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Equal Apparent Conspicuity Contours With Five-Bar Grating Stimuli

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ABSTRACT

The report discusses the results of laboratory studies on equal conspicuity (contrast) contours using as the test stimuli five-bar grating patterns, with the results of other experiments in this series conducted by NBS. These results are in agreement with the earlier studies. Basic groundwork is provided for additional experiments and analysis which will form a practical basis for recommending energy-conserving design illumination levels that conform to real-world office activities.

Key words: Conspicuity; contrast; energy conservation; illumination; illumination levels; lighting, suprathreshold seeing; visibility; vision.

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INTRODUCTION

The visibility of materials encountered in office work ranges from barely legible to highly legible. With technological advances in reproduction and writing implements, e.g., copiers, typewriters, pens and paper technology, the visual tasks prevalent in offices today are more legible than they were two or three decades ago. There are, however, no hard data quantifying the relative occurrence of tasks at various levels of difficulty.

For the designer, the problem faced is: "What illumination level should I recommend for lighting that will be efficient, yet provide good seeing for the tasks to be performed?". To conclude that, "I will recommend the lighting level required for the least legible task, since it follows that all other tasks with higher legibility will have increased visibility" may be erroneous. Arguments of this type are based on popular notions (e.g., more light, better sight) and are verified in the laboratory only for threshold tasks (e.g., barely seeing a gap in a circle or detecting a spot of light). These types of visual tasks are not usually encountered in office work. Workers would not tolerate conditions in which they had to deal with just barely legible materials on a sustained basis, unless the nature of the task absolutely required it. Instead, the lighting system and task parameters should permit the worker to read the materials without any undue difficulty. The foremost information the designer needs in specifying a lighting system is: considering the activity and the kind of tasks to be performed in the space, what illuminance levels will enable the worker to comfortably perform these tasks?

The following study is one in a series investigating the effect of light levels on "goodness of seeing" for threshold and suprathreshold tasks.

BACKGROUND

Studies conducted to date indicate that when the required response is, "I can just barely see the object" (threshold task), the form of the function obtained by plotting contrast against luminance is different from that obtained when the response is, "I can see the object, but it is easier to see, that is, it has better contrast, under luminance level X than luminance level Y" (suprathreshold task). Studies have been conducted with both letters (1) and sinusoidal and square-wave gratings (2). Both of these studies indicate that the forms of the function at threshold and suprathreshold levels are significantly different. For both types of stimuli, the form of the function near threshold levels agrees with that obtained in classical threshold studies. As luminance is increased, the contrast required to detect the presence of a target or the minimum separation between two lines decreases monotonically. That is, task visibility increases as luminance is increased. But on tasks for which detection is not a problem, i.e., in which the presence of the detail is definitely established, the form of the function differs significantly from that found at threshold levels. The suprathreshold data indicate that as luminance is increased, the degree of contrast required to maintain equality of apparent contrast decreases initially with increases in luminance, but that further increases in luminance require increases in contrast to maintain goodness of seeing. The relevance of these findings to lighting design is obvious: the popular notion of "more light, better sight" is valid for materials with poor legibility, but not for good or medium legibility visual tasks. In fact, for these suprathreshold visual tasks, more light can mean less sight, that is, increases in luminance can result in a loss of ease of seeing.

The studies described above involved a total of six subjects: four in the study using letters and two for the gratings studies. All six were experienced in visual psychophysical experiments. The following experiment was conducted to obtain data from a larger number of subjects, most of whom were inexperienced in psychophysics. The lighting system and targets were different from those previously used, but the procedure was the same in all important respects.

FIVE-BAR GRATING PATTERN EXPERIMENT

SUBJECTS

Fifty subjects participated in this experiment, all of whom were affiliated with the University of Virginia. Thirty were undergraduates, nineteen graduate students. All had little or no experience in visual psychophysical experiments. The one remaining subject was an experienced participant in vision experiments.

STIMULI

The stimuli were photographic reproductions of the NBS Microcopy Test Chart 1963A magnified two times. These charts are composed of groups of alternating dark and light bars of various bar widths and are used primarily for quality control and legibility evaluation of micrographic systems. Each group consisted of five dark and four light bars (Fig. 1). Two sets of charts were made, the background reflectance for the dark bars on one set being twice that of the other. The background reflectance was the same for all charts in a set. Each set was composed of charts which differed in contrast in steps of approximately 0.02, where contrast is defined as:

$$\text{Contrast} = (L_B - L_D)/L_B,$$

and the subscripts B and D stand for background and detail, respectively. Three bar widths, corresponding to 6.0, 3.8, and 2.4 minutes of visual angle, were used in the study; the contrast values for the charts used for each of these widths are shown in Figs. 2 and 3, for the high and low reflectance background sets, respectively. The 3.8 min. values have been displaced by 0.1 unit on the ordinate axis and the 2.4 min. values are 0.2 units higher. The contrast for each chart was measured with a microphotometer at the viewing angle used in the experiment (25 degrees from normal to the chart) and with the same lighting system used in the experiment. A test chart holder allowed only a 5 cm (2 in) square portion of each test chart to be exposed. The exposed portion of each test chart was surrounded by a cover with a reflectance that was an average of the backgrounds of the two sets of charts. The openings exposing the test chart details were separated by 22.5 degrees from center to center.

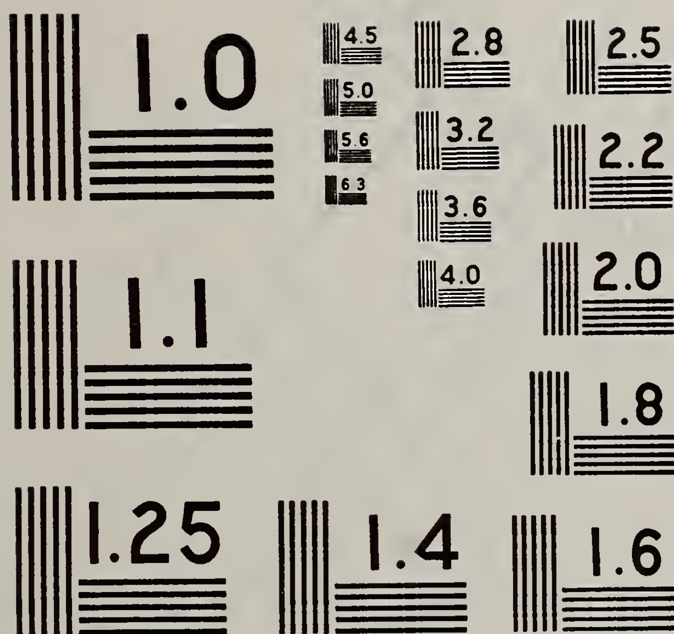

Figure 1. NBS Microcopy Test Chart.

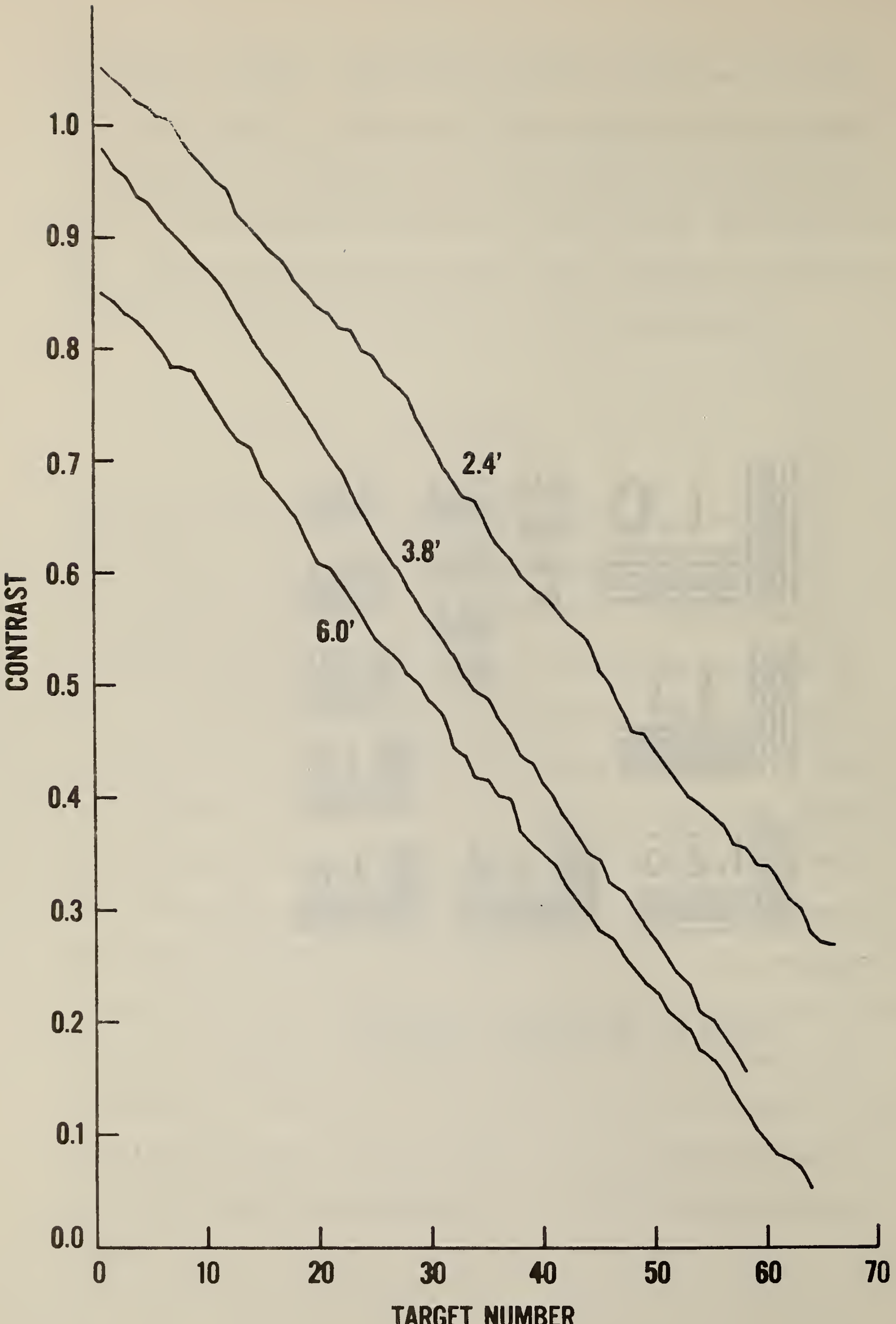

Figure 2. Contrasts of high reflectance background charts. Values for 3.8 min. and 2.4 min. curves have been displaced upward by 0.1 and 0.2 units, respectively, on the vertical axis.

