A COMPARISON OF CONTRAST DETECTION AND DISCRIMINATION

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Abstract—In order to complement previous studies of contrast detection, we have examined the effects of three stimulus variables (spatial frequency, retinal illuminance, retinal locus) and one visual disorder (amblyopia) on contrast discrimination. Although each factor has a profound effect on the detection of gratings on otherwise unpatterned displays, we find a similar dipper-shaped contrast discrimination function and similar supra-threshold Weber fractions for contrast under all these conditions.

Contrast Detection Discrimination Spatial frequency Retinal illuminance Eccentricity Amblyopia

INTRODUCTION

Although it is rare that we view low contrast stimuli in otherwise unpatterned visual environments, considerable emphasis has been placed on psychophysically determined contrast thresholds under these conditions. These experiments describe the border between the visible and the invisible. The most common experiments of this sort examine contrast sensitivity for sinusoidal luminance gratings (e.g. Campbell and Green, 1965). Contrast sensitivities measured this way are reliably affected by a wide variety of variables such as spatial frequency (Robson, 1966), space average luminance (Patel, 1966; Daitch and Green, 1969), retinal locus (Robson and Graham, 1981), and many visual disorders (e.g. amblyopia: Gistalder and Green, 1971). However, in addition to determining the effects of these factors on contrast detection, it is important to establish how they affect the perception of visible (supra-threshold) stimuli. In this report we describe experiments that examine how supra-threshold contrast discrimination is affected by several factors known to have profound effects on contrast detection. We compare the effects of three stimulus variables and one visual disorder on contrast thresholds for the introduction of a test grating onto either a spatially uniform screen (contrast detection), or a screen already containing a grating identical, except for contrast, to the test (contrast discrimination).

Recently, several studies have examined the effects of background (pedestal) contrast on contrast discrimination thresholds (e.g. Campbell and Kulikowski, 1966; Kohayakawa, 1972; Nachmas and Sansbury, 1974). Much of the experimental interest has centered on the slope of the contrast discrimination function (e.g. Legge, 1981, Swift and Smith, 1983) rather than the effects on contrast discrimination of variables known to have profound influences on contrast detection thresholds. Some earlier reports (Carlson and Pica, 1979; Bradley and Ohzawa, 1980) suggest that contrast discrimination thresholds were invariant across a number of dimensions known to affect contrast detection. In this paper we describe data that confirm most aspects of these earlier reports.

METHODS

Apparatus

All gratings were presented on a 20 × 30 cm Joyce Electronics Video Display (mean luminance 250 cd/m²) which was linear to within 2% up to 90% contrast. Display linearity is most critical for these supra-threshold experiments to ensure that low amplitude harmonic distortions are not visible. Grating contrast, waveform, spatial frequency, and timing were all under computer control. For all but the very lowest sub-threshold background contrasts, contrast increments could be varied in steps of less than 1% of the background. All stimuli were viewed through a 20 cm circular mask that had a uniform luminance of approximately 20 cd/m². Grating spatial frequency was varied from 0.3
to 34 c/deg by varying number of cycles in the screen (6–60) and viewing distance (57–570 cm).

**Subjects**

Two normal observers and two amblyopes participated in these experiments. Both amblyopes were anisometropic and one (CD) also had strabismus. The two amblyopes had acuities of 20/200 (JR), and 20/175 (CD) for their amblyopic eyes (detailed clinical and contrast sensitivity data for these two amblyopes are presented elsewhere: Bradley and Freeman, 1985; Bradley et al., 1985).

**RESULTS**

In the first series of experiments we examined the effects of grating spatial frequency on contrast discrimination thresholds. Because of a potential optical artifact, we ran these experiments cyclopeged (0.5% cyclogyl) viewing the screen monocularly through a 2.5 mm artificial pupil and an appropriate distance correction. In addition to the spatial-frequency-specific contrast attenuation introduced by optical defocus (Green and Campbell, 1965), dynamic accommodative fluctuations (Bour, 1981) may introduce retinal contrast differences between the first and second intervals of our 2AFC procedure. These optically induced contrast fluctuations in the retinal image will vary in magnitude with spatial frequency, and therefore may produce a spatial-frequency-specific change in discrimination performance. Topically applied cycloplegia can reduce these accommodative fluctuations (Johnson et al., 1984).

