Shifts in perception of size after adaption to gratings.

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SHIFTS IN PERCEPTION OF SIZE AFTER ADAPTATION TO GRATINGS

A Thesis Presented

By

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INTRODUCTION

Fourier theory has been used to describe the transmission of spatial information through the visual system for more than 25 years (Schade, 1948). The discovery of cortical neurons selectively responsive to a band of spatial frequencies and orientations led to the hypothesis that these neural units are channels carrying sine wave frequency information (Campbell, Cooper, and Enroth-Cugell, 1969; Campbell, Cooper, Robson, and Sachs, 1969). According to the hypothesis, the pattern of excited channels constitutes a frequency code of the spatial content of the visual world (Campbell and Robson, 1968). A basic psychophysical technique employed in studies testing this hypothesis has been adaptation of one of these independent channels and examination for change in detection threshold as a function of frequency or for change in perceived frequency of grating patterns (e.g. Campbell and Robson, 1968; Blakemore and Campbell, 1969; Blakemore and Sutton, 1969; Blakemore, Nachmias, and Sutton, 1970; Graham and Nachmias, 1971). With some exceptions (Campbell, Carpenter, and Levinson, 1968; Weisstein and Bisaha, 1972), these studies have typically employed stimuli having a repetitive luminance distribution, such as a sine wave grating, because it is a primitive in the Fourier space, in that it contains only one spatial frequency, and in only one dimension.

Of particular relevance to the present experiment is prior work which has shown perceived frequency shifts using gratings as both adapting and test objects. Figure 1 is a copy of the Blakemore and Sutton (1969) demonstration of the perceived frequency shift in patterns containing a single spatial frequency. Blakemore, Nachmias, and Sutton (1970) quantified the perceived spatial frequency shift using sine wave gratings, although Figure 1 is composed of square wave gratings.

Adaptation to a sine wave grating produces shifts in perceived frequency of gratings of frequencies near that of the adapting grating. After adaptation, gratings of higher frequency, at the upper right in Figure 1, appear to have a still higher frequency, while gratings of lower frequency, at the lower right of the figure, appear still lower in frequency. Thus, adaptation tends to make gratings appear more different from the adapting frequency than they really are.

Despite apparently strong evidence for frequency specific channels, a space domain model based on neural bar detecting units can account remarkably well for much of the experimental data collected in testing the frequency channels hypothesis. In particular, the perceived frequency shift obtained after adaptation (Blakemore, Nachmias, and Sutton, 1970) is equally consistent with space demain models (Macleod and Rosenfeld, 1974). The Blakemore and Sutton aftereffect (1969) may also be described in terms of size mechanisms as