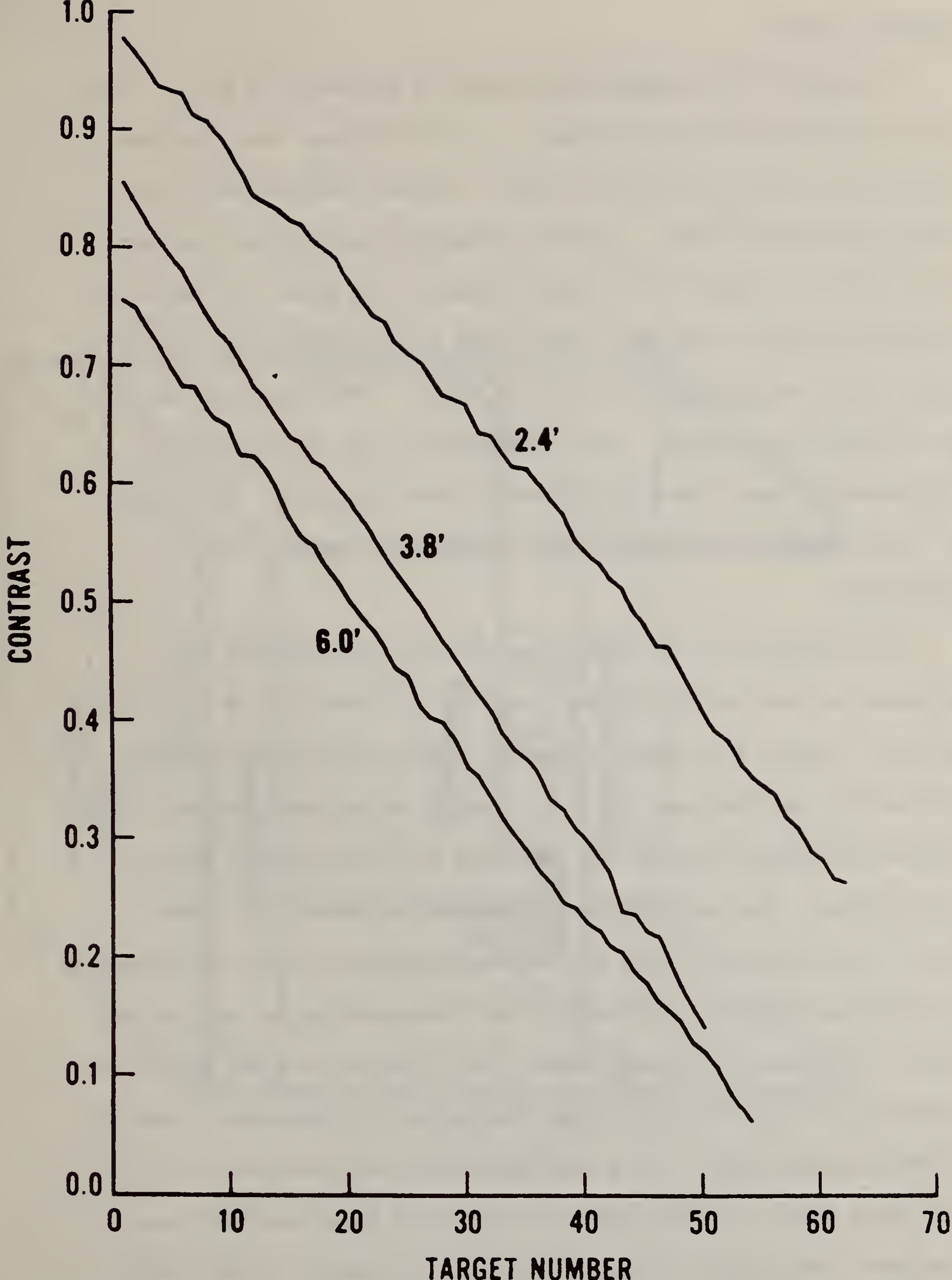

Figure 3. Contrasts of low reflectance background charts. Values for 3.8 min. and 2.4 min. curves have been displaced upward by 0.1 and 0.2 units, respectively, on the vertical axis.

LIGHTING SYSTEM

A drawing of the experimental booth is presented in Fig. 4. The booth was 1.8 m (6 ft) across and 1.5 m (5 ft) deep, with the lamps located 2.1 m (7 ft) above the floor. The task surface was 75 cm (30 in) above the floor. A white, translucent plexiglass cast sheet, 6.4 mm (1/4 in) thick with a matte finish on one side, was installed 21 cm (8 in) below the lamps. The lamps were standard 40w cool white rapid start lamps spaced 7.6 cm (3 in) apart. The booth was enclosed by a white cloth curtain. The illuminance in the booth could be continuously varied using a solid-state dimming system. No change in color temperature occurred when dimming the lamps.

PROCEDURE

The observer (O) was seated and the chin and forehead rest adjusted so that the target was viewed at a distance of 38 cm (15 in) and at an angle of 25 degrees from the normal to the task surface. Two charts, one from each set, were placed in the chart holder, the angular separation between the test bars on the two charts being 22.5 degrees. The observer was instructed to look at the center bar on the comparison (high reflectance background) chart and compare its apparent contrast with that of the corresponding bar on the test (low reflectance background) chart. If O thought that the bar on the test chart had more contrast than the bar on the comparison chart, he asked the experimenter for a test chart with less contrast. If, on the other hand, O thought that the bar on the test chart had less contrast than the bar on the comparison, he asked for a test chart with more contrast. The process continued until the observer perceived the bars on the two charts as being equal in apparent contrast.

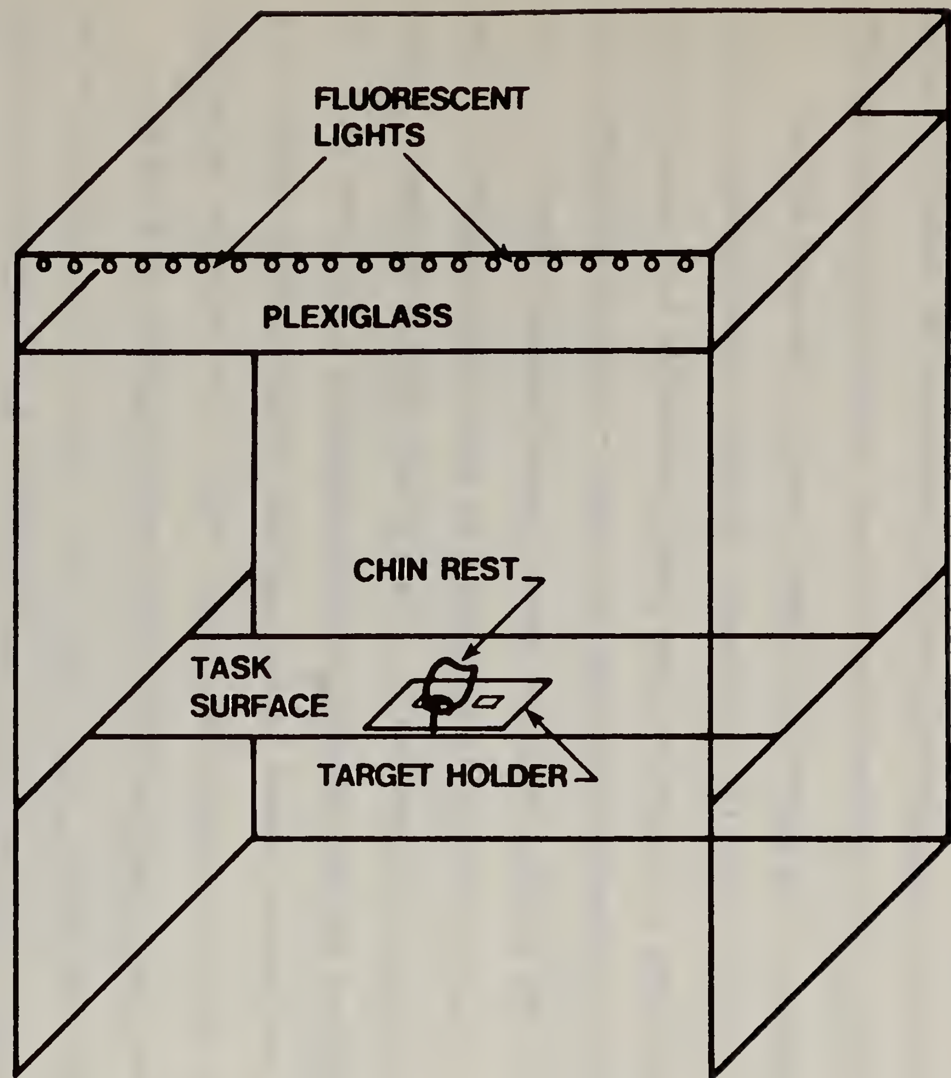

Figure 4. Drawing of apparatus.

Three such matches were made, and the median contrast of the test chart chosen in these matches was recorded. The illumination level was then halved, and the contrast of the test chart chosen in these matches was recorded. The illumination level was then halved, and the comparison chart was replaced by one of the same physical contrast as the median test chart recorded above (thus each new comparison chart was determined by the observer's contrast matches on the previous set of trials). The observer made three more matches, and a new standard was determined. This process was repeated until 0 completed the range of luminances for the experiment, 700 cd/m^2 to 5.5 cd/m^2. The instructions to the subjects are given in Appendix A.

Twelve experimental conditions were used -- three target sizes (6.0, 3.8, and 2.4 min. of visual angle, corresponding to chart numbers 1.4, 2.0, and 3.2, respectively) at four initial contrast levels (0.7, 0.5, 0.3, and 0.15). The order of these conditions was randomized for each subject, with one exception. The first session was balanced across subjects so that an equal number would begin at each of the twelve conditions. Half of the subjects had the comparison chart placed on their right, while the other half had it placed on their left.

