could no longer inhibit the other neural population. At this point, the appearance of the stimulus configuration would change. For example, the fading of the horizontal component of an H-V pattern is a function of adaptation of the activity in this channel and inhibition from the vertical channel. With continued viewing, the vertical channel adapts and, as a result, the horizontal channel is released from inhibition and begins to inhibit the activity of the vertical channel. The appearance of a composite grid may result from one population being partially adapted and the other partially inhibited.

Erke and Graser propose that when the neurons of the antagonistic system cease to maintain inhibition, they display an activity nearly as great as at the beginning of their previous period of firing. The following adaptation period is, therefore, shorter because of the lower starting level. This predicts that alternation rate should increase over a time for a given viewing duration. However, since the antagonistic interactions should reach a state where the time for the adapted populations to recover equals the time necessary for the adaptation of the active populations, the rate of oscillation should level off. The purpose of this experiment was to determine if the rate of alternation as a function of viewing period followed a curve consistent with the Erke-Graser (1972) model and whether the same curve described the results for H-V and O-O patterns.

Method

Subjects. Thirty-four introductory psychology students with normal visual acuity were recruited for this experiment. They participated for course credit and had not participated in the earlier experiments.

Apparatus and Procedure. In this experiment, the test stimuli were either O-O or H-V patterns whose mean luminance was 92.2 log cd/m² and contrast .10. The spatial frequency of the components of this pattern was 5 cpd. The patterns were viewed for 3 min. This viewing period was divided into 18 10-sec intervals. During each interval, the frequency of alternations were recorded.

The experiment was replicated twice. Half of the observers viewed the stimuli in the following order H-V, O-O, O-O, H-V; the other half viewed them in the order O-O, H-V, H-V, O-O. Otherwise, the procedure of the experiment was the same as that of Experiment 1. The experiment was a three-factor repeated measures design: 2 (order of presentation) × 2 (orientations) × 18 (times intervals) × 34 (observers).

Results

Since there was no main effect or interactions of order of presentation with orientation or time, the data were averaged over this variable. Figure 3 summarizes the results of this experiment. The rate of alternation as a function of viewing time is described by a negatively accelerated function, which levels off at about 1.5 min. These changes with time appear to be dependent on orientation, and this is confirmed by statistical analysis; orientation significantly interacts with time [$F(17,661) = 15.78$, $p < .001$]. The H-V data show a more rapid initial rise with duration than the O-O results, and the former asymptote at a higher level.

Discussion

These results are consistent with the Erke-Graser model. The number of reversals with viewing time is described as a negatively accelerated curve for both patterns. However, these results depend upon pattern orientation. The frequency of reversals increases over time at a faster rate and asymptotes at a higher level for the H-V pattern.

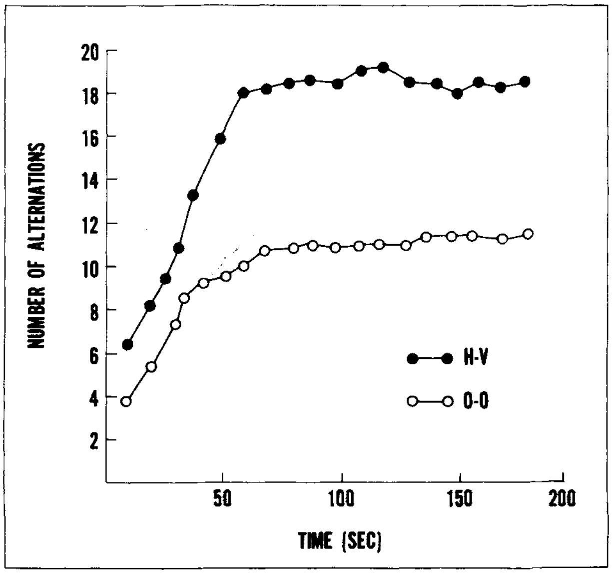

Figure 3. Alternation rate is plotted as a function of viewing time for an H-V pattern (circles) and O-O pattern (squares). The spatial frequency of the components of the pattern was 5 cpd. The mean luminance was 92.2 cd/m², and the contrast was 10%.

The finding that the frequency of alternation is slower for the O-O condition suggests that the oblique sensitive channels may differ not only in tuning (e.g., Andrews, 1967), but also in their temporal integration characteristics. Furchner and Young (1975) have conceptualized contour-sensitive channels as having an analyzing component that is sensitive to orientation and an integrating component that pools the output of the analyzing component over some small time interval. In finding that the oblique sensitive channels have a greater magnitude of adaptation and subsequently recover at a slower rate, Furchner and Young (1975) suggest that these channels have less convergent input for integration or less inhibition-produced signal-to-noise enhancement than the horizontal or vertical channels. The results of Figure 3 are consistent with this interpretation.

SUMMARY

The present study suppports and extends earlier work. It indicates that pattern alternation rate is a function of both the spatial frequency and the orientation of the components of the pattern. Greater alternation rates are found for H-V patterns than for O-O patterns at intermediate spatial frequencies. These effects diminish with mean luminance but are independent of contrast. Pattern alternation rate increases as a negatively accelerated function of time. The rate of increase and the final asymptotic levels are higher for the H-V than for the O-O pattern.

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