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LIGHT AND DARK BARS; CONTRAST DISCRIMINATION

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Abstract—*Contrast increment thresholds* were measured for light and dark bars as a function of the base contrast of the bars. The bars were superimposed on a uniform field of 340 cd/m^2. They had either rectangular or Gaussian luminance profiles, varied in width from 0.1° to 10°, and in duration from 10 to 200 msec. For the 200-msec presentations, the resulting *contrast discrimination functions* all had approximately the same shape when contrast was defined as $(L_{\max} - L_{\min})/(L_{\max} + L_{\min})$, and closely resembled corresponding results for sine-wave gratings. The similarity in shape of contrast discrimination functions for light and dark bars is attributed to a retinal nonlinear intensity transformation. The 10 msec contrast discrimination functions differed from the 200-msec functions in ways that can be explained by differences in temporal integration.

Contrast discrimination   Contrast detection   Retina

INTRODUCTION

Studies of contrast discrimination provide one means for investigating suprathreshold contrast processing in vision. In several studies, sine-wave gratings have been used to study contrast discrimination. For a review, see Legge (1981). In such studies, observers are typically required to discriminate between two sine-wave gratings that differ only in their contrasts, C and $C + \Delta C$. The smallest value of ΔC that allows for a reliable discrimination is called the *contrast increment threshold*. The corresponding contrast C may be called the *base* contrast. The relation between ΔC and C may be termed the *contrast discrimination function.*

There is general agreement that the contrast discrimination function for sine-wave gratings is dipper-shaped. As the base contrast increases from 0, the increment threshold first "dips" below the detection threshold contrast, and then rises as base contrast continues to increase.

Sine-wave gratings have the appearance of being composed of light and dark bars. It is possible that the properties of contrast discrimination for light bars differ from those for dark bars and that perhaps only one, or neither, determine the properties of contrast discrimination for sine-wave gratings.

In the 19th century, Helmholtz (1962, Section 19) and Hering (1964, Chap. 2) argued that the visual sensations of white and black (or light and dark) were qualitatively distinct. Five recent lines of psychophysical research seem to support the idea that the visual system handles light and dark pattern information in different ways.

(1) In studies based on the perceived spatial-frequency shift effect (Blakemore and Sutton, 1969) it has been shown that the perceived width of light and dark segments of rectangle gratings can be separately affected by the appropriate adapting gratings (Burton *et al.*, 1977; De Valois, 1977). Moreover, the perceived widths of white or black test bars are affected only by adaptation to white or black adapting bars, respectively (De Valois, 1977).

(2) In studies based on sine-wave grating threshold adaptation, Nagshineh and Ruddock (1978) reported that adaptation to high contrast square wave gratings led to threshold elevation for rectangle gratings which was selective for the width of the light bars but not the dark bars. However, Georgeson and Reddin (1981) found separate, but equally strong selectivity for light and dark bar widths in a similar experiment.

(3) Krauskopf (1980) showed that adaptation to a temporal, luminance sawtooth differentially elevated thresholds for luminance increments and decrements. He argued that his results were consistent with the existence of independent detectors for positive and negative internal responses.

(4) Vicars and Lit (1975) measured reaction times for suprathreshold flashes of small target spots on a uniform background. They found that reaction times decreased with increasing target luminance until an asymptotic level was reached when the targets were lighter than the background (positive contrast), but were independent of target luminance for dark targets (negative contrast).

(5) There is evidence that luminance decrements are slightly more detectable than luminance increments (see, e.g. Cohn and Lasley, 1975), although this result is not always found (see, e.g. Rashbass, 1970).

It is possible that contrast discrimination for light bars is different from dark bars, and that one or both differ from sine-wave gratings. Accordingly, we measured contrast discrimination for light and dark bars.

We studied contrast discrimination for bars having rectangular and Gaussian luminance profiles. See Fig. 1. Campbell *et al.* (1981) have shown that patterns

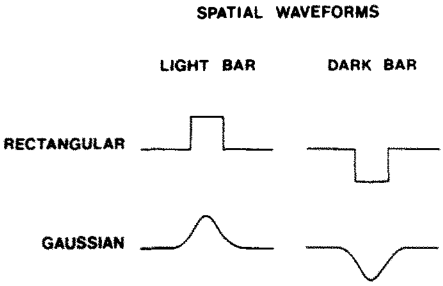

Fig. 1. Luminance profiles. The stimuli were light and dark bars with either rectangular or gaussian luminance profiles. They ranged in width from 0.1 to 10°.

containing only low spatial-frequency content (such as broad Gaussians) are detected by different means than patterns that contain high spatial-frequency content (such as rectangles).

We varied the width of our bars from 0.1 to 10° and duration from 10 to 200 msec. Shapley (1974) and Legge (1978a) have shown that thresholds for rectangular bars show a different dependence on stimulus width than Gaussians or sine-wave gratings.