All subjects first did one practice run at 0.5 contrast, 6 min. target size, which consisted of five matches at each luminance level. The initial luminance level was 700 cd/m^2 and the final level was 5.5 cd/m^2, but a reverse run condition was also included in which the comparison and test charts were switched, and the luminance level progressed from lowest to highest.

RESULTS

Figs. 5-7 present a summary of the data. Each curve is an equal apparent contrast contour, that is, all of the connected points were perceived to be equal in contrast at the different levels of illumination. The four symbols represent different starting contrast levels at 700 cd/m^2: open circle = 0.70, square = 0.50, triangle = 0.30, and hexagon = 0.15. Each point on a curve represents the arithmetic average of fifty observers. Figs. 5, 6, and 7 represent the results for the different bar widths -- 6.0, 3.8, and 2.4 min., respectively.

The functions are similar for these three figures. In general, the two higher starting contrasts (0.70 and 0.50) have a positive slope, whereas the two lower starting contrast levels (0.30 and 0.15) have a negative slope. In visibility terms, for the two lowest sets of curves, as we increase luminance, the contrast required for the bars to be subjectively equal <u>decreases</u> monotonically. But the apparent contrast contours for the two higher levels are the opposite. The contrast required for the bars to be subjectively equal <u>increases</u> monotonically as luminance is increased.

DISCUSSION

Figures 8 and 9 compare the results of the five-bar grating pattern experiment with those of the earlier grating study (2). The solid lines in Figs. 8 and 9 are the equal apparent contrast contours obtained when the stimulus was a square-wave grating pattern with a bar width of 7.7 min. Each figure gives the results for a single observer. The dashed lines connect the points shown in Fig. 5, and were

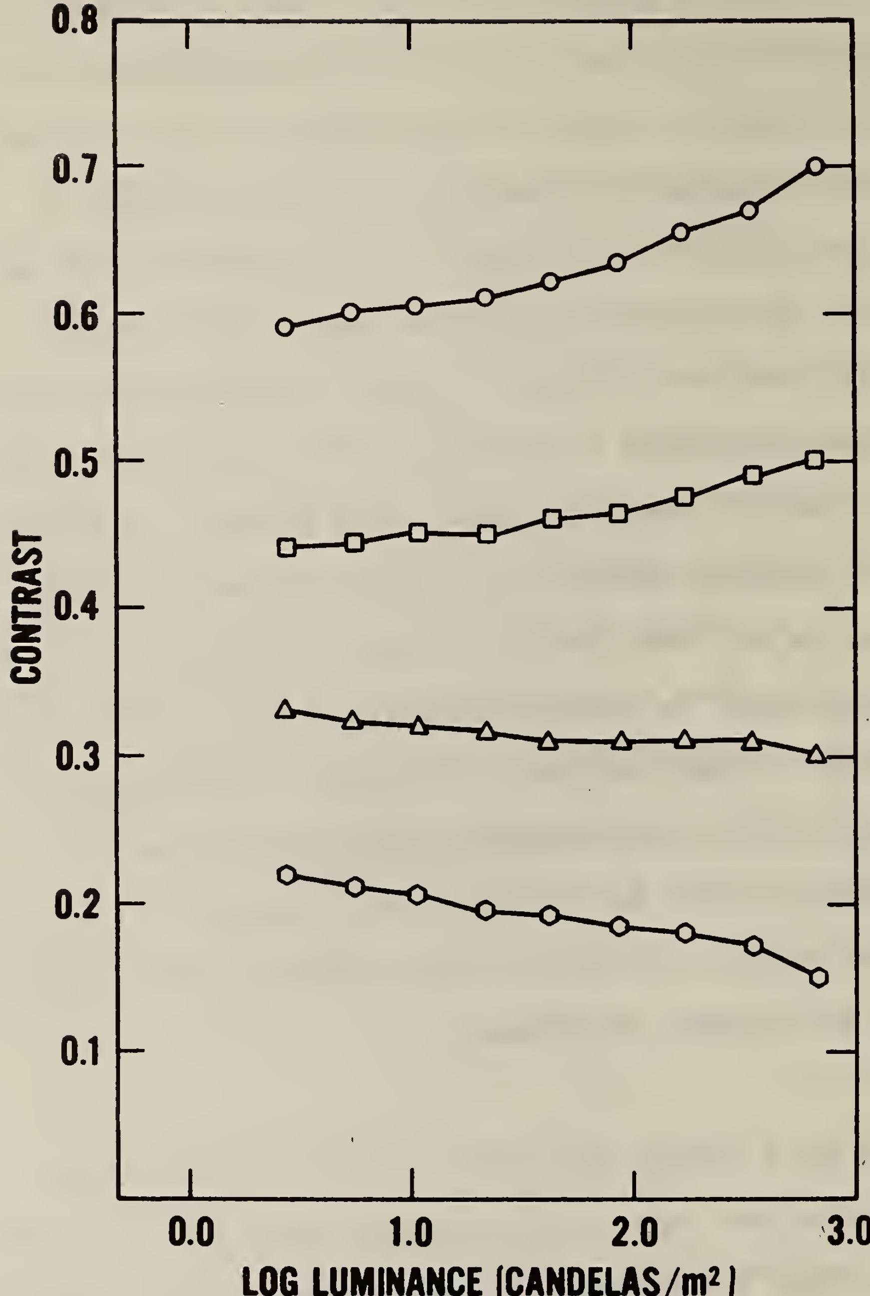

Figure 5. Equal apparent contrast contours for five-bar grating pattern stimuli. Bar width = 6.0 min. of visual angle. Data points are averages for fifty observers.

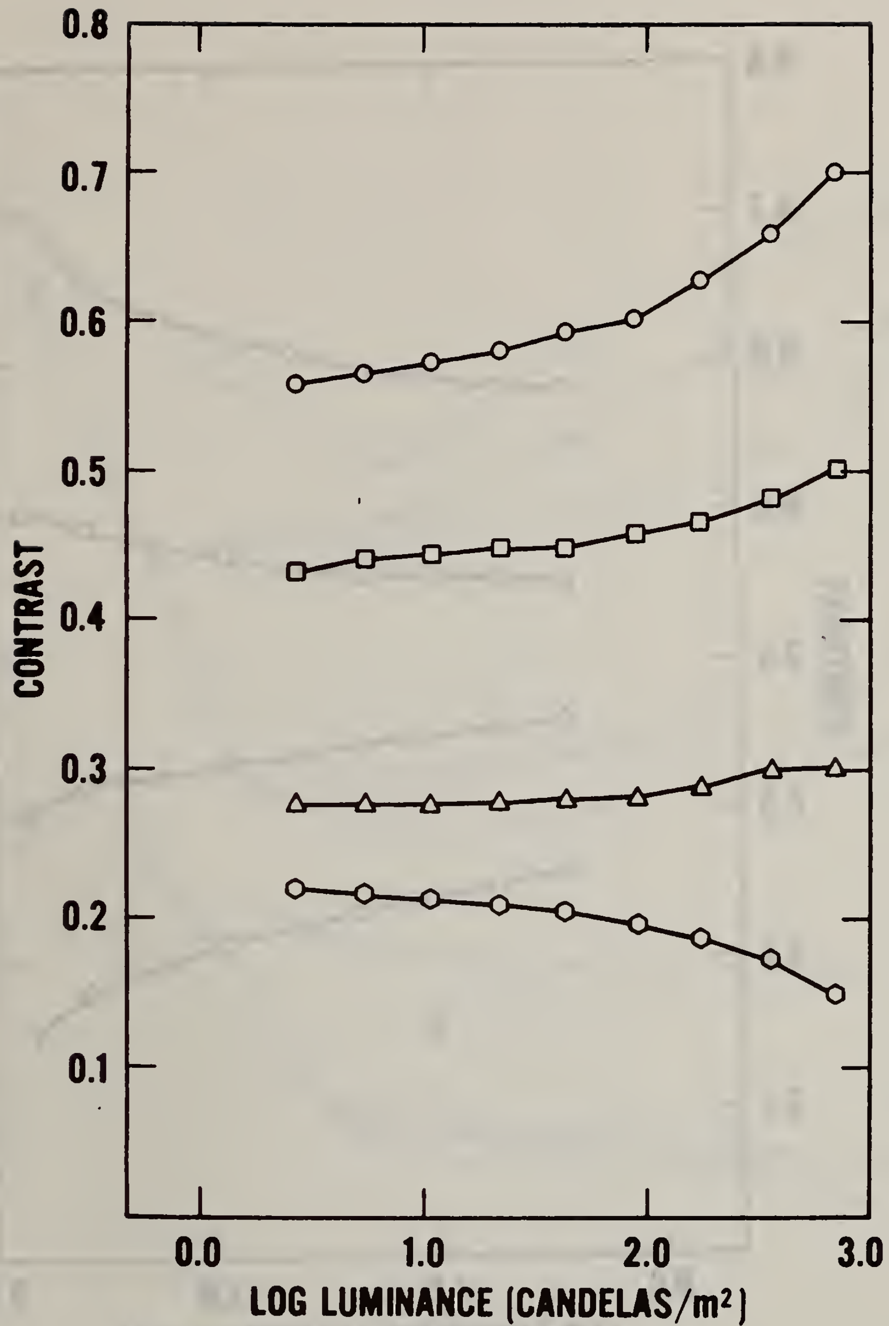

Figure 6. Equal apparent contrast contours for five-bar grating pattern stimuli. Bar width = 3.8 min. of visual angle. Data points are averages for fifty observers.