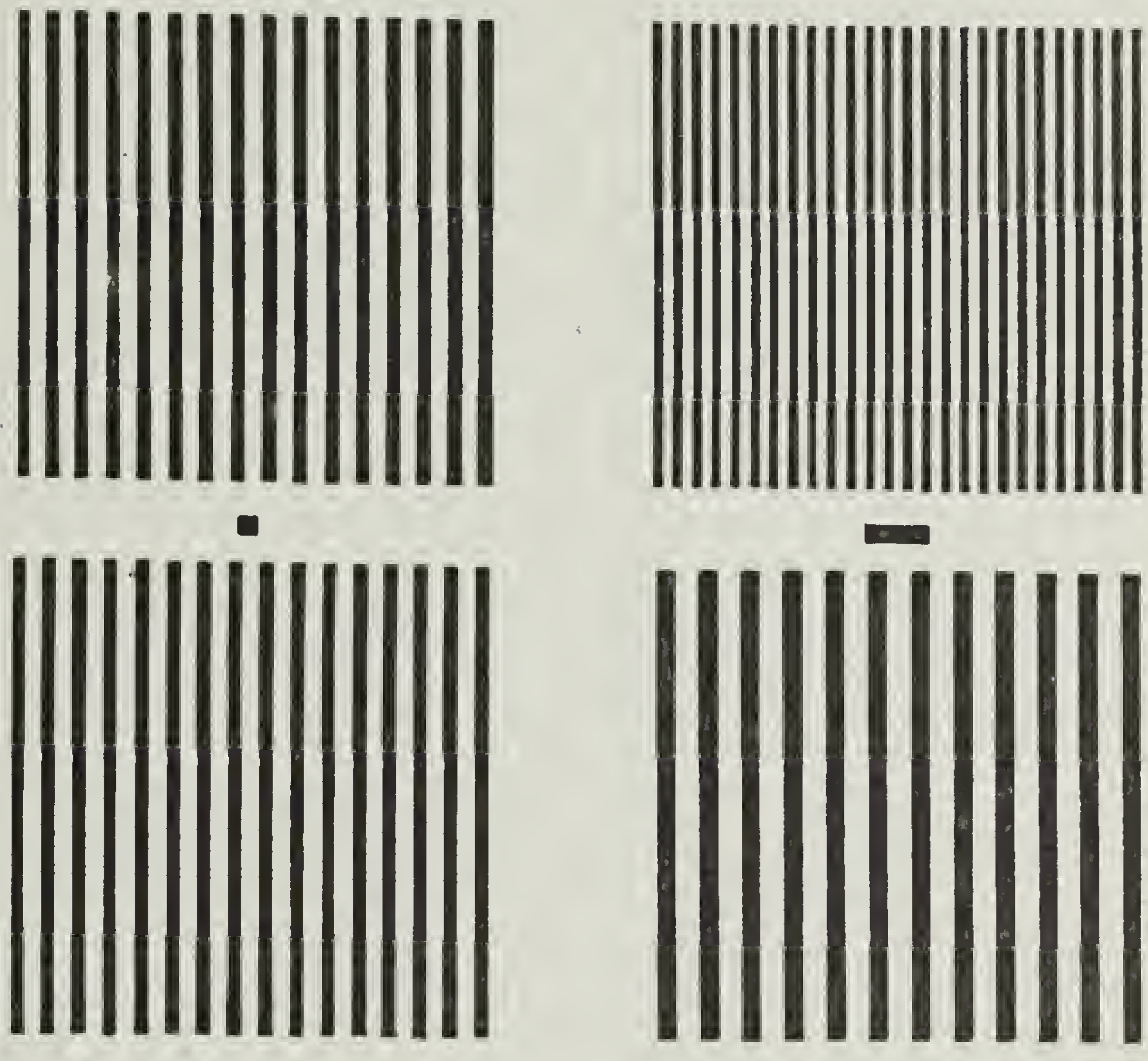

Figure 1

well as frequency mechanisms: after adaptation, bars that are smaller than adapting bars appear smaller still, while larger bars appear even larger. There is no significant size aftereffect at the adapting size itself, although of course there is a reduction in sensitivity at that size. In addition, the Blakemore and Sutton (1969) aftereffect has some of the properties associated with the older Gestalt concepts of figural aftereffects (Koehler and Wallach, 1944).

Since frequency and period are simply inverses of each other, when sine wave grating patterns are used as stimuli, frequency and size have a perfect correlation. This relationship obviously does not hold for single objects which have a continuous multiple frequency spectrum. Therefore, the use of single objects as stimuli might allow for differential predictions of size and frequency models. Moreover, a single object has a luminance distribution which varies in more than one spatial dimension, as does the visual array of the real world.

This experiment used size judgments of a single object both before and after adaptation to a sine wave grating. Figure 2 shows the stimulus object. This rectangle, although it is familiar and appears simple, is quite complex in the Fourier domain. This object has a continuous frequency spectral distribution. In both the horizontal and vertical dimension, this spectral distribution may be described by the function sin x/x, as illustrated in Figure 2.