Contrast detection and discrimination thresholds were examined over a wide range of spatial frequencies from 0.3 to 34 c/deg. At select frequencies we ran complete series of successive staircases with both sub- and supra-threshold background contrasts (0.2–50%). Sample contrast discrimination functions are shown in Fig. 2 for grating spatial frequencies of 0.5, 2, 4, 16, and 27 c/deg. Each point was obtained from a single staircase, and dashed lines are fit by eye through the points. Each data set and corresponding ordinates have been displaced vertically for display purposes. Several features of these data are of interest. First, the general shapes of the curves are similar. Each has two sections, one at low contrasts with a negative slope, and one at higher contrasts with a positive slope. As has been shown previously (Nachmias and Sansbury, 1974; Legge, 1979), the minimum contrast increment thresholds are produced with near threshold backgrounds.
Fig. 2. Contrast increment thresholds (ΔC in %) are plotted against background contrast (c in %) for five different spatial frequencies (0.5, 2, 4, 16, 27 c/deg). Each function and its corresponding ordinate has been displaced vertically for clarity. Arrows indicate threshold background contrasts. Dashed lines are fit to the data by eye.

This can be seen in Fig. 2 by the correspondence of the arrows (indicating contrast detection thresholds) and the dips in each function. The different horizontal locations of the arrows reflect changes in contrast sensitivity with spatial frequency. The second feature of these data concerns the effect of supra-threshold background contrasts on discrimination thresholds. In each case the supra-threshold points are well fit by a straight line on these log-log coordinates. The slopes of the four lowest functions are similar; they are 0.87, 0.88, 0.86 for the 2, 4, 16, and 27 c/deg functions, respectively. But, as has been reported previously (Kulikowski, 1979; Legge, 1981), we observed a lower slope (0.70) for the lowest spatial frequency (0.5 c/deg).

In order to facilitate comparison we have plotted contrast increment thresholds for two spatial frequencies (4 and 20 c/deg) on the same axes Fig. 3(A). Again, the same dipper-shaped function is found with minimum increment thresholds occurring with near-threshold backgrounds (indicated by the arrows). The most striking feature of these data can be seen by comparing the effects of spatial frequency on contrast detection and discrimination. As is typical (e.g. Campbell and Green, 1965) detection thresholds for 20 c/deg are about a factor of ten higher than they are for 4 c/deg. However, contrast discrimination thresholds with supra-threshold backgrounds are similar for both frequencies.

All of the functions shown in Fig. 2 and 3(A) show the same pattern: as background contrast is increased contrast increment thresholds first decrease until the background grating becomes visible, where-upon increment thresholds then show a continuous increase. The quantitative similarity of these patterns can be seen in Fig. 3(B) where the 4 and 20 c/deg data have been replotted, not on absolute contrast axes, but on contrast axes normalized to detection threshold. That is, both contrast increment and background values have been converted to multiples of detection thresholds. This plot shows that the amount of threshold reduction or elevation for both 4 and 20c/deg is precisely regulated by the amount that the background is below or above
show a somewhat different function. Over most of the range (0.4–10 c/deg) discrimination thresholds are similar. It is only above 10 c/deg that contrast discrimination thresholds begin to rise substantially, but even there the changes are not as large for discrimination as they are for detection. Essentially the contrast discrimination function exhibits a similar but less bowed shape as the detection function (see also Legge, 1979).

In the next experiments, we examined the effects of retinal illuminance and eccentricity on contrast discrimination. These two factors are known to have profound effects on contrast detection thresholds in normal observers. The effects of retinal illuminance and eccentricity on contrast detection vary considerably with spatial frequency, being minimal at low frequencies and maximal at high frequencies (Patel, 1966; Robson and Graham, 1981). However, high spatial frequencies can only be detected over a narrow range of eccentricities and luminances. Therefore we have chosen a medium spatial frequency (4 c/deg) with which to compare the effects of retinal illuminance and eccentric viewing on contrast detection and discrimination. Contrast discrimination functions from each experiment are shown in the top and bottom halves of Fig. 5. In both cases the open circles show data collected at photopic levels (1250 td) with central fixation. The solid circles in the top half of Fig. 5 show data obtained with a 2.0 td centrally fixated display. As predicted from the contrast sensitivity functions measured under these conditions (see inset), contrast increment thresholds for sub-threshold backgrounds are considerably elevated. However, discrimination thresholds for both 1250 and 2 td are essentially identical at high supra-threshold contrasts. A similar pattern can be seen in the bottom half of Fig. 5 for the eccentrically viewed display. Although detection thresholds are elevated by a factor of about ten, discrimination thresholds are only elevated by about a factor of two.