There are two common definitions for the contrast of luminous bars. In the "max–min" definition of contrast:

$$C = (L_{\max} - L_{\min})/(L_{\max} + L_{\min})$$

where $L_{\max}$ and $L_{\min}$ are the maximum and minimum luminances in the pattern. For light bars on a uniform background, $L_{\min}$ is equal to the background luminance. For dark bars on a uniform background, $L_{\max}$ is equal to the background luminance. According to this definition, the contrast of both light and dark bars can never exceed a magnitude of 1.0. In the "delta" definition of contrast,

$$C = \Delta L/L_0$$

where L_0 is the background luminance and ΔL is the change in luminance associated with the bar. According to the "delta" definition, the contrast of a light bar can have any positive value, but the contrast of a dark bar can never be less than −1.0. From a physical standpoint, the "delta" definition is more fundamental. For stimuli of the same extent and duration, the "delta" contrast is proportional to the change in the mean number of photons affecting vision. The two definitions are equivalent for sine-wave gratings. We were interested in how the two definitions of contrast would affect the form of our light and dark bar contrast discrimination functions.

These considerations led us to formulate the following four questions, to which our experiments were directed. How does contrast discrimination for bars: (1) depend on their polarity (light or dark); (2) depend on the spatial luminance profile (Gaussian or rectangular); (3) depend on target width and duration; (4) "behave" when interpreted in terms of the two contrast definitions?

METHOD

Apparatus

Vertical light and dark bars were produced on the face of a Joyce Electronics CRT display by Z-axis modulation (Campbell and Green, 1965). The display was of the electromagnetic deflection type, with a raster frequency of 100 kHz, and a non-interlaced frame rate of 100 Hz. The display had a P-31 phosphor, an unmodulated luminance of 340 cd m^{2}, and a dark surround. Two viewing distances were used. At the viewing distance of 57 cm the screen subtended 30° horizontally by 16° vertically. For the 10 msec viewing conditions (see below), the viewing distance was 228 cm, and the screen subtended 7.5° horizontally by 4° vertically. Photometric calibrations were conducted with an UDT 80X Opto-meter, which was photopic-luminance corrected.

The light and dark bars consisted of luminance modulation above and below the unmodulated luminance of 340 cd/m^2. The spatial modulation had either a rectangular or Gaussian luminance profile. See Fig. 1. The vertical bars had horizontal widths of 0.1, 1 and 10°. In the case of the Gaussian bars, the width was defined as the distance between 1/e points. The bars were presented at the center of the display.

The luminance waveforms were synthesized digitally by an LSI-11/2 computer. In each 10 msec frame, the computer generated 617 voltage samples through a 12-bit digital-to-analog converter. This waveform was routed through two buffered paths whose voltage amplitudes were separately controlled by programmable dB attenuators. The outputs of the attenuators were added before being applied to the Z-axis. The two paths provided separate control of *base* and *increment* patterns, identical in all respects except for amplitude.

Procedure

Contrast increment thresholds ΔC were measured by a version of the temporal two-alternative forced-choice staircase procedure (Wetherill and Levitt, 1965). The base pattern of contrast C was presented in both intervals of the trial. The contrast increment ΔC was assigned at random to one of the two intervals. (In the case of dark bars, both the base contrast and the increment were actually negative, that is, reductions in luminance.) The intervals were either 200 or 10 msec in duration, separated by 600 msec, and were marked by auditory tones. Prior to a block of trials, the observer was shown an example of the base pattern to be used in the block. In a forced-choice trial, the observer was required to identify the interval containing the bar of higher contrast. Three correct choices at one base contrast were followed by a 1 dB reduction in the magnitude of the increment contrast. An incorrect choice was followed by a 1 dB increase. Feedback was provided. The mean of the first six contrast peaks and valleys in the resulting sequence was taken as an estimate of the threshold increment con-

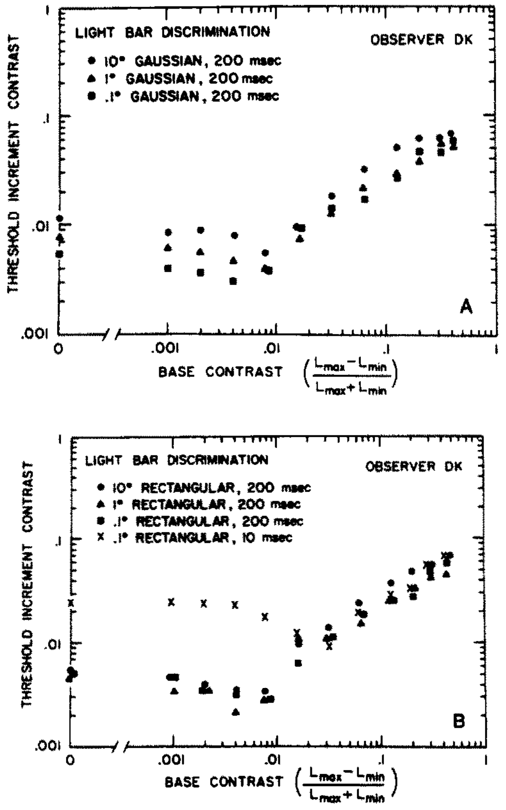

Fig. 2. Contrast discrimination for light bars. Increment threshold contrasts are plotted as a function of background contrast for three bar widths and two durations. Data points are the geometric means of 4 threshold measurements each derived from a block of forced-choice trials. Standard errors were almost always less than 15%. Detection thresholds are shown on the left-hand ordinate. Data are for Observer DK. (A) Gaussian bars. (B) Rectangular bars.

trast. The procedure estimates the increment contrast that yields 79% correct in forced choice (Wetherill and Levitt, 1965).