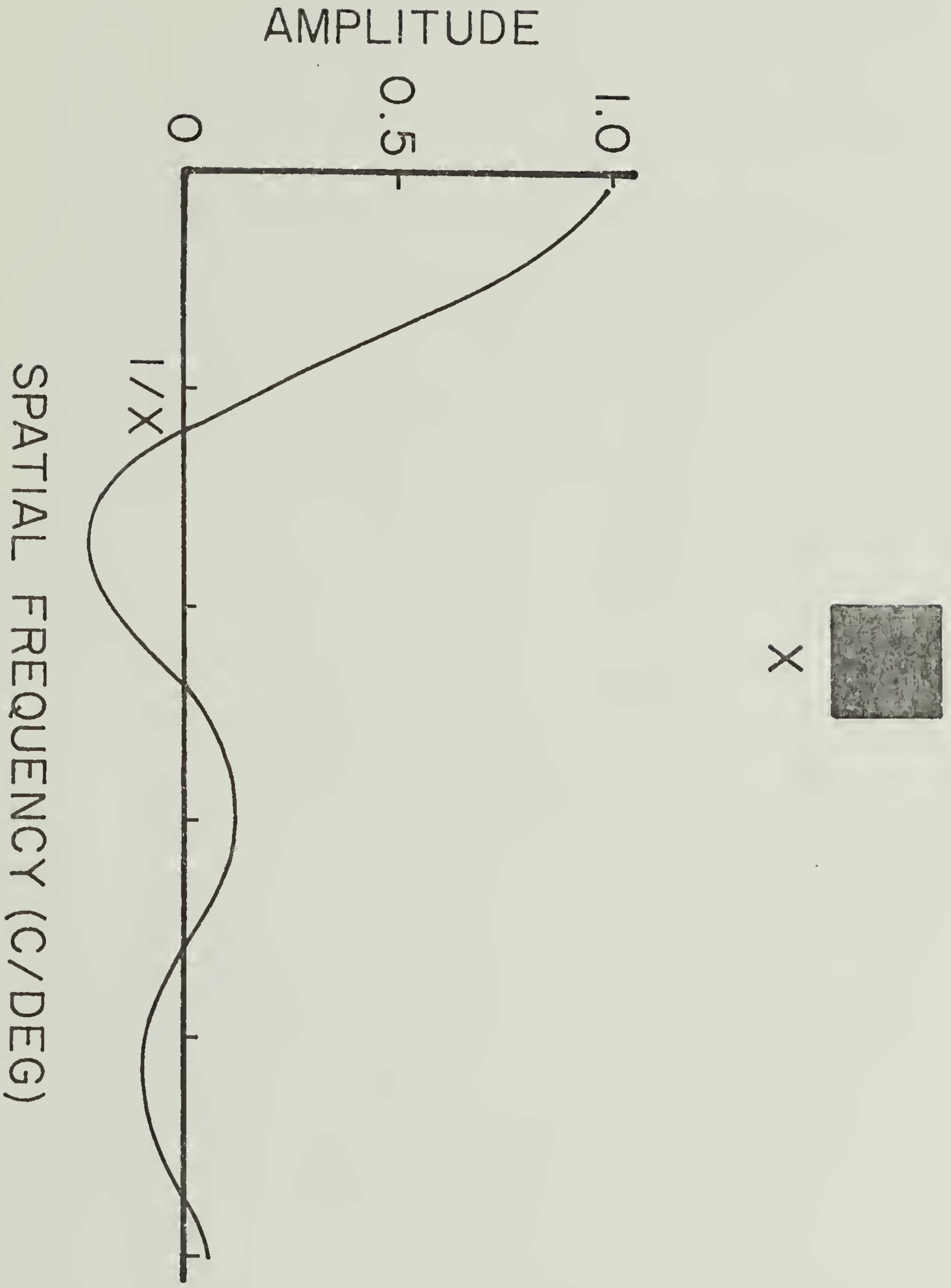

Figure 2

According to the frequency channels hypothesis, by appropriately choosing the widths of the bars of the adapting grating and of the test stimulus rectangles, it would be possible to induce shifts in the signals from neurons which contribute to the perception of size. Adaptation to a grating depresses the sensitivity of those neural elements that respond to the adapting grating. After adaptation there would be a change in the neural response distribution--neural responses at frequencies lower than the adapting frequency are those which in an unadapted visual system would result from a wider (lower frequency) target. Similarly, induced neural responses at higher frequencies mimic the response of an unadapted visual system to an even narrower (higher frequency) target than that presented to the adapted visual system. If the perception of size is signalled by either the mode or other measure of central tendency of the responses in frequency selective channels, as suggested by Blakemore _et_ _al_. (1970), this should be revealed by the data of the present experiment. However, if the perceived spatial frequency shifts obtained by those authors is merely another example of contour repulsion, the results of the perceived size of a single rectangle after adaptation to a grating should not differ significantly from results with a test grating whose bars are the same width as the test rectangles used in this experiment. What kind of size aftereffect will result after adaptation to a sine wave grating and then looking at a rectangle? Prior to empirical test we cannot predict the percept.

METHODS

Subjects

There were five subjects who made observations at the University of Maryland and another two made observations in a similar experiment at the University of Massachusetts. When necessary, observers wore glasses to bring them to 20:20 vision by the Snellen test.

Apparatus and Procedure

Figure 3 shows the stimuli used. (Square wave gratings are shown in the figure, but sinusoidal gratings were used in the experiments.) Three high contrast sine wave adapting gratings of different spatial frequencies were used--3, 4, and 6 c/deg. These were chosen because they are in the region of maximal sensitivity of the visual system and have shown large magnitude adaptation effects. The gratings were used in both horizontal and vertical orientations. Every adapting grating was used with each test stimulus.

Test stimuli were three solid luminous rectangles of variable height and fixed width--5, 7.5, and 10 min arc. In most cases the observer's task was to adjust the vertical dimension of the rectangle so as to make the figure look square (n=11). In some cases, observers were asked to identify a