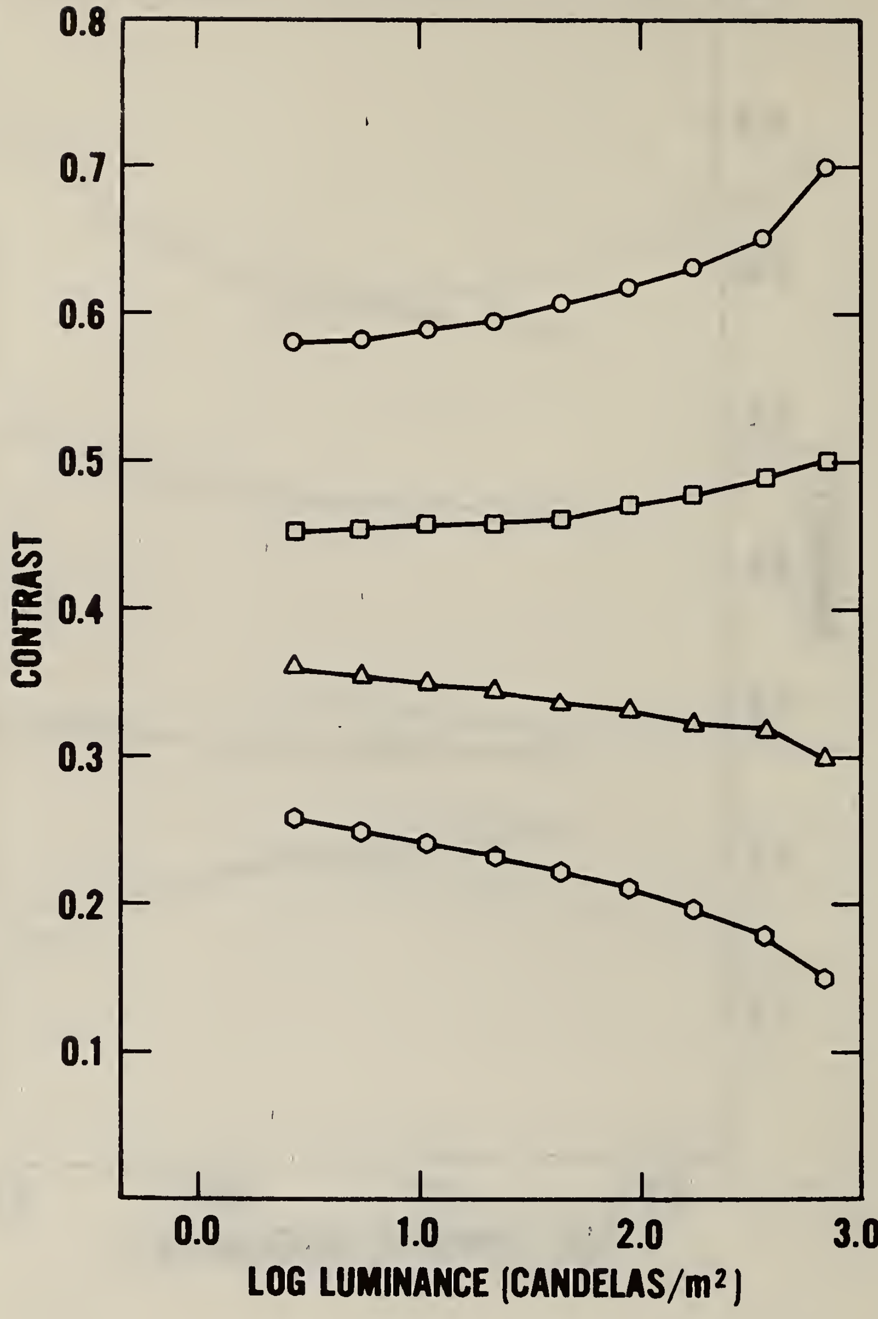

Figure 7. Equal apparent contrast contours for five-bar grating pattern stimuli. Bar width = 2.4 min. of visual angle. Data points are averages for fifty observers.

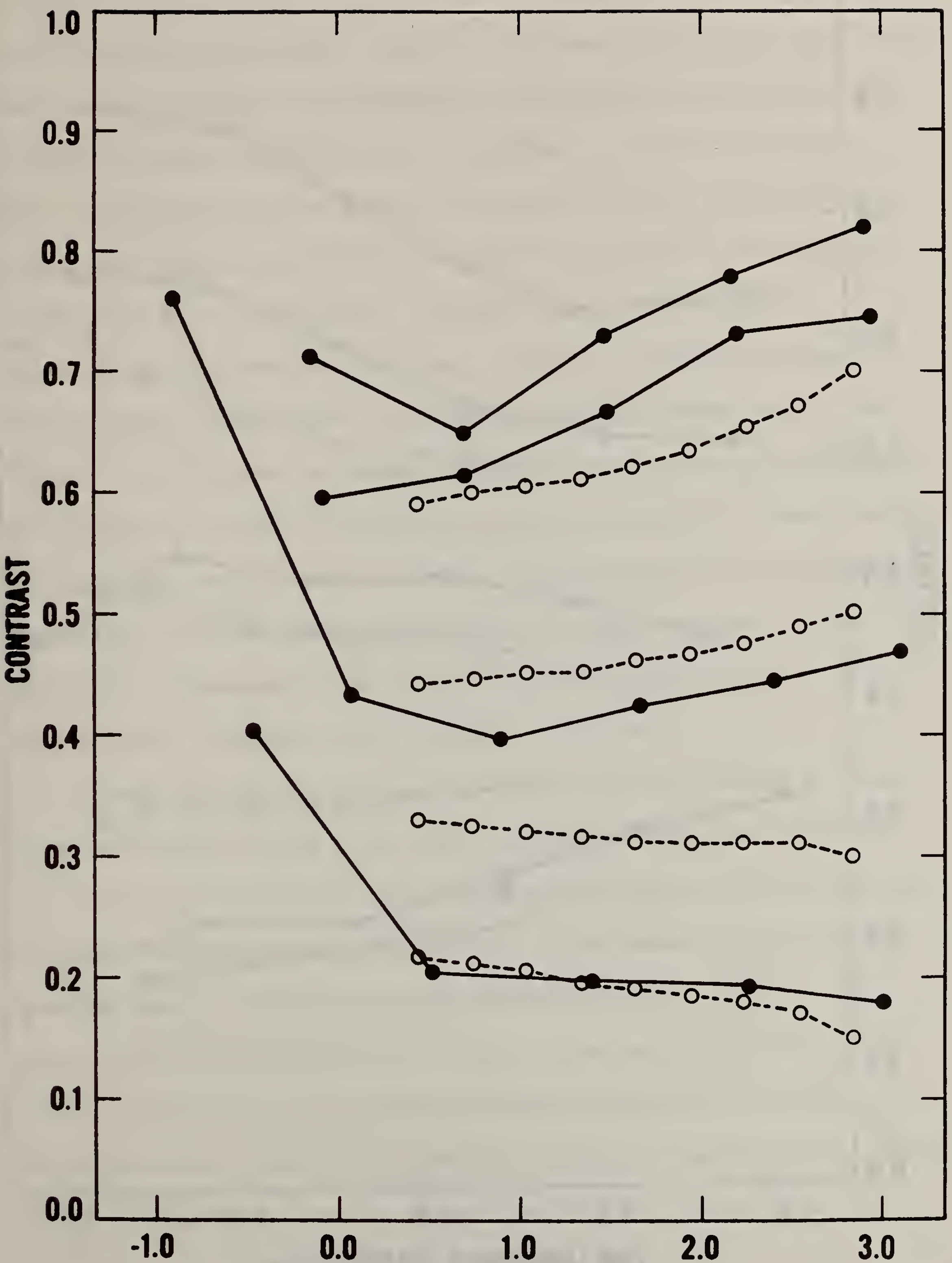

Figure 8. Comparison of equal apparent contrast contours for five-bar and square-wave grating stimuli. Bar width = 6.0 and 7.7 min. of visual angle for five-bar and square-wave gratings, respectively. Data points for five-bar grating curves are averages for fifty observers. Data points for square-wave grating curves are for a single observer (GY).

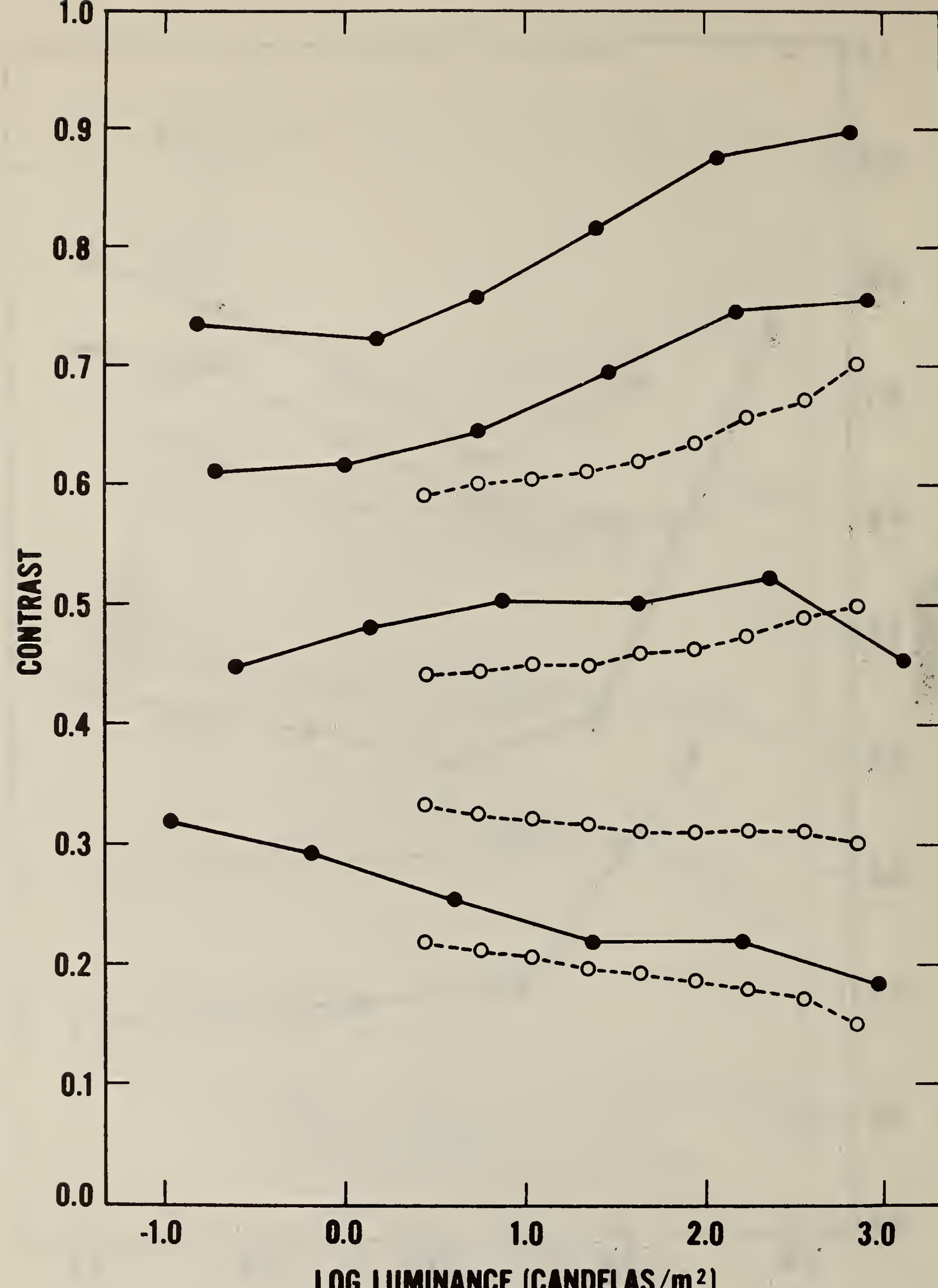

Figure 9. Comparison of equal apparent contrast contours for five-bar and square-wave grating stimuli. Bar width = 6.0 and 7.7 min. of visual angle for five-bar and square-wave gratings, respectively. Data points for five-bar grating curves are averages for fifty observers. Data points for square-wave grating curves are for a single observer (YK).

