The effect of exposure duration on the apparent contrast of sinusoidal gratings

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Apparent contrast determined for sinusoidal grating targets which were flashed for varying durations appears to follow a temporal course similar to a Broca-Sulzer curve, and this temporal course is also influenced by the spatial frequency of the grating target. These results were discussed in terms of differential latency and temporal integrating characteristics of spatial frequency channels.

Exposure duration seems to have parallel effects on contrast at both threshold and suprathreshold levels of stimulation. For example, at threshold, contrast sensitivity for grating targets was found to increase with increases in the duration of target exposure (Nachmias, 1967). Recently, Young, Diamond, and Cole (1974) showed that the threshold for a small spot of light superimposed upon a larger background increased with corresponding increases in the exposure duration of the background.

At suprathreshold levels of stimulation, Alpern (1963) found that the brightness of a test stimulus could be depressed by varying the exposure duration of a test-annulus configuration even though the luminances of both were held constant.

Young et al. (1974) have suggested that the parallel effects of duration at the two levels of stimulation may be due to the operation of similar processes. If one analyzes the grating targets used in the threshold experiments, the light bars of the targets could be considered as the inducing fields and the dark bars as the test fields. They suggested that the effects of exposure duration were due to temporal summation of the neural output in channels of the visual system responsive to the inducing field. With increases in exposure duration, the output of the inducing channels would increase, and as a result of increased lateral inhibition, the output of the test channels would be progressively attenuated.

At suprathreshold levels of stimulation, an increase in the inducing field duration should result in an increase in apparent contrast. That is, the light bars become progressively lighter and the dark bars darker. Flock, Wilson, and Poizner (1966), Kitterle (1975), and Stecher, Sandberg, and Minsky (1970) have shown that brightness contrast does increase with inducer duration. Unfortunately, the effects of exposure duration on the apparent contrast of grating targets at suprathreshold levels of stimulation have not been measured.

The apparent contrast of suprathreshold grating targets also depends upon spatial frequency (Bryngdahl, 1966; Franzen & Berkley, 1975;

Watanabe, Mori, Nagata, & Hiwatashi, 1968). Apparent contrast for grating targets of a constant physical contrast is an inverted U-shaped function of spatial frequency. In essence, this function is qualitatively similar in form to the contrast sensitivity function measured at threshold (Campbell & Robson, 1968). The joint effects of exposure duration and spatial frequency upon apparent contrast has not, however, received much attention. Nachmias (1967) and Watanabe et al. (1968) have shown that at threshold contrast sensitivity increases more rapidly with increases in exposure duration for high spatial frequency than for low-frequency grating targets. In the present investigation, this relationship is examined at suprathreshold levels of stimulation.

Another variable which influences apparent contrast is the physical contrast of the grating. Franzen and Berkley (1975) have shown that subjective contrast increases more rapidly with changes in physical contrast for higher as compared to lower spatial frequencies. However, it is not known how this relationship varies with changes in exposure duration.

Thus, the present experiment was designed to determine the effects of exposure duration, spatial frequency, and physical contrast upon the apparent contrast of sinusoidal grating targets.

METHODS

Subjects

Thirteen subjects participated in this experiment for course credit in introductory psychology. All had normal or corrected-to-normal vision and were naive about the purpose of the experiment.

Apparatus and Stimuli

The stimuli were photographic transparencies of sine-wave gratings generated on the face of a Tektronix 561-B oscilloscope with a P-31 phosphor. The stimuli were presented in a Kodak Carousel slide projector. Exposure durations of these stimuli were varied with a Lafayette Instrument shutter control.

At a viewing distance of 307.34 cm, the slides projected a rectangular target which subtended visual angles of $14.6^\circ \times 9.4^\circ$. The spatial frequencies of the sinusoidal gratings in the target area were 0.25, 0.31, 0.36, 0.51, and 0.73 cycles/deg. The stimuli were

Figure 1. Magnitude estimates of apparent contrast as a function of exposure duration. The parameter of the curve is the spatial frequency of the sinusoidal targets.

presented in a vertical orientation for exposure durations of 7, 10, 20, 40, 100, and 500 msec.