A session consisted of obtaining threshold estimates for 12 base contrasts for a given bar pattern. Four sessions were conducted for each observer for each bar pattern. The data points in the figures are geometric means of the four threshold estimates so obtained. Standard errors of the means were typically 10%.

Observers

There were three emmetropic observers. DK is one of the authors. HK and VK were naïve to the details of the experiment. Viewing was binocular with natural pupils, and with a fixation point at the center of the screen.

RESULTS

Figure 2 presents light-bar contrast discrimination functions for observer DK, plotted using the "max–min" definition of contrast. Threshold increment contrast ΔC is plotted as a function of base contrast C in log–log coördinates. The base contrasts ranged from 0.001 to 0.41. Each data point is the geometric mean of four forced-choice threshold estimates. Figures 2(A) and 2(B) show data for Gaussian bars and rectangular bars, respectively, having widths of 0.1, 1 and 10°, each presented for 200 msec. A fourth set of data in Fig. 2(B) shows contrast discrimination results for 0.1° rectangle bars, presented for 10 msec. Contrast detection thresholds (0 base contrast) are represented by the data points on the ordinates.

The seven contrast discrimination functions in Fig. 2 have similar shapes. For a range of low base contrasts, there is a facilitation effect for which the increment thresholds dip below the detection thresholds. Such a result has been noted before for luminance increment discrimination (Barlow, 1962; Leshowitz *et al.*, 1968; Nachmias and Kocher, 1970; Cohn *et al.*, 1974). For suprathreshold base contrasts, the increment threshold rises steadily. We have fit straight lines to these portions of the contrast discrimination functions using the least squares method. The slopes appear in Table 1. These slopes represent the exponent of a power function relation between ΔC and C for suprathreshold base contrasts. For the 200 msec duration, the slopes in Table 1 do not seem to vary consistently with condition or observer. They are all less than 1.0. A value of 0.56 is representative. The slopes for the 10 msec discrimination functions are a bit higher, and the dark bar slope (1.03) is greater than the light bar slope (0.74).

The contrast discrimination functions in Fig. 2 show greater differences for subthreshold and near-threshold base contrasts than for suprathreshold base contrasts. The detection thresholds (0 base contrast) are given in Table 2. They are lower for rectangular bars than for the corresponding Gaussian bars.

Table 1. Slopes in "max–min" coordinates*

Duration (msec)	Width (deg)	Waveform	Light	Dark
		Observer DK		
200	10	Rectangular	0.63	0.55
200	1	Rectangular	0.51	0.53
200	0.1	Rectangular	0.63	0.56
200	10	Gaussian	0.51	0.54
200	1	Gaussian	0.59	0.54
200	0.1	Gaussian	0.56	0.62
10	0.1	Rectangular	0.74	1.03
		Observer HK		
200	10	Rectangular	0.59	0.65
200	1	Rectangular	0.71	0.58
200	10	Gaussian	0.52	0.36
200	1	Gaussian	0.52	0.49
		Observer VK		
10	0.1	Rectangular	0.95	1.17

*The slopes were computed for the base contrasts where the increment thresholds exceeded the detection threshold.

Table 2. Detection thresholds in "delta" coordinates*

Duration (msec)	Width (deg)	Waveform	Light bar Mean	Light bar SE (%)	Dark bar Mean	Dark bar SE (%)
		Observer DK				
200	10	Rectangular	0.012	11	0.0111	6
200	1	Rectangular	0.0094	10	0.0084	5
200	0.1	Rectangular	0.0105	10	0.0079	15
200	10	Gaussian	0.024	5	0.0216	12
200	1	Gaussian	0.0166	16	0.0149	14
200	0.1	Gaussian	0.0108	8	0.0112	9
10	0.1	Rectangular	0.0535	6	0.0461	6
		Observer HK				
200	10	Rectangular	0.0175	16	0.0116	6
200	1	Rectangular	0.0155	11	0.0131	27
200	10	Gaussian	0.0275	1	0.0271	18
200	1	Gaussian	0.0138	15	0.0191	10
		Observer VK				
10	0.1	Rectangular	0.0586	5	0.0481	5

*The thresholds are given in "delta" coordinates ($\Delta L/L_0$) for easy comparison with previous studies of increment and decrement thresholds. The thresholds in "max min" coordinates are approximately a factor of two smaller.

In Fig. 3, corresponding dark-bar contrast discrimination functions are shown for observer DK. They are remarkably similar to the light-bar discrimination functions. They possess all the properties just described for light-bar discrimination functions.

In Fig. 4, light-bar and dark-bar contrast discrimination functions for observer DK have been replotted after normalization by threshold contrast. For each data point, base contrast and threshold increment contrast have been divided by the appropriate detection threshold contrast. As a result, the detection threshold contrast is represented on the graph by a normalized contrast of 1.0. Solid curves have been drawn through the normalized data. The upper, straight line portions of the solid curves have mean slopes of 0.56.

Normalization by threshold contrast largely removes differences due to bar width and spatial profile for both light and dark bars. This result suggests that these stimulus properties affect overall sensitivity, but not the shape of the contrast discrimination function. A similar shape invariance for contrast discrimination functions has been noted by Legge (1979) for sine-wave gratings of medium and high spatial frequencies, by Legge and Foley (1980) for sine-wave gratings having few or many cycles, and by Burton (1981) for different sizes, luminances, and aspect ratios of his "triphasic" targets. Normalization also serves to illustrate the great similarity between light-bar and dark-bar contrast discrimination functions, and the similarity of both to sine-wave grating contrast discrimination functions. Normalization by threshold does not, however, fully eliminate effects of stimulus duration. Duration effects will be considered further below.