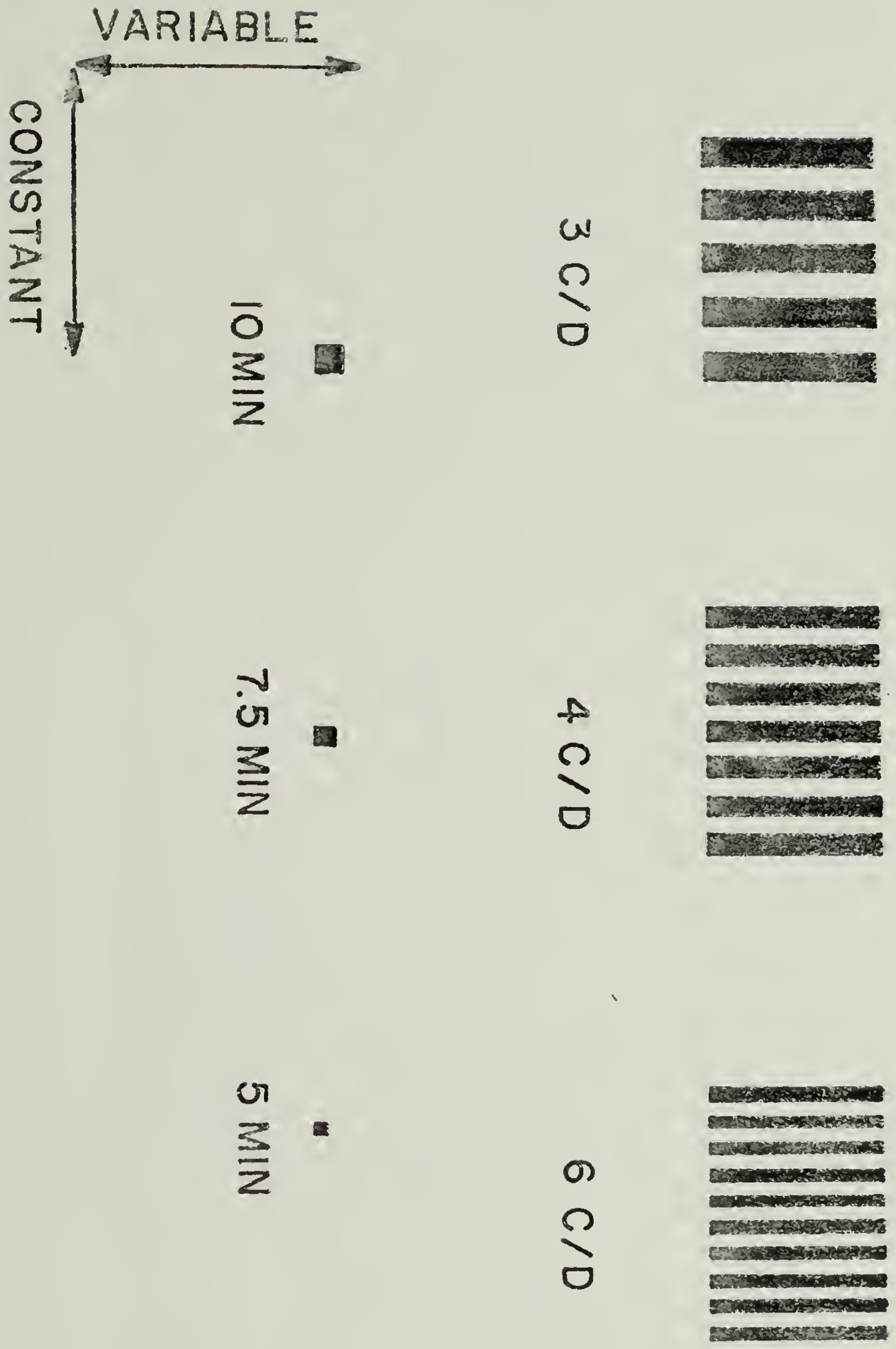

Figure 3

square in a series of rectangles presented in a random, double staircase order (Cornsweet, 1962). There were approximately 50 reversals over the 200 trials.

Each experimental session consisted of a control condition with a homogeneous adapting field, a 10 minute rest period, and the grating adaptation condition. The homogeneous field in the control condition was of the same average luminance as the grating field. The initial adaptation in both the control and grating adaptation was 5 minutes long. During adaptation, the observer scanned the field in the direction orthogonal to the bars of the grating being used. This scanning was an attempt to avoid the formation of an afterimage. After the initial adaptation there was a judgment of the vertical size needed for perceived squareness. Each judgment of squareness required only a few seconds. After each judgment there were 15 seconds of re-adaptation. These adaptation periods were chosen to maintain adaptation at a maximum level in accordance with the findings of Blakemore and Campbell (1969). A practice session for which no results were analyzed was conducted first in order to acquaint the observers with the task. Each observer completed only one experimental session per day.

The experimental set up is shown in Figure 4. The rectangles were electronically generated on a cathode ray tube equipped with a P-31 phosphor. The equipment was masked so that the screen of the CRT was seen through a circular aper-