obtained using the five-bar stimulus with line widths of 6.0 min. The curves all show that as the contrast level of the equal apparent contrast contours increases, the slopes fan out, that is, we start with a negative slope and end with a positive slope. Both sets of curves thus demonstrate that for tasks of low contrast, the contrast required to give a perception of equal contrast monotonically decreases as luminance is increased. However, for higher contrast levels (more visible tasks), increasing luminance beyond some value results in a decrease in contrast sensitivity; the actual contrast must be increased at higher luminances to give a perception of equal contrast. Although the results for the five-bar chart do not show a minimum, the results for the square-wave gratings suggest that with further decreases in luminance, the two upper dashed curves in Figs. 8 and 9 will probably reverse, i.e., a minimum will occur.

Figure 10 compares the results of the five-bar grating pattern study with those of the study using letters (1). The solid curves in Fig. 10 are the results of the experiment using letters with stroke widths of 6.5 min. as the task stimulus. The dashed curves are the results from the five-bar grating experiment given in Fig. 5. The test stimuli are different, one being letters and the other, straight lines. But again, the differences between the curves as we go higher up the contrast scale are the same for both sets, and there is a fanning out of the curves as seen in Figs. 8 and 9.

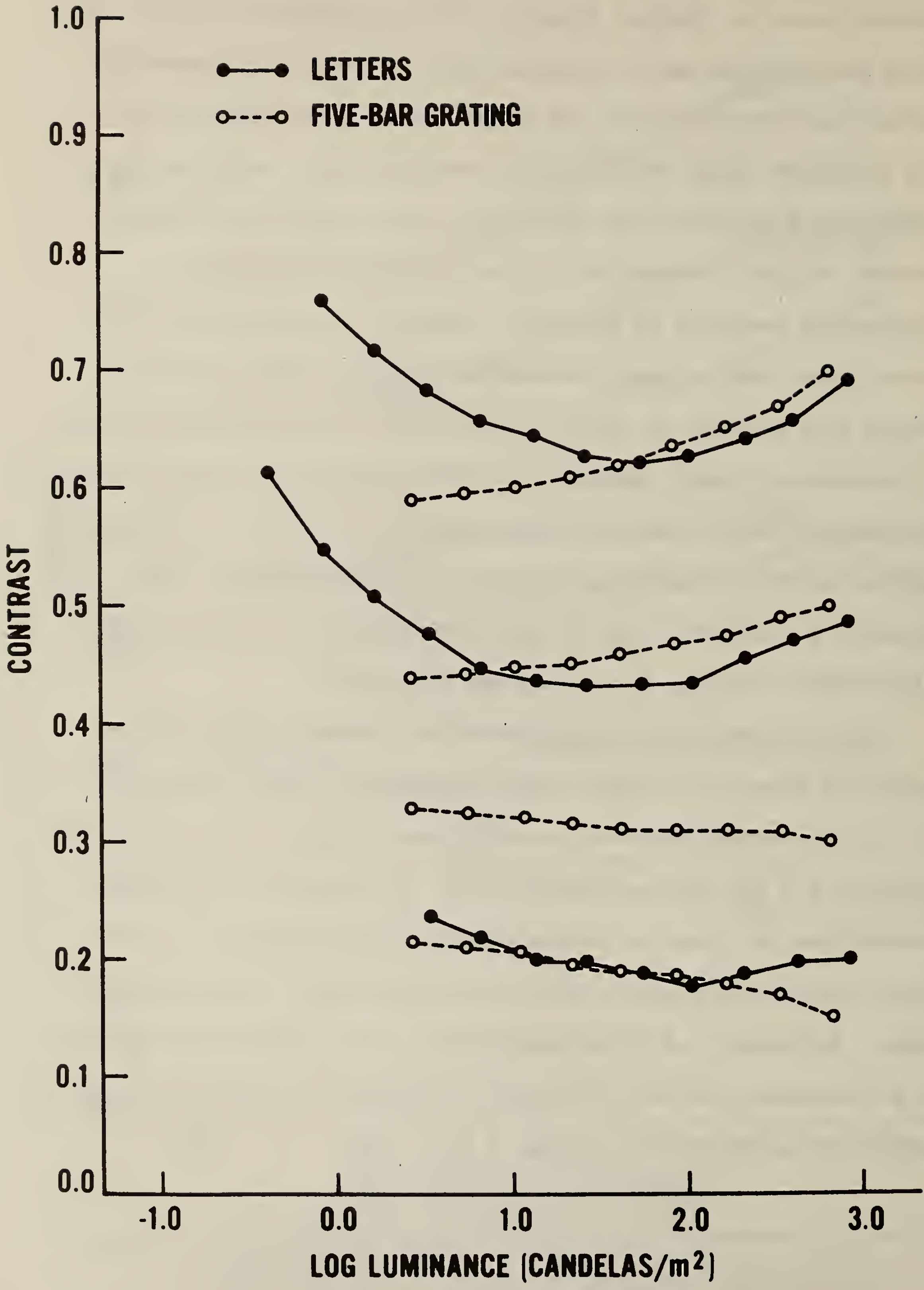

Figure 10. Comparison of equal apparent contrast contours for five-bar grating and letter stimuli. Bar and stroke widths = 6.0 and 6.5 min. of visual angle, respectively, for gratings and letters. Data points are averages for fifty observers for gratings and four observers for letters.

A second study using the letter stimuli was also conducted in conjunction with the present study, using the same procedure. The results are given in Figs. 11, 12, and 13, for stroke widths of 6.5, 4.0, and 3.2 min. of visual angle, respectively. Each data point is the arithmetic average for nine subjects. The results for all three stroke widths are quite similar. They are also similar to the results obtained with the five-bar charts, although the fanning out of the lines is not as pronounced as it is for the five-bar stimuli.

The results of both of the grating studies and both of the letter studies indicate that the function changes from a "more light, better sight" one to a "more light, less sight" curve as the contrast of the task increases. For low visibility tasks, increasing luminance results in increased "goodness of seeing", but for tasks with contrasts greater than approximately 0.4, increasing luminance does not enhance visibility. More seriously, a loss in clarity of detail occurs as luminance is increased for these suprathreshold tasks.

Four sets of data utilizing the apparent equal contrast contour technique have been presented and discussed. There are clear indications that a single function cannot qualitatively treat visual tasks that are at or near threshold levels and nonthreshold tasks. The first letter study utilizing four subjects indicates that for tasks above approximately 0.4 contrast the optimum level is approximately 50 cd/m^2 (15 ftL). The data from the grating studies and the second letter study, however, indicate a lower optimum luminance level. Although no definite value can be stated at this time, it appears to be significantly less than those being recommended by the IES in the 5th edition of their handbook.