Figure 5 presents corresponding normalized results for observer HK. Her slopes and detection thresholds are given in Tables 1 and 2. Although her results were slightly more variable than those of DK, they have the same general properties.

Most of the slopes in Table 1 lie close to 0.6. If the 10 msec conditions are excluded, DK's mean slopes for light and dark bars are 0.57 and 0.56, respectively.

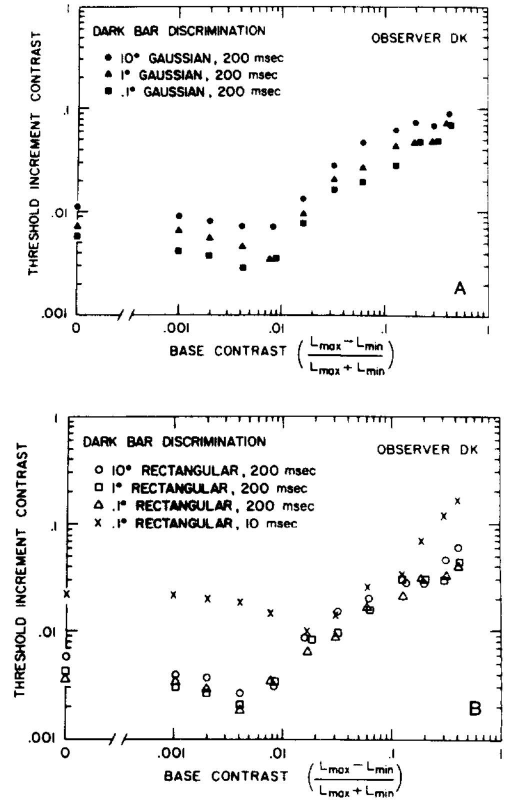

Fig. 3. Contrast discrimination for dark bars. Other details as in Fig. 2.

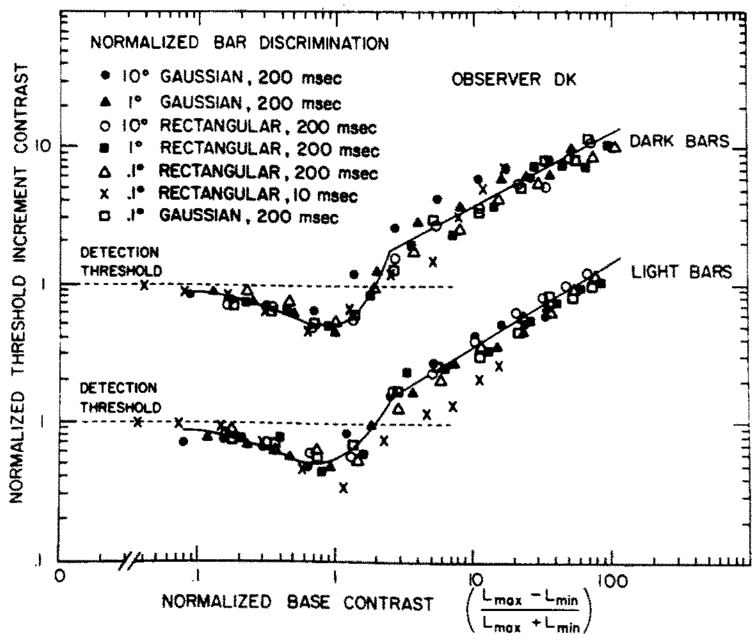

Fig. 4. Contrast discrimination for light and dark bars normalized by detection threshold. The data of Figs 2 and 3 have been replotted with background contrast and increment contrast divided by threshold contrast. A normalized contrast of 1 corresponds to detection threshold (dashed line). The straight line portions of the solid curves have slopes of 0.57 and 0.56 for the light and dark bars, respectively. These data are for observer DK.

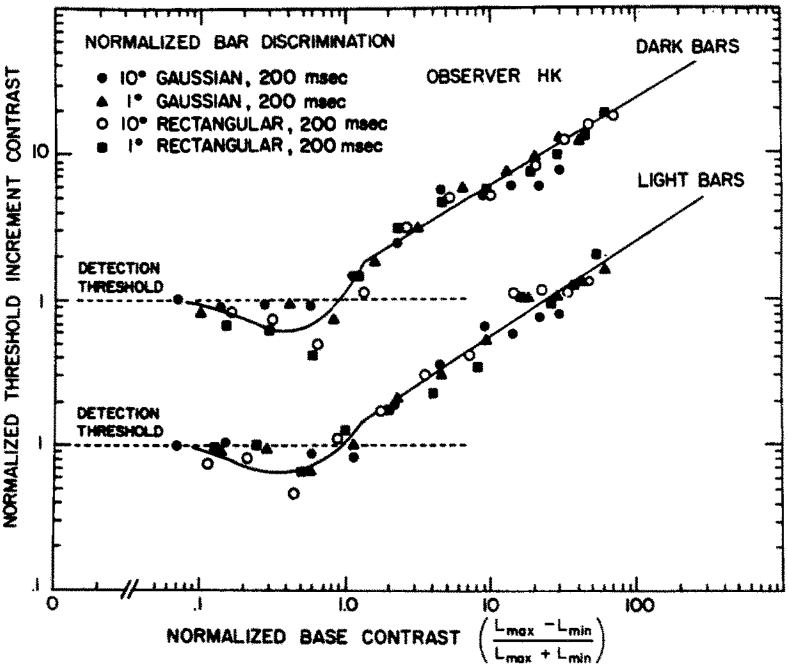

Fig. 5. Contrast discrimination for light and dark bars normalized by detection threshold. These data are for observer HK. The straight line portions of the solid curves have slopes of 0.59 and 0.52 for the light and dark bars respectively. Other details as in Fig. 4.