The mean luminance of the targets (maximum luminance + minimum luminance)/2 was either 20%, 30%, or 40% as measured with an S.E.I. photometer.

Procedure

Subjects were light adapted to the mean luminance for 5 sec. Following this, a grating target of 7 cycles/deg was presented as an example of the kind of stimuli they were to judge. They were instructed to judge the apparent contrast (i.e., the difference in brightness between the light and dark bars of the target). They were told that a zero judgment meant that there was no difference between the black and white bars; in other words, this was the judgment to be given to a uniform field. One hundred was to correspond to the greatest difference between the black and white bars. Thus, the subjects were instructed to judge the magnitude of apparent contrast along a scale which varied from 0 to 100. After a few trials, the experiment was begun. No fixation point was provided. The subjects were instructed to look at the center of the field.

The conditions of the experiment were presented in random order, and each condition was replicated five times. The mean of the judgments for each subject was determined and averaged for each condition. There were 1,170 conditions (13 subjects by 6 durations by 5 spatial frequencies by 3 levels of contrast).

RESULTS

The results of this experiment have been summarized in Figures 1 and 2.

Since the nature of the interaction between spatial frequency and duration did not change over levels of physical contrast, the results were averaged over the levels of physical contrast. In Figure 1, magnitude estimates of apparent contrast are plotted as a function of log stimulus duration with the parameter of the curve being spatial frequency. This figure shows that perceived contrast follows a temporal course similar in form to that reported by Alpern (1963). The fact that the curves become more peaked with an increase in spatial frequency indicates that perceived contrast depends upon spatial frequency as well as duration. The rates of increase and decrease in apparent contrast with changed duration are much more marked at the higher spatial frequencies.

These results parallel those of Nachmias (1967), where contrast sensitivity was found to change more rapidly for higher, as opposed to lower, spatial frequencies. Kulikowski (1972) has also shown this for a more extensive series of spatial frequencies and durations of exposure.

In Figure 2, the results are summarized to reveal a different aspect of the data. Here the results for each spatial-frequency/physical-contrast condition have been averaged over duration. It should be apparent that perceived contrast grows with spatial frequency more rapidly for higher than for lower physical contrasts.

Another way of describing these results, which allows for comparison with other studies, is to consider the rate at which apparent contrast changes with increases in physical contrast for each of the

Figure 2. Magnitude estimates of apparent contrast as a function of spatial frequency. The parameter of this figure is the contrast (physical) of the grating.

spatial frequencies. It is apparent that perceived contrast changes at a greater rate for the higher spatial frequencies—a result in rather good agreement with Bryngdahl (1966). Franzen and Berkley (1975) also obtained qualitatively similar results, although the spatial frequencies they used (3.5, 9.0, and 18.0 cycles/deg) were considerably higher than those used in the present study.

DISCUSSION

The present results parallel those of Alpern (1963) in that apparent contrast appears to follow a temporal course qualitatively similar to a Broca-Sulzer curve (Katz, 1964). This similarity may provide support for the hypothesis of Young et al. (1974) mentioned earlier in this paper. Basically, the outputs of the channels responding to the bright bars increases in responsiveness with an increase in duration up to some critical duration. This increase in output corresponds to the increase in brightness of the lighter bars with an increase in duration. With an increase in output, a corresponding increase in lateral inhibitory effects is assumed to take place. As a result, the dark bars of the grating become progressively darker. Together, the changes in light and dark bars result (as seen in Figure 1) in an increase in perceived contrast due to temporal summation and lateral effects.