In all three experiments described above (spatial frequency, eccentricity, and illuminance) the same pattern is seen: discrimination thresholds dip to a minimum near threshold backgrounds and then progressively rise with similar slopes. Furthermore, despite large differences in detection thresholds, contrast discrimination thresholds at high contrasts were largely unaffected by these variables.

In addition to these contrast discrimination comparisons in normal observers, we have made
similar comparisons with amblyopes. Amblyopia is a monocular visual anomaly known to elevate contrast detection thresholds selectively at middle and high spatial frequencies (Hess and Howell, 1977; Bradley and Freeman, 1981). Both amblyopes used in these experiments are anisometric and follow this typical pattern (see insets in Fig. 6). The discrimination data shown in the top half of this figure (subject J.R.) from the nonamblyopic eye show a pattern similar to that observed for normal observers [e.g. Fig. 3(A)]. The pattern is similar but displaced for the amblyopic eye (solid circles). Although detection thresholds are elevated by a factor of almost 20, discrimination thresholds are only slightly higher for the amblyopic eye.

Amblyope CD was tested at two spatial frequencies (bottom half of Fig. 6). The interocular contrast sensitivity difference is less at 4 than at 8 c/deg. However, in each case, the high contrast amblyopic discrimination functions show consistently less elevation than the detection thresholds. These results confirm an earlier report (Hess et al., 1983) of normal or nearly normal contrast discrimination in amblyopes with elevated contrast detection thresholds.

**DISCUSSION**

We have compared psychophysical contrast detection and discrimination thresholds. Although spatial frequency, retinal illuminance, eccentric viewing, and amblyopia all have profound effects on contrast detection, they have little effect on contrast discrimination with supra-threshold gratings. Consistent with previous nonlinearity and uncertainty models (Nachmias and Sansbury, 1974; Lasley and Cohn, 1981; Legge and Foley, 1980; Pelli, 1985), a dipper-shaped function was found under all conditions with the degree of threshold reduction (facilitation) or elevation (masking) being regulated by the degree to which the background is sub- or supra-threshold [e.g. Fig. 3(B)]. Therefore, under conditions where contrast detection thresholds are high, a high contrast supra-threshold background grating will produce little masking. Conversely, when contrast detection thresholds are very low, a high contrast background grating will produce considerable masking. Therefore, low detection thresholds and the corresponding greater masking will tend to counteract each other resulting in the observed approximate invariance of contrast discrimination thresholds for high contrast gratings. Invariance of contrast discrimination thresholds has been observed with a number of stimulus variables that affect detection thresholds: spatial frequency (Legge, 1979; Burton, 1983), number of grating cycles (Legge and Foley, 1980), monocular vs binocular viewing (Legge, 1984), retinal illuminance (Burton, 1983), visual noise (Pelli, 1985) and retinal eccentricity (Legge and Kersten, personal communication). Therefore, although the range of stimuli that are visible may be severely reduced in certain viewing situations (e.g. low retinal illuminances), effects on contrast discrimination of still visible (supra-threshold) stimuli may be absent or only slight.
The invariance of contrast discrimination thresholds parallels the reported invariance of the apparent contrast of supra-threshold gratings. Perceived contrast of high contrast (e.g., 50%) gratings is largely unaffected by grating spatial frequency, temporal frequency, mean luminance, retinal locus, or amblyopia (Watanabe et al., 1968; Blakemore et al., 1973; Georgeson and Sullivan, 1975; Kulikowski, 1976; Hess and Bradley, 1980; Hess et al., 1983; Loshin and Levi, 1983; Bowker, 1983; Swanson et al., 1984; Cannon, 1985). Invariances of contrast discrimination and appearance have both been attributed to a decelerating contrast response function within the visual system (Swanson et al., 1984). Decelerating contrast response functions predict that contrast discrimination thresholds will increase as background or pedestal contrast is increased above its own threshold. In addition, this model predicts a high contrast convergence in both slope and absolute level of such decelerating functions even though they may be displaced with respect to each other along the contrast axes. If perceived contrast is related to the absolute level, and discrimination thresholds are related to the slope, an invariance of both is predicted for high contrast stimuli irrespective of contrast detection threshold.

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REFERENCES


amblyopia spatial frequency or retinal locus specific? Vision Res. 25, 47–54.