For HK, the corresponding mean slopes are 0.59 and 0.52. However, when 0.1° rectangular bars were presented for only 10 msec, the slopes were higher, particularly for the dark bars.

Figures 6(A) and 6(B) compare light and dark bar contrast discrimination, and illustrate the effects of the two definitions of contrast. In Fig. 6(A), observer DK's contrast discrimination functions for 0.1°, 200 msec duration light and dark rectangular bars are plotted, using the "max–min" definition of contrast. The two sets of data closely overlap, and have the properties already described. A single curve has been drawn through the two sets of data. In Fig 6(B), the same data are replotted, using the "delta" definition of contrast. For low contrasts, the data overlap. But at high contrasts, the two sets of data diverge and cover different ranges of contrast. Separate curves have been drawn through the light and dark bar data. A comparison of Figs 6(A) and 6(B) shows that in this case, the "max–min" definition of contrast yields discrimination functions for light and dark bars that are nearly identical, but the "delta" definition does not.

Figures 7(A) and 7(B) show a similar comparison, but this time for 10 msec data. Here, the light and dark bar data overlap when the "delta" definition of contrast is used. When the "max–min" definition is used, the data diverge for base contrasts above 20%. The curves through the data are predictions of a temporal-integration model that endeavors to account for differences between the 200 and 10 msec data. See the Discussion below.

Table 2 presents the various detection thresholds.

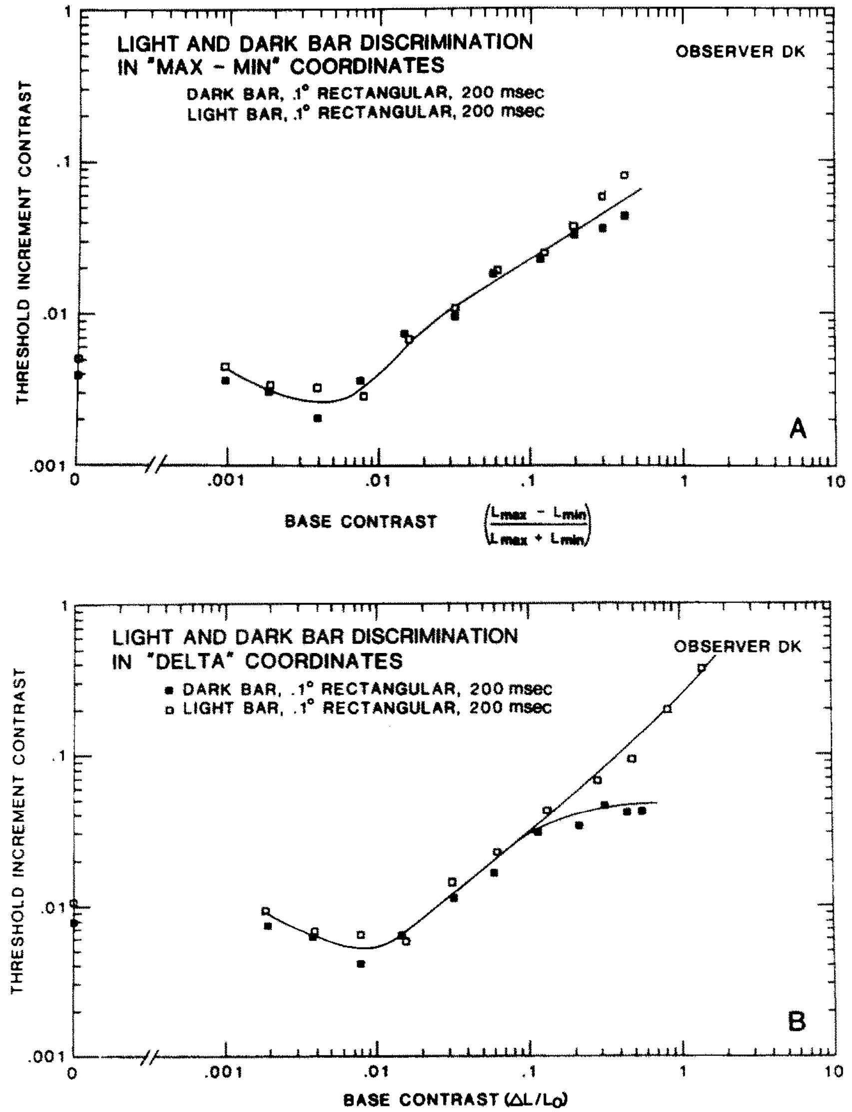

Fig. 6. Light and dark bar discrimination with 200 msec exposures: Comparison of two definitions of contrast. Light and dark discrimination data for .1° rectangular bars have been taken from Figs 2(B) and 3(B). A. Plotted with the "max–min" definition of contrast. B. Plotted with the "delta" definition of contrast. Smooth curves have been fit to the data by eye.

