Sources of variability in apparent-contrast measurements made by brightness matching*

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The apparent contrast of backward- and forward-masked spatial sinusoids was measured by a brightness-matching technique suggested by Davidson (1966), designed to be free of artifacts associated with earlier matching methods. Data variability was relatively large due predominantly to (1) fluctuations in masking-interval duration, and (2) changes in the O's criteria produced by the salient temporal and spatial differences between test and comparison fields. Several other potential sources of data variability were found to be negligible.

Davidson (1966) suggested a novel method for measuring the apparent contrast of gratings, designed to be free of the artifacts associated with earlier matching techniques. In this method, the O adjusts the brightness of a comparison target until it matches in brightness first the dark and then the bright portion of the test grating. From these two measurements, apparent contrast is easily calculated. Davidson's findings led him to recommend the following characteristics for the comparison target: (1) Its spatial frequency content should be dominated by high frequencies (e.g., a narrow line with sharp edges) so that it will appear of uniform brightness along its entire length; (2) its range of required luminance changes should be as small as possible (i.e., the comparison target should be viewed against a background equal in luminance to the space-averaged value of the test target and made adjustable to values above or below this background level), to maximize the range of applicability of linear or small-signal analysis of matching data; (3) it should be spatially separated from the test target by at least 30 min of visual angle, to preclude spatial interaction effects between the two fields. Cornsweet (1970, p. 331) reiterated Davidson's suggestions, noting that the technique had not yet been reported in the psychophysical literature.

Since then, Corwin (1971) has used the brightness-matching technique to measure the apparent contrast of briefly flashed sinusoidal gratings of equal physical contrast that were either preceded or followed by a short homogeneous masking flash at one of four masking intervals. It proved possible to measure significant differences in apparent contrast

between experimental conditions. Nevertheless, the variance of the data obtained using this technique was considerably higher than is common in psychophysical experiments. It is the purpose of the present article to consider the possible sources of this variability, and to assess the relative importance of each source.

METHOD

Figure 1 shows the O's view of the stimulus fields. As recommended by Davidson, the two 4.3 x 10 deg rectangular areas were separated (by 1.8 deg) to eliminate spatial brightness interactions. Both fields were seen in monocular Maxwellian view against a dark background.

The left-hand area, the comparison field, was continuously present; it consisted of a uniform background and a thin (0.13-deg) horizontal comparison line located at the center of the field but not extending completely across it at the right, to eliminate simultaneous-contrast effects between the line and the dark surround. The luminance of the comparison line was adjustable by the O to values above or below the comparison-field background level. In the right-hand area, the test field, the test grating, and a homogeneous spatially overlapping mask were presented in one of four temporal sequences. The grating appeared as a briefly presented set of horizontal dark and bright stripes, degraded in contrast by the mask. Gratings of three spatial frequencies were used: 0.25, 1.0, or 4.0 cycles per degree (cpd). All gratings had the same physical contrast (0.61) and a duration of approximately 0.5 msec. The mask was a uniform rectangular patch of light spatially overlapping the test-field area, with a duration of 20 msec. The masking flash appeared at one of four temporal intervals with respect to the test flash: -42, -7, +8, or +43 msec. For negative (backward masking) intervals, in which the test flash preceded the masking flash, the masking interval was defined as the

time elapsed between test offset and mask onset.

A test/mask presentation reoccurred every 2 sec. For most of the intertrial time, the test-mask field was illuminated by a homogeneous adaptation field, which also contained a small fixation dot at its center. The brightness of the adaptation field was matched to that of the comparison field background, the space-averaged value of the test grating, and the masking flash, in order to minimize changes in the O's state of adaptation during a trial.

The apparent contrast of the grating-mask combination was measured by the method of adjustment. By glancing at the center of the test field and at the center of the comparison field on alternate trials, the O adjusted the luminance of the comparison line to match the brightness of that portion of the test grating located opposite it. By raising or lowering the grating, either a bright or dark stripe could be located opposite the left end of the comparison line.

Os were allowed as many trials as necessary to establish a brightness match. Under each condition, four or more consecutive matches were obtained. Prior to each match, the neutral density wedge controlling comparison-line luminance was moved silently away from the match point by the E (in opposite directions after successive matches).

Within a session, four or more consecutive brightness matches were obtained for the dark stripe followed by four or more consecutive matches for the bright stripe. The apparent

Fig. 1. Stimulus configuration as seen by the O. CF: comparison field. TF: test field. CF was continually present; TF contained either a homogeneous adapting stimulus, a test grating, or a 20-msec homogeneous masking flash. The O adjusted the luminance of the thin line in CF to match the brightness of that portion of TF opposite to the line.

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Fig. 2. Standard deviations of apparent-contrast measurements as a function of stimulus spatial frequency for each masking condition. Masking intervals indicated on each graph. Filled circles, O.R.F.; open circles, O.T.C. Symbols at bottom of the leftmost graph denote the standard deviation of steady-state brightness matches for the two Os.

contrast was then calculated from the pair of averages obtained for each experimental condition. Each condition was repeated at least eight times for each of two experimental Os.

Figure 2 shows the standard deviations of the apparent-contrast measurements obtained as a function of the spatial frequency of the test grating for each of the four masking intervals. Standard deviations are expressed in scale units proportional to the wedge density from which apparent contrast scores were calculated.

POSSIBLE SOURCES OF VARIABILITY

A number of factors may have conspired to create the variability of apparent-contrast measurements. These will be listed, and an attempt made to assess the relative contribution of each.