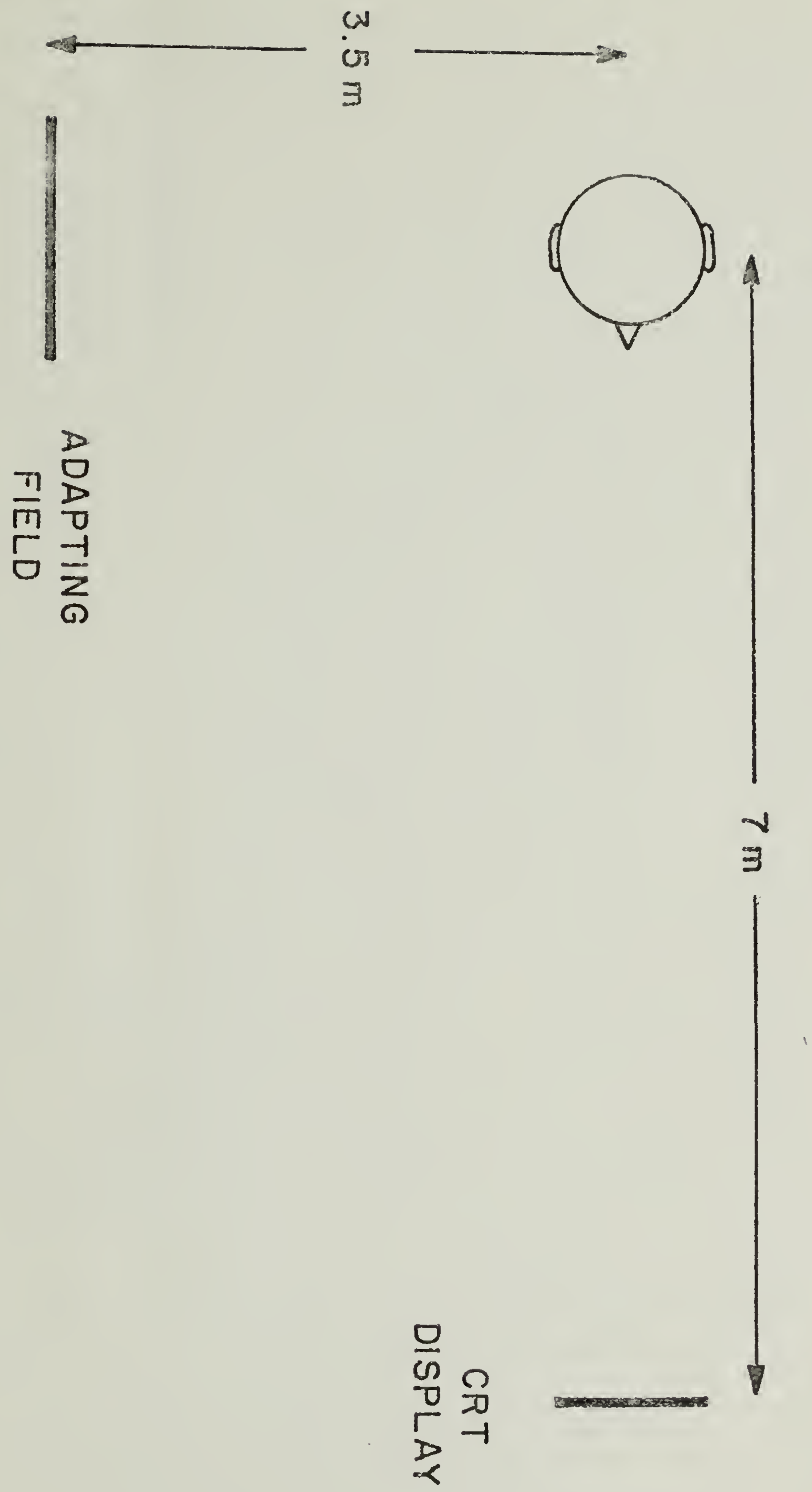

Figure 4

ture cut in a large surround. The observer viewed the rectangle while positioned in a chinrest at a distance of 7 m. The adapting gratings were 35 mm slides projected on a screen at 3.5 m from the observer. The adapting field subtended 6 x 6 deg arc in some experiments and 15 x 20 deg arc in others. The screen was oriented at right angles to the CRT, so that the observer turned 90 degrees during adaptation.

Some procedural variables were changed with no apparent effect on the results. These variables include changes in stimulus contrasts (sine wave grating contrasts were 37.5% in some experiments and 60% in others), room illumination, a change from monocular to binocular viewing, and the use of both paid naive observers and highly trained psychophysical observers. As a control for order effects, experimental sessions were run with two observers in which both adaptation conditions were two average luminance fields.

RESULTS

Figure 5 shows individual subject data for the combinations of adapting gratings and rectangle widths described above. Individual standard error was no larger than the extent of a plotted point for all observers. Figure 6 shows the average for all observers' data with the standard error of the mean between subjects indicated for each data point. The abscissa in these figures is the ratio of adapting grat-