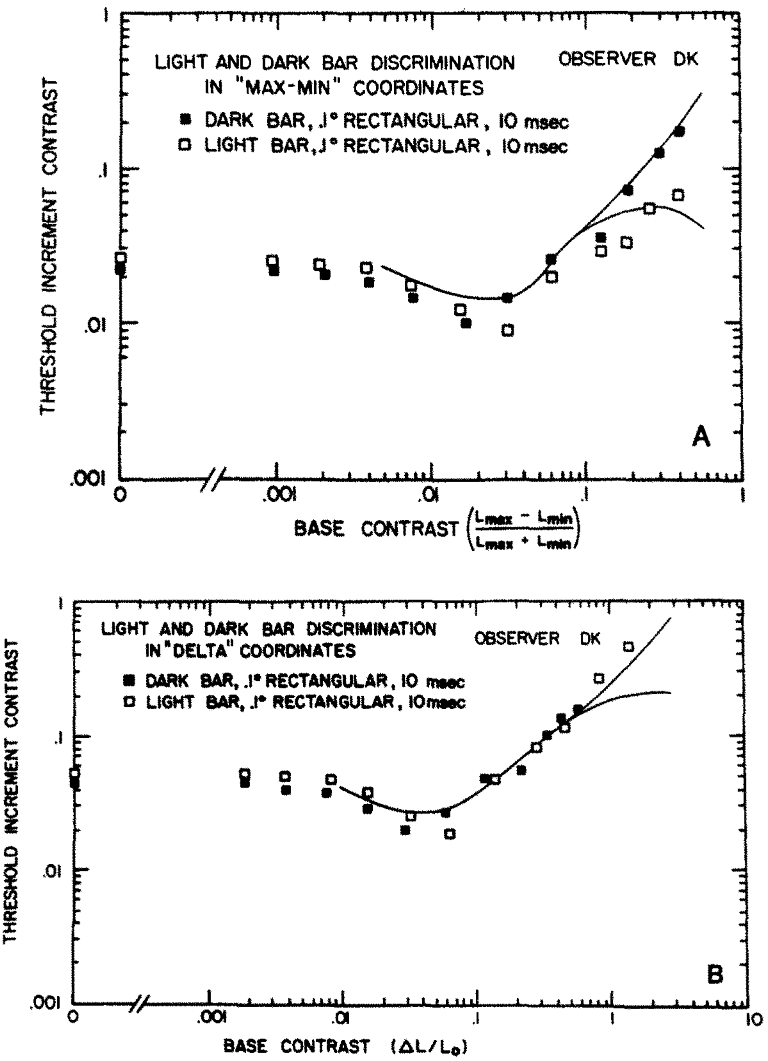

Fig. 7. Light and dark bar discrimination with 10 msec exposures: Comparison of two definitions of contrast. Other details as in Fig. 6. Smooth curves represent predictions of a temporal-integration model that attempts to account for differences between 10 and 200 msec contrast discrimination functions. See text.

The thresholds are given in terms of the "delta" definition of contrast. (For low contrast bars, the "max–min" definition gives contrast values that are about half those of the "delta" definition.) There is a tendency for the dark bar thresholds to be lower than the light bar thresholds. The average ratio for the 12 comparisons is 0.91. Table 2 also indicates that narrower Gaussian bars have lower detection thresholds than wider ones, but there is little effect of width on the rectangular bar thresholds. The table also shows that thresholds are higher for the 10 msec rectangular bars than for the 200 msec rectangular bars, differing by about a factor of 5 for DK.

DISCUSSION

Effects of contrast polarity

We return to a question posed at the end of the introduction: how does contrast discrimination for bars depend on their polarity (light or dark)? The two contrast definitions will help us address this question.

According to the "delta" definition, the contrast of a bar is $\Delta L/L_0$, and is therefore proportional to the luminance change associated with the bar. If the human visual system treated positive and negative luminance changes equivalently in contrast discrimination, we would expect contrast discrimination functions for light and dark bars to match in "delta" coordinates. Except for the 10 msec case (see next subsection), they do not. We conclude that equal luminance increments and decrements are not equivalent as far as contrast discrimination is concerned. An asymmetry exists.

The asymmetry in discrimination behavior may be related to the fundamental asymmetry in the physics of the situation. For a uniform field luminance L_0, dark bars ranging from lowest contrast to the blackest are associated with decrements ΔL in the finite range 0 to $-L_0$. By comparison, bright bars are associated with luminance increments spanning an infinite range from 0 upward. Often, an increment ΔL will exceed L_0. Even allowing for saturation effects for very bright bars, the visual system is confronted with coding decrements over a limited range and increments over a much larger range. The "max–min" definition of contrast maps the asymmetric luminance increment/decrement variable into a contrast variable having a finite range, 0–1, for both increments and decrements. When our contrast discrimination data are plotted in terms of this contrast variable, a parsimonious description of the results obtains. In "max–min" coordinates, light and dark bars have almost identical contrast discrimination functions. In other words, as far as contrast discrimination is concerned, the visual system treats light and dark bars equivalently when they are matched according to the "max–min" definition of contrast.