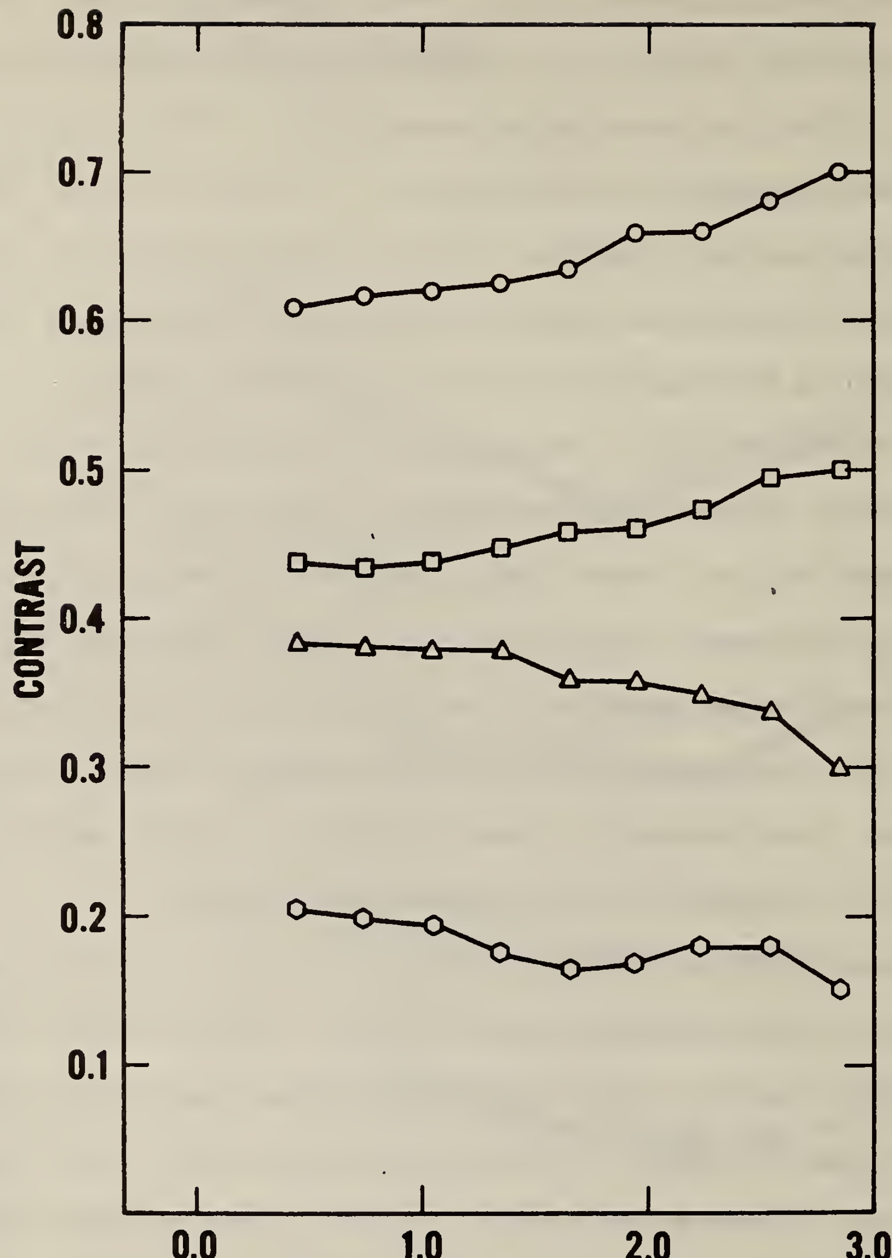

Figure 11. Equal apparent contrast contours for letter stimuli. Stroke width = 6.5 min. of visual angle. Data points are averages for nine observers.

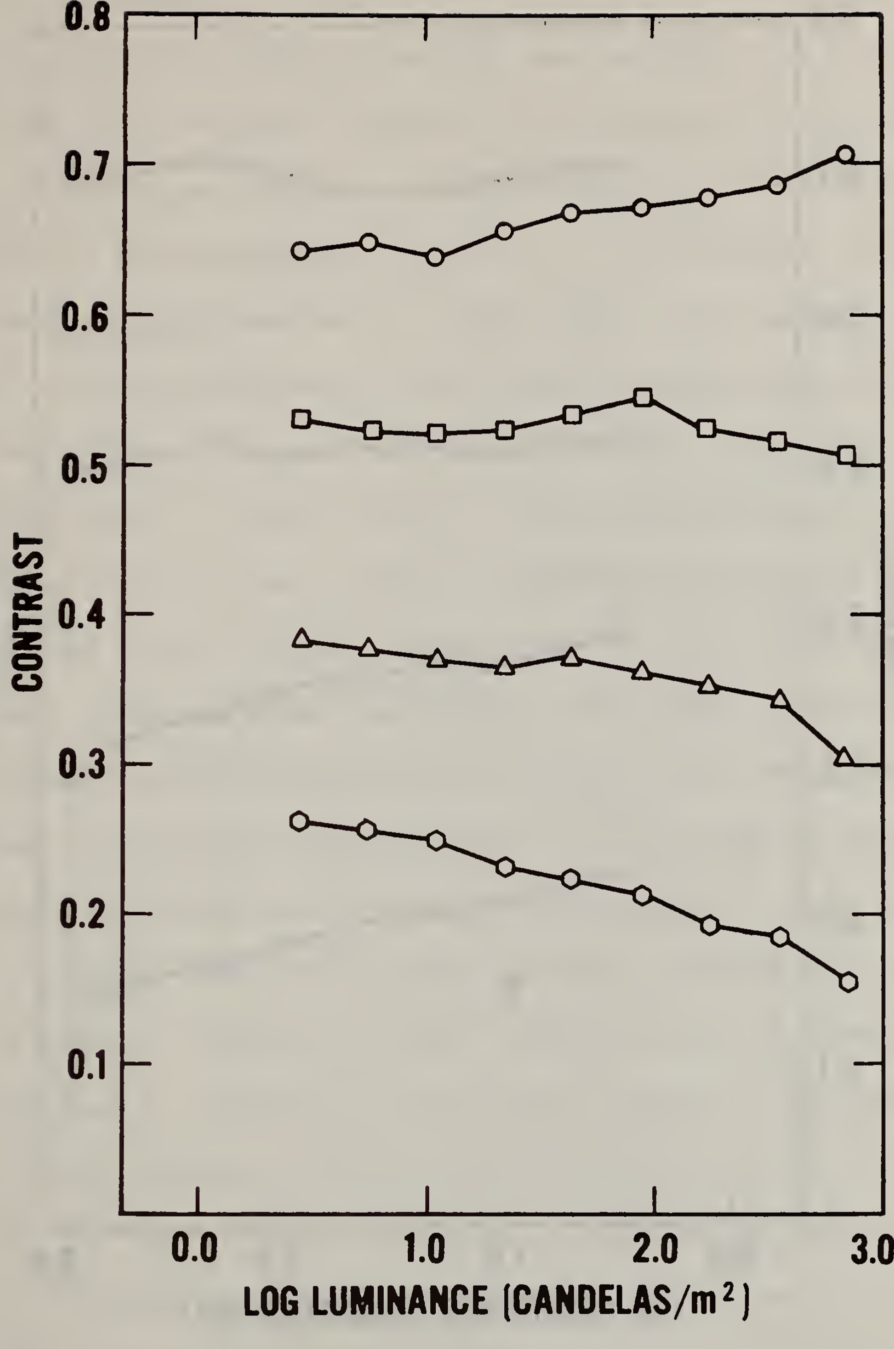

Figure 12. Equal apparent contrast contours for letter stimuli. Stroke width = 4.0 min. of visual angle. Data points are averages for nine observers.

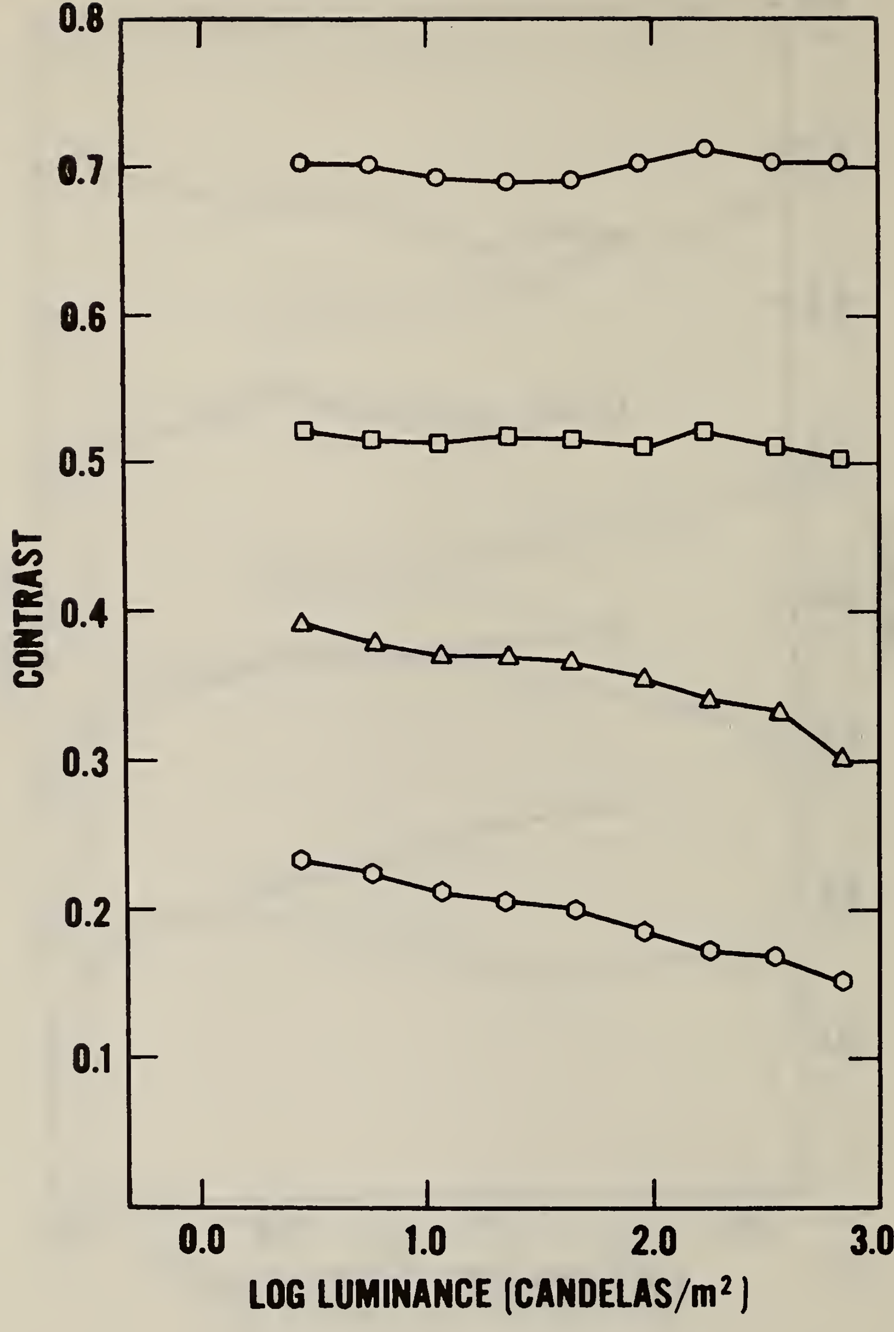

Figure 13. Equal apparent contrast contours for letter stimuli. Stroke width = 3.2 min. of visual angle. Data points are averages for nine observers.

The tendency of workers to evaluate the lighting system by how bright the environment is, rather than by how well they can see, must be considered in lighting level recommendations. But it is not valid to use preferred light levels as the criterion for lighting quality, as preference studies conducted to date have shown that this will result in extraordinarily high levels. The assessment should be made by an open-ended questioning of the workers, that is, the criterion should be complaints received, and not what the workers say they prefer. No indication should be given that it is the light levels which are being investigated. If more than 10% of the workers complain that the light level is too low, it may be considered unacceptable.