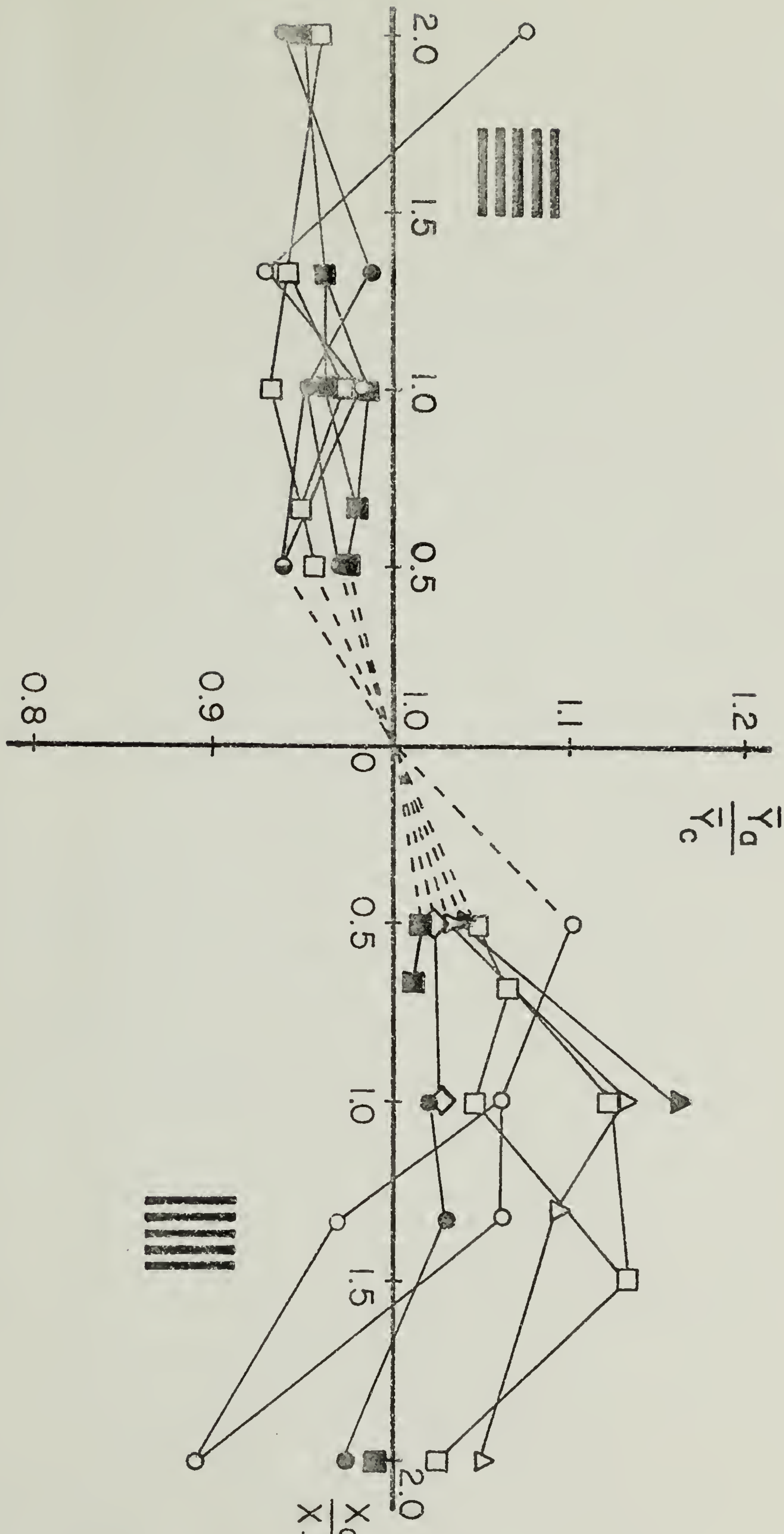

Figure 5

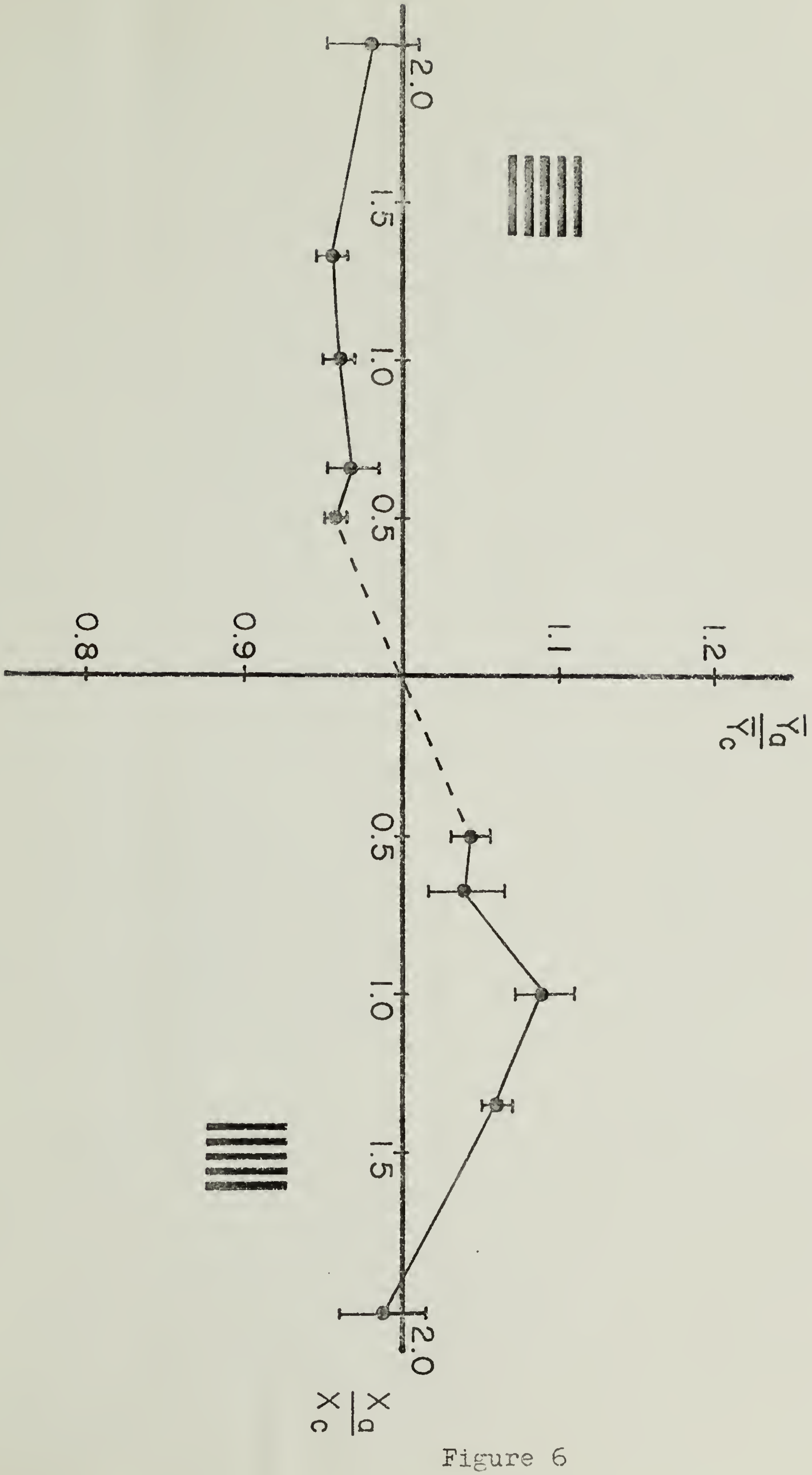

Figure 6

ing bar widths to test rectangle widths. Each ordinate point is the ratio of the mean vertical extent needed for perceived squareness after grating adaptation to the mean vertical extent needed for squareness before grating adaptation. The right side of Figures 5 and 6 illustrate the results obtained when adapting with vertically oriented grating bars, and the left sides illustrate results obtained when horizontally oriented adapting grating bars were used.

For nearly all width ratios, the rectangle appeared broader on the dimension orthogonal to the bars of the grating. In other words, for vertically oriented adapting bars, the rectangle appeared wider; a greater vertical extent was required for perceived squareness. With horizontally oriented adapting bars, the rectangle appeared taller; less vertical extent was required for the figure to be perceived as square. No statistically significant differences were found between aftereffects with horizontal and vertical bars when means for all subjects who ran in both horizontal and vertical adapting conditions were computed.

Note that an abscissa value of 1.0 represents the condition in which the rectangle width and the width of a single bar in the grating are equal. This is where th largest effect was obtained, whereas, the prior work of Blakemore _et al._ (1970) found no size aftereffect when adapting and test bars were of equal size.

The obtained data extend only as far as a grating bar to rectangle width ratio of 2.0. This ratio was obtained only with the smallest usable rectangle of 5 min arc width. The data points at this ratio indicate a trend away from the increased perceived size. This trend cannot be due to failure of adaptation at 3 c/deg because the same adapting frequency when used with a 10 min arc rectangle resulted in one of the largest shifts in the increasing direction.

The data obtained for the smallest bar to rectangle ratio have been joined with the origin. This may be considered a real value since grating bars of extremely high spatial frequency are perceived as a homogeneous average luminance field. In the control sessions in which both adaptation conditions were to average luminance fields, the ratio of the mean values of these successive average luminance adaptations was 1.0 for both subjects who participated.

DISCUSSION

Figure 7 shows the quantitative results obtained by Blakemore <u>et al</u>. (1970) with sine wave gratings as both adapting and test stimuli. These results are dramatically different from the present experiment in which a rectangle was used as a test stimulus. The abscissa is the ratio of adapting grating bar widths to test bar widths. Ordinate values greater than 1 indicate apparent widening after adaptation. Ordinate values less than 1 indicate apparent narrowing after