The underlying basis for this behavior may be found at the level of retinal physiology. Here, the corresponding problem is to map an infinite range of stimulus luminance, asymmetrically distributed around an adapting level, into a finite range of cellular response. Typical measurements have revealed sigmoidal relations between cell response and log intensity. Cornsweet (1970) has pointed out that such functions are approximately linear—that is, response is proportional to log intensity—over a moderate range of intensities around the adapting level. This is indeed the case for cone responses to luminance increments and decrements in the turtle (Normann and Perlman, 1979), in the mudpuppy (Normann and Werblin, 1974), and in the walleye (D. A. Burkhardt, personal communication). But one of the transformations that is roughly equivalent to the log transformation over a moderate range of luminances is just the "max–min" contrast. For an adapting luminance L_0, the "max–min" contrast C of a bar of luminance L is approximately equal to the log of the relative luminance of the bar, for contrasts ranging up to about 0.7:

$$C = (L - L_0)/(L + L_0) \cong \log(L/L_0),$$
$$0.2 < L/L_0 < 5.0, \; -0.7 < C < 0.7$$

Negative contrasts correspond to dark bars. Therefore, luminance increments and decrements that are matched for "max–min" contrast may produce early retinal, possibly photoreceptor, incremental and decremental responses that are matched in magnitude. If subsequent visual processing is equivalent for increments and decrements, we would expect to find the psychophysical results for light and dark bars that we obtained. In short, the "max–min" definition of contrast is particularly apt because it mimics the luminance transformation performed by the retina.

A related line of psychophysical evidence also points to the conclusion that the visual system treats as equivalent light and dark-bar stimuli that are matched according to "max–min" contrast. In an extensive series of experiments, Burkhardt *et al.* (1982) used a contrast matching paradigm to find pairs of light and dark bars that had equal apparent contrast magnitudes. When "max–min" contrast was used, near symmetry existed so that light and dark bars of equal "max–min" contrast had equal perceived contrasts. For example, for a uniform field luminance of 200 cd/m^2, an increment of 400 cd/m^2 (bright bar) appeared to be matched in contrast magnitude to a decrement (dark bar) of 135 cd/m^2, both stimuli having "max–min" contrasts of about 0.50.

Effects of duration and width

Stimulus duration was the one factor in our study that affected not only detection thresholds, but also the shape of the contrast discrimination function. For 0.1° rectangular bars, a reduction in stimulus duration from 200 to 10 msec led to a fivefold increase in the detection threshold. This difference was almost certainly due to temporal integration (see, e.g. Graham and Kemp, 1938; Barlow, 1958; Blackwell, 1963). Legge (1978b) measured detection thresholds for sine-wave gratings as a function of stimulus duration. For gratings with frequencies above 1 c/deg, thresholds increased by about a factor of five as stimulus duration was decreased from about 200–18 msec. These sine-wave results may account for the dependence of rectangle thresholds on duration, if we suppose that the narrow, rectangular bars are detected by means of their medium and high spatial-frequency components.

Temporal integration may also account for the differences in shape of the 10 msec and 200 msec discrimination functions. Because of temporal integration, a 10 msec increment must be larger than a 200 msec increment to have the same visual effect. Partial integration accounts for the fivefold change in detection threshold. If the same holds true for bar discrimination, we should be able to predict the 10 msec discrimination functions from the corresponding 200 msec functions, simply by scaling all luminance increments (or decrements) by a factor of five. In Fig. 7(B), the curves through the 10 msec data have been derived in this manner from the curves through the 200 msec data in Fig. 6(B). The predicted 10 msec functions for light and dark bars overlap, even at the highest contrasts studied. This is because the scaling procedure has "shifted" the divergent portions of the curves in Fig. 6(B) beyond the range of measurement in Fig. 7(B). Whereas temporal integration predicts a simple scaling of the "delta" coordinates, it has more complicated effects on the shapes of functions plotted in "max–min" coordinates. The curves through the data in Fig. 7(A) represent the temporal integration prediction for the 10-msec data, but this time in "max–min" coordinates. In qualitative agreement with the data, the predicted curves for light and dark bar discrimination diverge at high contrasts.

We found that detection thresholds for rectangular bars changed very little for widths varying from 0.1 to

10°. Similar results for rectangles have been presented by Kulikowski and King-Smith (1973), Shapley (1974), Hines (1976) and Legge (1978a). These authors have suggested that thresholds for rectangular bars of moderate widths are determined by edge detection. (Distortions due to spatial integration, analogous to those just discussed for temporal integration, do not arise here because the region of full summation for foveal viewing at our luminance level is less than the width of our narrowest bars.) On the other hand, we found that detection thresholds for Gaussian bars increased by more than a factor of two as bar width increased from 0.1 to 10°. Shapley (1974) found a factor of 7 change in threshold for Gaussian bars over a range from 0.1 to 1°. The difference between Shapley's results and ours is almost certainly due to temporal properties of the stimuli. Shapley used the method of adjustment, thus eliminating sudden temporal transients. We used a method of forced choice in which patterns were presented with sudden onsets and offsets. There is little doubt that these transients were important in the detection of our wide Gaussian bars.