Kitterle (1975) has provided evidence in favor of the temporal summation hypothesis by showing that, with an increase in the exposure duration of an inducing field, the temporal range over which successive brightness contrast is found also increases. Presumably, the increased output of the inhibitory channels (i.e., those channels stimulated by the annulus) resulting from an increase in duration perseverates for a longer period of time after the offset of the inducing field. However, Kitterle (1975) pointed out that the relationship between duration and brightness, as well as contrast, may be quite complex. Results from a recent experiment by Corwin (1971) amplify this point.

Corwin (1971) determined the effects of a masking flash upon the apparent contrast of subsequently presented grating targets by measuring the brightness of the light and dark bars of the gratings. He found that when the masking flash and test flash were within the limits of temporal summation, the apparent contrast of the grating target increased for certain spatial frequencies. He did not find any effect upon perceived contrast when a backward masking paradigm was used (i.e., the grating preceded the masking flash).

If the increase in apparent contrast is due to temporal integration or summation, then Corwin should have found either no change in apparent contrast or, more likely, a reduction in contrast for both kinds of masking paradigm and for all spatial

frequencies, as predicted by the luminance-summation-contrast reduction hypothesis (Eriksen & Hoffman, 1963). The fact that masking depended upon spatial frequency and was not found with backward masking suggests that additional assumptions must be made about the effects of duration upon perceived contrast. Perhaps, with an increase in duration, greater contrast effects occur because of a greater temporal convergence of inhibitory and excitatory signals (Young et al., 1974). This additional hypothesis implies that contrast enhancement occurs because the latency between excitatory and inhibitory arrival times decreases with increases in exposure duration up to a critical duration. This additional assumption may explain why there was a failure to find contrast enhancement under backward masking conditions in Corwin's (1971) study.

It might be that simultaneous brightness contrast and suprathreshold grating contrast are mediated by size-tuned visual channels. The changes in apparent contrast with changes in exposure duration suggest that these channels may have different temporal characteristics. Some recent psychophysical data suggests that this may be the case (Kulikowski, 1975; Tolhurst, 1975; Tynan & Sekuler, 1974).

Differential temporal characteristics of spatial frequency channels have recently been demonstrated by Kaye and Kitterle (in preparation) and Thomas and Kitterle (in preparation) in monocular pattern alternation. When two orthogonal, optically superimposed sinusoidal gratings are viewed, they undergo alternation. One component appears dominant, then the suppressed component "recovers" and now suppresses the formerly dominant component. This phenomenon has been attributed to lateral interactions among orientation detectors. The fact that the frequency of alternations of the pattern and duration of visibility of its components change with spatial frequency of the components of the pattern indicates different latency characteristics of these spatial frequency channels.

The differences found in apparent contrast for different spatial frequencies are similar to those reported by Franzen and Berkley (1975) and Watanabe et al. (1968) and probably reflect the differential sensitivity of visual channels mediating contrast perception. These differences can be readily observed by observing, on an oscilloscope, the apparent contrast of a grating target which has a constant physical contrast as its spatial frequency is changed or by scanning Figure 12.21 in Cornsweet (1970) from left to right along a horizontal path. Indeed, the differential sensitivity to spatial contrast is readily observable in Cornsweet (1970).

The interaction between spatial frequency and physical contrast (Figure 2) also provides support of the hypothesis that spatial frequency channels may mediate the perception of apparent contrast. As the

physical contrast of a grating target is lowered, the mean sensitivity of the entire population of spatial frequency channels shifts toward the lower spatial frequencies. The sensitivity of the relatively higher spatial frequency channels diminishes. If these same channels are also responsible for the perception of contrast, then lowering the physical contrast of a high-frequency grating target should produce a relatively greater change in apparent contrast than lowering the physical contrast of a grating target of considerably lower spatial frequency, and this was the result obtained in Figure 2.

The results of the present experiment suggest that the reason for the parallel effects of exposure duration and spatial frequency upon threshold and suprathreshold contrast perception is because both phenomena are mediated by similar mechanisms, namely, spatial frequency channels. In addition, the fact that exposure duration interacts with spatial frequency suggests that spatial frequency channels may have different latency characteristics.

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