Psychophysical Brightness Saturation

Comparison-line brightness changes most rapidly with luminance when its luminance is close to that of its background. When the luminance of the comparison line is very much higher or lower than the background, its brightness changes relatively little as the luminance is changed. Therefore, if the luminance required for a brightness match is very much higher or lower than that of the comparison-field background, slight changes in the perceived brightness of either the test or comparison field from trial to trial would yield large changes in the O's determination of comparison-line luminance. This would produce high variances in apparent contrast measurements.

If this brightness-saturation factor had a significant influence on apparent contrast variability, it would be expected to produce large variances for experimental conditions in which apparent contrast was highest, and relatively low variances when apparent contrast was low. In fact, this was not the case; no systematic relation was found between average apparent contrast measurements and the variability of those measurements. For example, relatively high apparent contrasts were obtained for both Os for the 4-cpd grating presented with a +8-msec mask, and relatively low apparent contrasts were obtained for all gratings under the -42-msec and -7-msec masking conditions. Thus, brightness saturation may be ruled out as a significant source of the variability shown in Fig. 2.

Accommodation Changes

Since the sinusoidal luminance distributions used in this study remain sinusoidal under defocusing, they do not provide visual cues to proper accommodation. It is therefore possible that the O's accommodative state may have changed during an experimental session without his becoming aware of it. These changes, if present, would have produced variations in the brightness of stimulus patterns, especially for the high-frequency stimuli. Thus, accommodative changes would be expected to yield more highly variable measures of apparent contrast for stimuli of high spatial frequency than for stimuli of low spatial frequency.

Figure 2 indicates no systematic trend of increased variability with respect to spatial frequency, making it unlikely that accommodative changes had a significant influence on data

variance. The presence of a fixation point and the sharply defined edges of both comparison and test fields probably provided adequate accommodation cues.

Changes in Fixation

Small eye movements made from trial to trial undoubtedly caused changes in the exact registration of the test grating on the O's retina. Since the grating was horizontal, horizontal changes in fixation would not have affected apparent contrast. Vertical changes in fixation, on the other hand, could have caused significant reduction in apparent contrast. However, because this reduction would be greater for stimuli of high spatial frequency than for low, contrast variability should be directly proportional to spatial frequency. Figure 2 shows this not to be the case, in general.

Steady-State Reliability in Brightness Matching

Much of the variability in measuring apparent contrast could be a result of momentary changes in the O's criterion as to what constitutes a brightness match. Thus, each O produces a range of comparison line settings, each of which is acceptable. This range may be said to reflect the O's criterion reliability. To obtain an estimate of this reliability for the Os in this study, each was required to adjust the comparison line until it matched its background in brightness. These steady-state brightness matches were repeated 10 times in succession, and the standard deviations calculated (bottom of the leftmost curve in Fig. 2). It is clear that this source of variability did not contribute significantly to experimental variance.

The Nature of the Psychophysical Task

In the present study, the O is required to compare two fields that are spatially separated, with markedly different spatial brightness distributions and very different time courses. Furthermore, because the light in the test and comparison channels was produced by one source, and the light in the mask and adaptation channels was produced by another source, a noticeable hue difference existed between the two halves of the O's field. Under these conditions, the O is required to ignore a number of salient but irrelevant differences in appearance between test and comparison fields in determining a brightness match. Because the matching task is difficult in this sense, it is likely that the effects of practice from session to session and the effects of fatigue within sessions could lead to

significant changes in the responses made to identical stimulus presentations. These factors probably account for much of the variability encountered in the present study, but do not explain the way in which this variability changed over experimental conditions.

One potentially important dimension along which test and comparison fields differ is in the relative size of the comparison line and the width of the dark or bright stripe in the test grating. The perceived width of the comparison line is approximately that of a bright or dark stripe of the intermediate frequency (1 cpd) grating. If this factor contributes significantly to response variability, variance should be minimized for judgments made on the intermediate frequency grating and be relatively large for the high- and low-frequency gratings. With the latter, a large perceived difference exists between the width of the comparison line and the bright or dark band of the stimulus distribution. Figure 2 shows no systematic tendency for gratings of intermediate frequency to yield lower variances. Consequently, the factor of comparison-line width may be assumed to be a relatively unimportant source of error variance.

Temporal Changes in
Test and Mask Interaction
The masking intervals used in this

study are in the range within which disruptive effects created by the masking flash change rapidly with time. Because of this, small changes in masking interval or in the visual system's own sensitivity would be expected to create sizable alterations in visual performance. Slight variation in masking intervals during a session could therefore cause variability in the perceived brightness of a test/mask pattern from trial to trial. This effect should be large for the short masking intervals and smaller for the longer intervals. The data of Fig. 2 show systematically higher variances for the short (-7 and +8 msec) masking intervals as compared to variances for the longer intervals (-42 and +43 msec).

SUMMARY AND CONCLUSION

A brightness-matching psychophysical method was used to measure the apparent contrast of sinusoidal gratings under several conditions of masking by light. The method was sufficiently sensitive to measure significant differences in apparent contrast between some experimental conditions, but the variability of the data was relatively large. By examining the standard deviations of the measurements for the various stimuli and experimental conditions, the following inferences were possible: (1) The relatively slow changes of brightness with luminance for relatively high and low luminances

(psychophysical "brightness saturation") did not create a significant increase in variability. (2) Variation in the O's state of accommodation or point of fixation from trial to trial did not contribute significantly to variability. (3) The fluctuation of Os' ability to make steady-state brightness matches was small compared to the overall variability. (4) A major source of variability appeared to be associated with the requirement that the O abstract the brightness dimension from two stimulus fields which differed in spatial and temporal dimensions. However, the size differences between the width of a grating stripe and the comparison line did not appear to influence overall variability. (5) The systematic change of variance across experimental conditions was associated with the rapid changes in visual performance with respect to the time interval between test and masking stimuli.

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