Comparison of increment and decrement detection thresholds

On our graphs and in Table 2, contrast-detection thresholds for light and dark bars refer to the case of 0 base contrast and correspond to what others have called increment and decrement thresholds. Most of our decrement thresholds are less than the increment thresholds. The mean ratio from Table 2 is 0.91. This observation has been made before. Short (1966) and Patel and Jones (1968) measured increment and decrement thresholds for circular test flashes of several sizes and durations against various backgrounds. Decrement/increment ratios for their data range from about 0.5–0.9. Patel and Jones (1968) found the greatest difference between increment and decrement thresholds for small sizes (15′ dia) and short durations (50 msec). Short (1966) reported the greatest difference at low background levels (3.7 log quanta sec^{-1} deg^{-2}). At high adaptation levels (7.3 log quanta sec^{-1} deg^{-2}), Short (1966) found no significant difference between increment and decrement thresholds. Cohn (1976) has reported steeper ROC curves for decrements than for increments for foveal viewing.

Comparing contrast discrimination for bars with other luminance waveforms

Our results indicate that the form of contrast discrimination functions is very similar for light and dark bars, for bars with Gaussian and rectangular luminance profiles, for narrow and wide bars, and differs only a little for bars presented for 10 or 200 msec. The bar discrimination functions have a dipper-shape like the sine-wave grating contrast discrimination functions. Although these results are consistent with the idea that sine-wave grating contrast discrimination depends on local contrast discrimination of light or dark bars, the results do not support the idea that sine-wave grating contrast discrimination depends differentially on either light or dark bar contrast discrimination.

A few studies have shown that contrast discrimination functions for patterns besides sine-wave gratings and simple bars have the same general dipper shape. Barlow (1962) showed that maximum efficiency for discrimination occurred near threshold for spots of light against various light backgrounds. Other patterns that have been studied include difference-of-Gaussians (Wilson, 1980) and triphasic stimuli (similar to difference-of-Gaussians) (Burton, 1981).

Legge (1981) examined the nature of the suprathreshold portion of sine-wave grating contrast discrimination functions for 200 msec exposures at 2 and 8 c/deg. For base contrasts above threshold, sine-wave grating contrast discrimination functions were well described by power functions with exponents of 0.6 and 0.7 at 2 and 8 c/deg, respectively.

Several models have been proposed recently to account for the shape of contrast discrimination functions (Legge and Foley, 1980; Carlson and Cohen, 1978; Wilson 1980; Burton, 1981). These models all have some form of nonlinear relation between internal response and stimulus contrast, as well as one or more sources of internal noise. Lasley and Cohn (1981) and Pelli (1980) have suggested that properties of near-threshold discrimination can be explained with reference to signal uncertainty.

Comparison with intensity discrimination

Cornsweet and Pinsker (1965) measured intensity discrimination for 50′ disks of light presented for 4.5 msec against a dark background. They found close adherence to Weber's law over a wide range of intensities with a Weber fraction of 0.14.

It is possible to look at contrast discrimination for bars as luminance discrimination. This can be done if we examine only the luminance of the bars, ignoring the uniformly illuminated surround as with a reduction tube. In this way, we can compute the luminances of just-discriminable bars having contrasts of C and $C + \Delta C$. For example, consider contrast discrimination for 200-msec, 0.1° bars for observer DK. The highest base contrast we used for bright bars was 0.41 (max–min definition). DK's increment threshold in this case was 0.06. This means that he was just able to discriminate between bright bars having contrasts of 0.41 and 0.47. The luminances of these bars (background of 340 cd/m^2 plus luminance increment) were 822 and 949 cd/m^2. Therefore, DK was just able to discriminate between bars having these two luminances. The luminance Weber fraction is just $(949 - 822)/822 = 0.15$. Similarly, DK was just able to discriminate between dark bars having contrasts of 0.39 and 0.44. The corresponding luminances were 148 and 133.4 cd/m^2, with a luminance Weber fraction of 0.11.

It is interesting to note the similarity of these luminance Weber fractions to the Weber fraction found by Cornsweet and Pinsker. Perhaps contrast discrimination is just a special case of luminance discrimination and can be described by Weber's law. Certainly, when observers are required to discriminate between very bright bars superimposed on a dim background, the case is very much like the one studied by Cornsweet and Pinsker. However, a departure from this simple explanation is immediately apparent when we look at the luminance Weber fraction associated with contrast detection. DK's contrast-detection threshold (0 base contrast) for light bars was 0.0051. He was just able to discriminate between contrasts of 0 and 0.0051. The corresponding luminances were 340 cd/m^2 (uniform field) and 343.5 cd/m^2 (uniform field plus just-detectable increment). The luminance Weber fraction is $3.5/340 = 0.01$. The discrimination is even better at the bottom of the "dipper" where the luminance Weber fraction dips to 0.006. Similar values obtain for dark bars. These luminance Weber fractions are more than a log unit less than those computed for high-contrast bars. Apparently, in the domain of low contrasts, observers are able to make much finer discriminations of relative luminance than are possible for high-contrast stimuli. It is as if the presence of the uniformly illuminated surround sharpens the discriminating capacities of mechanisms responsible for contrast discrimination. When the luminances of the stimuli and surround become very different, the surround is no longer useful in performing the discrimination, the advantages of contrast are lost, and the coarser discrimination based on luminance alone results.

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