Since the levels that most people prefer are significantly above the optimum levels for visual performance, the optimum levels determined from laboratory studies should be used together with the open-ended questionnaires to optimize physiological and psychological aspects of illumination requirements for visual task performance. This compromise may be a level higher than the laboratory determined optimum (beyond which loss of visibility occurs), but lower than the preferred level, and should not lead to rejection of the lighting system as intolerable.

The equal apparent contrast or equal visibility contours describe the effect of luminance on the apparent contrast of the task, but do not provide the information required to determine the apparent contrast that should serve as the standard visibility criterion function. That is, what level of visibility or ease of seeing should be recommended for visual task performance? Obviously, a threshold or near-threshold level criterion will be unsatisfactory, as it assumes working under difficult visual conditions, unless it is only encountered occasionally or is inherent in the task. Conversely, to set the visibility criterion at a high level, although it may be preferable from the worker's point of view, may make meeting the criterion impossible or difficult at best because of economic reasons.

One method for determining what visibility level should be recommended is to experimentally determine the criterion level that will be acceptable to most workers, e.g., 90%. To this end, a preliminary study was conducted using the subjects, lighting system, and stimuli from the Microcopy test chart experiment. At a given luminance level, task contrast was varied and observers were asked to choose the contrast level which they felt would be "just acceptable" for sustained work (reading for four hours). They were also asked to choose the level they felt would be "definitely acceptable". The highest just acceptable contrast level would then serve as the lower boundary and the lowest definitely acceptable level as the upper boundary of the region comprising contrast values that were neither too good nor too poor for sustained visual task performance. That is, assume all observers have chosen their just good enough and definitely good enough contrast levels, and that the spread of the data points is such that all just good enough points lie between a lower level A and an upper level B, and that all definitely good enough points lie between lower level C and upper level D. Further assume that level C is higher in contrast than level B. It is then possible to say that an acceptable contrast level for sustained visual work lies between contrast levels B and C.

The means and standard deviations for the acceptability experiments are given in Table 1. If we assume that the extreme upper and lower 10% of the subjects, respectively, were either overly demanding or understating needs, for reasons other than visual goodness of the task, the range of values remaining will be the mean plus and minus 1.28 times the standard deviation. By making this a one-tailed test, mean plus 1.28 standard deviations for the just acceptable and mean minus 1.28 standard deviations for the definitely, we include 90% of the population. The region where the just and definitely acceptable bars do not overlap would represent contrast values that are acceptable, that is, not too good nor what would be called a poor or low visibility task for 90% of the sampled population.

The results are presented in Figs. 14-16. None of the pairs of bars presented in these figures show a nonoverlap region. These results indicate that there are large differences among observers' evaluations of "goodness of task" required for sustained visual work. What is considered "definitely acceptable" by some observers may be considered less than "just acceptable" by others. The large overlapping of just and definitely acceptable goodness of seeing <u>between</u> observers may be due to psychological (subjective) factors that differ from observer to observer. Rather than relying on impression of acceptability, a measure more directly assessing contrast sensitivity may lead to less variability between subjects.

Table 1

Mean and Standard Deviation (in parenthesis) of Task Contrasts for Five-bar Grating Stimuli Perceived to be Acceptable for Sustained Reading (N=45)

Line Width (min. of arc)	Just Acceptable Luminance (cd/m^2)			Definitely Acceptable Luminance (cd/m^2)		
	700	88	11	700	88	11
2.4	0.361 (.178)	0.379 (.185)	0.431 (.193)	0.540 (.171)	0.562 (.172)	0.613 (.172)
3.8	0.326 (.169)	0.329 (.169)	0.392 (.184)	0.508 (.169)	0.532 (.172)	0.573 (.166)
6.0	0.293 (.158)	0.307 (.161)	0.356 (.177)	0.486 (.159)	0.507 (.174)	0.556 (.172)

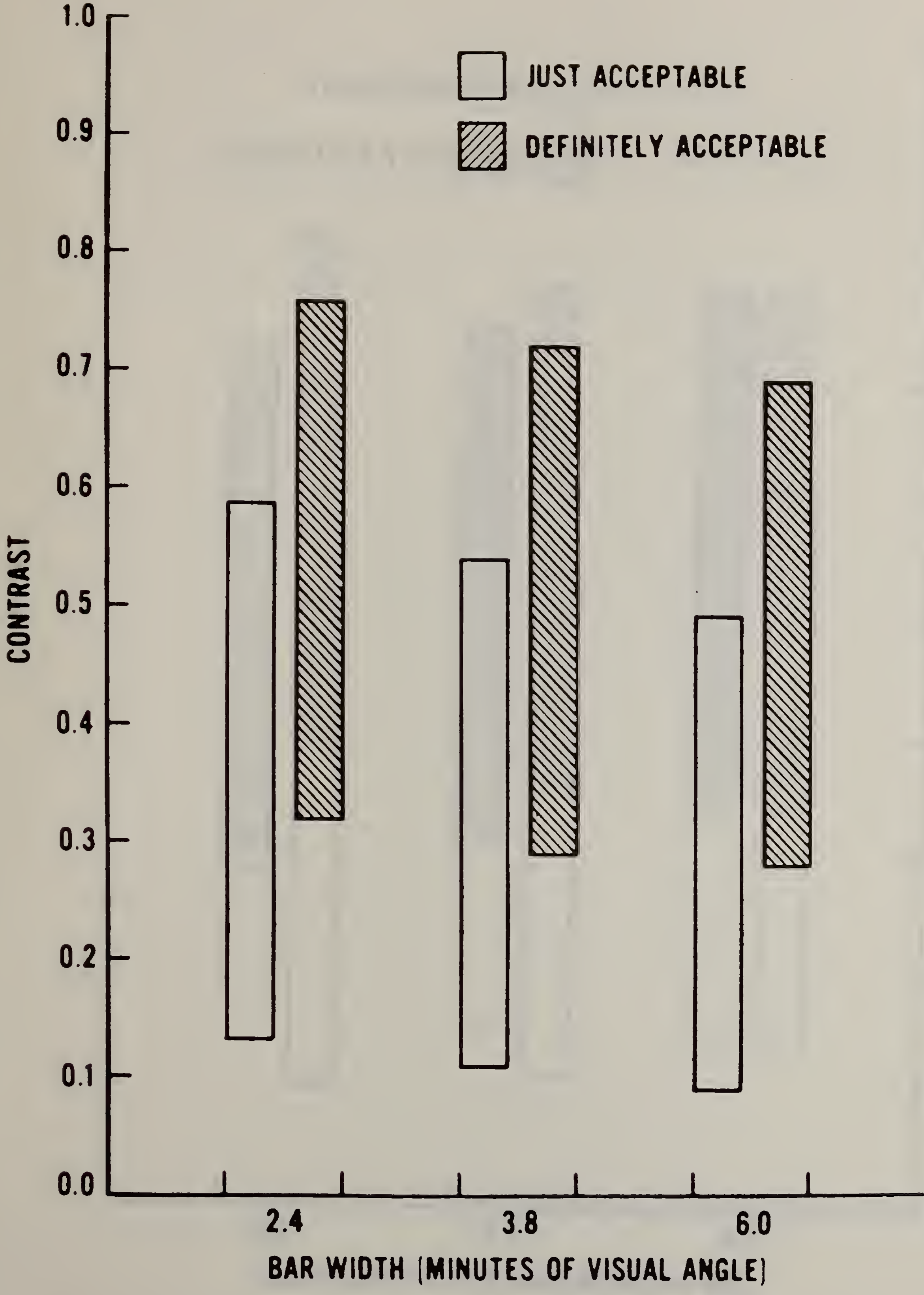

Figure 14. Ranges of contrasts judged "just acceptable" and "definitely acceptable" for sustained reading. Five-bar grating pattern stimuli at luminance of 700 candelas/m^2.

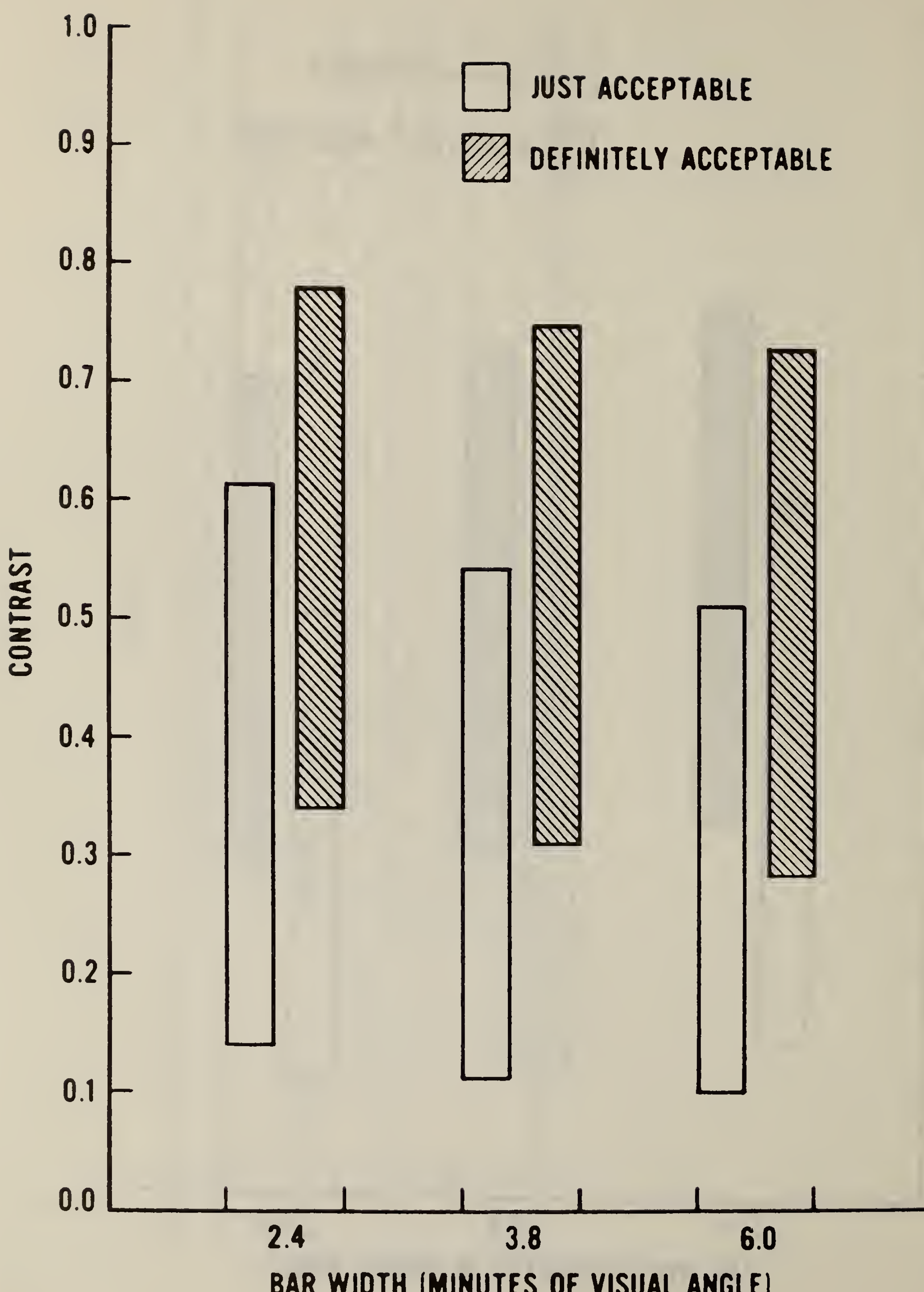

Figure 15. Ranges of contrasts judged "just acceptable" and "definitely acceptable" for sustained reading. Five-bar grating pattern stimuli at luminance of 88 candelas/m^2.

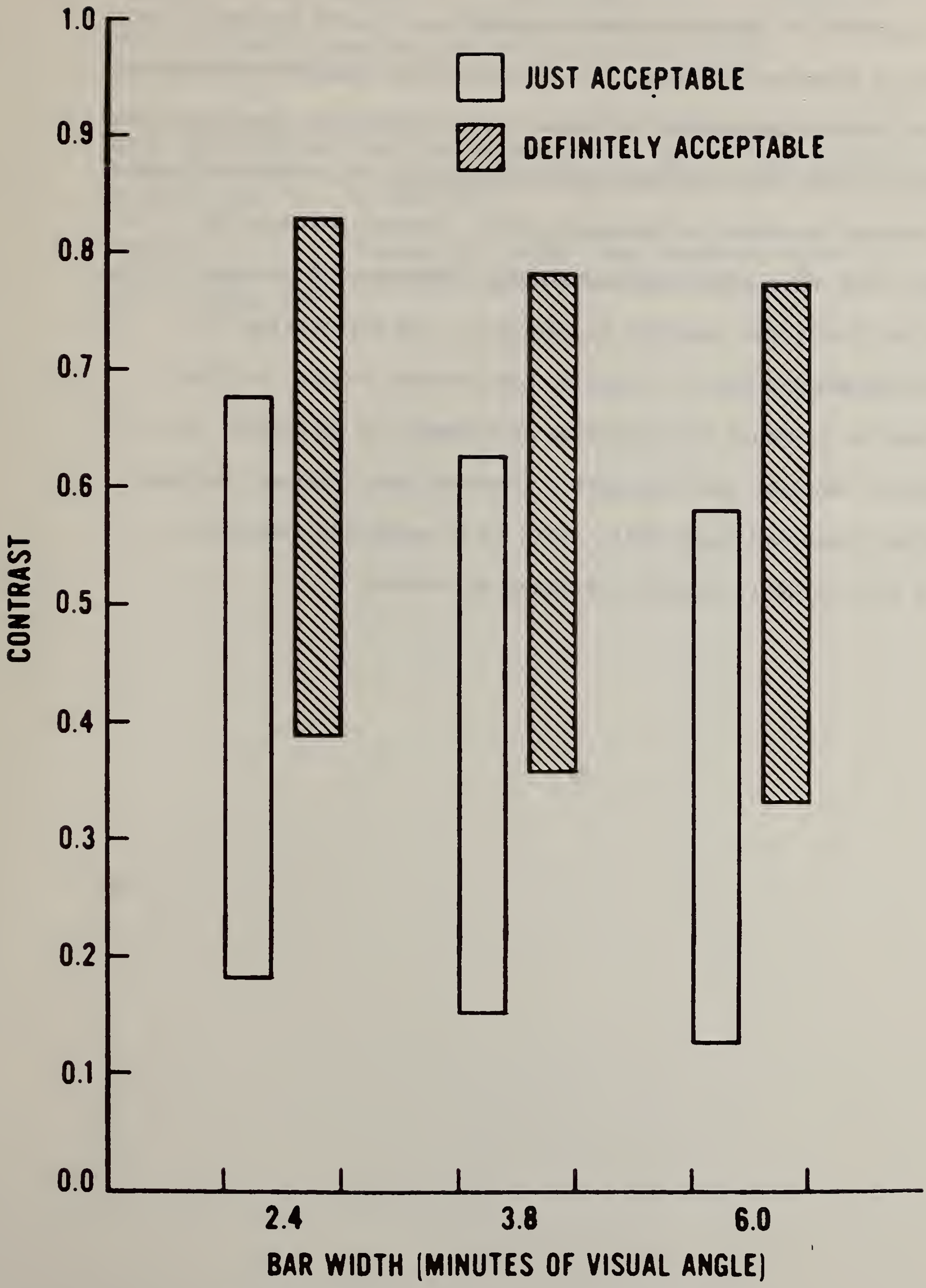

Figure 16. Ranges of contrasts judged "just acceptable" and "definitely acceptable" for sustained reading. Five-bar grating pattern stimuli at luminance of 11 candelas/m^2.

We are proposing to use a method in which response variability within observers as opposed to between observers is used as the indicator of goodness of seeing. It is known that response variability increases as discriminability decreases. For example, in matching two fields so that they are identical in all respects, the variability in the matches increases as luminance and/or angular subtense is decreased (3). At a given luminance level, matches will be made between two fields for equality in contrast. The expectation is that the variability will be large at low contrast levels, and that variability of response will decrease as contrast is increased. A variance vs. contrast plot may give a function with a natural division between the lower and upper half. This is an empirical question, and will have to await further experimental studies.

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APPENDIX A

INSTRUCTIONS

THIS IS AN EXPERIMENT ON CONTRAST, THAT IS, HOW WELL DETAILS STAND OUT AGAINST THEIR BACKGROUNDS. YOU WILL BE SHOWN TWO CHARTS, SIDE BY SIDE, THAT ARE DIFFERENT. YOUR TASK WILL BE TO REPLACE ONE OF THESE CHARTS UNTIL YOU FIND ONE WHICH HAS THE SAME CONTRAST AS THE OTHER CHART.

(Experimenter puts in card #1, 1.4 size, on subject's left and #2 on subject's right)

NOW LOOK AT THE MIDDLE HORIZONTAL DARK BAR OF THE 1.4 GROUP ON THE LEFT CHART. THEN LOOK AT THE SAME BAR ON THE RIGHT CHART. NOTICE THAT THE BAR ON THE RIGHT CHART HAS MORE CONTRAST, THAT IS, IT STANDS OUT FROM ITS BACKGROUND BETTER THAN THE BAR ON THE LEFT CHART. WHENEVER THIS HAPPENS, SAY "LESS" AND I WILL REPLACE THE RIGHT CHART WITH ONE THAT HAS LESS CONTRAST.

ON THE OTHER HAND, THE RIGHT CHART MAY LOOK MORE LIKE THIS.

(Experimenter takes out card #2, puts in #3)

NOW THE MIDDLE BAR ON THE RIGHT CHART DOES NOT STAND OUT FROM ITS BACKGROUND AS WELL AS THE BAR ON THE LEFT CHART DOES. WHEN THIS HAPPENS, SAY "MORE" AND I WILL REPLACE THE RIGHT CHART WITH ONE THAT HAS MORE CONTRAST.

(Experimenter takes out card #3, puts in #4)

HERE IS A CHART WHOSE CONTRAST IS CLOSER TO THAT OF THE OTHER CHART. IF IT HAD A LITTLE MORE OR LESS CONTRAST, IT MIGHT BE EQUAL IN CONTRAST TO THE OTHER CHART. WHEN YOU ARE SATISFIED THAT THE TWO BARS HAVE THE SAME CONTRAST, SAY "EQUAL".

HERE ARE 2 CARDS THAT HAVE THE SAME CONTRAST. NOTICE THAT THEY DIFFER IN DARKNESS AS WELL. WE WANT YOU TO MAKE YOUR MATCHES ON THE BASIS OF HOW WELL THE ITEM STANDS OUT FROM THE BACKGROUND, NOT ON THE BASIS OF DARKNESS.

YOU SHOULD ATTEND TO THE RATIO OF EACH CARD, NOT THE TOTAL DARKNESS.

THERE IS NO TIME LIMIT NOR RESTRICTION ON THE NUMBER OF CHARTS YOU MAY ASK FOR. YOU MAY LOOK AT THE SAME CHART MORE THAN ONCE. YOU SHOULD LOOK AT CHARTS WHICH ARE BOTH HIGHER AND LOWER IN CONTRAST THAN THE ONE YOU ULTIMATELY SELECT. DOUBLE-CHECK YOUR SELECTION BEFORE YOU SAY "EQUAL". USE MORE TIME FOR YOUR FINAL SELECTION.

DO YOU HAVE ANY QUESTIONS?

LET'S TRY AN EXAMPLE.

(Experimenter replaces cards #1 and #4 with randomly selected light and dark background cards from the 1.4 series. Subject makes a match.)

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15. SUPPLEMENTARY NOTES
This report summarizes the results of laboratory research related to task lighting conducted by the University of Virginia, Dept. of Psychology, through a grant to the Illuminating Engineering Research Institute by an NBS grant.

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The report discusses the results of laboratory studies on equal conspicuity (contrast) contours using as the test stimuli five-bar grating patterns, with the results of other experiments in this series conducted by NBS. These results are in agreement with the earlier studies. Basic groundwork is provided for additional experiments and analysis which will form a practical basis for recommending energy-conserving design illumination levels that conform to real-world office activities.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*
Conspicuity; contrast; energy conservation; illumination; illumination levels; lighting; suprathreshold seeing; visibility; vision.

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