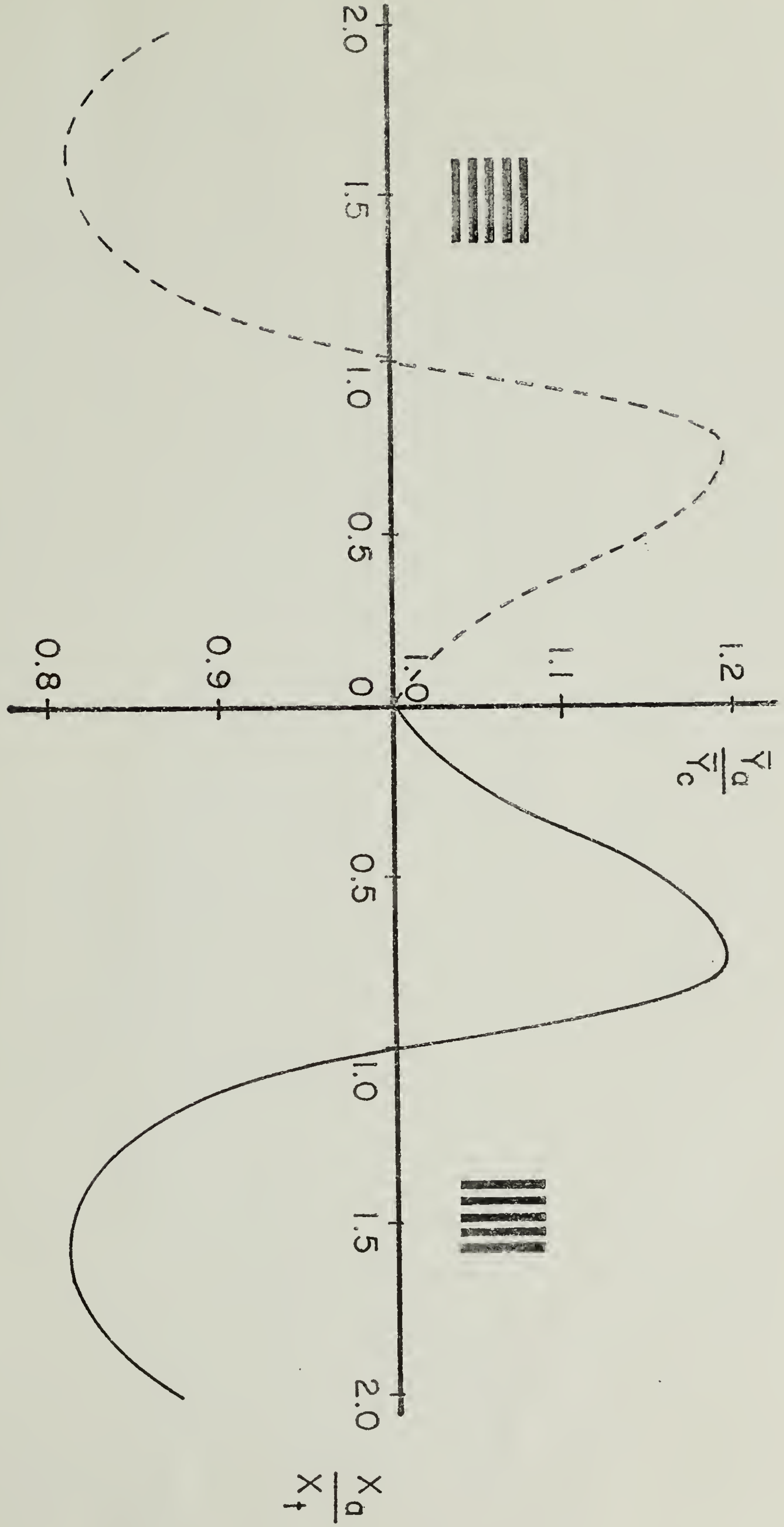

Figure 7

adaptation. These authors' results were obtained only with vertically oriented gratings. If similar results had been obtained with horizontally oriented gratings, they would be represented by the dashed curve on the left in the figure.

It should be noted that when adapting and test bars were equal, as indicated by an abscissa value of 1.0, there is no size shift. When the test bars were wider than the adapting bars, they looked wider still. When the test bars were narrower than the adapting bars, they appeared even narrower. These data were consistent with size aftereffect data.

The size aftereffect data is not consistent with the data of the present experiment. Whereas Blakemore et al. (1970) found no size shift when adapting and test stimuli were equal in width, and symmetric size shifts away from the adapting size, the present results indicate a maximum size shift when adapting and test stimulus widths are equal, with apparent widening to both broader and narrower rectangles. These obvious differences in results between a sinusoidal grating and a single square as test figures may be resolved by use of the frequency model.

It has been found that adaptation to a single spatial frequency reduces sensitivity maximally at that frequency with noticeable reduction even an octave away. Blakemore et al. (1970) describe the consequences of the reduction in sensitivity by assuming that frequency selective neurons form frequency channels and that the stimulus size is coded by the distribution of activity in these channels. Adaptation introduces a change in the central tendency of the distribution which shifts the perception away from the most adapted region. This shift produces a more complicated situation in the interpretation of this data than in that of Blakemore *et al.* (1970) because of the multiple-frequency spectral distribution in the stimuli. Figure 8 shows the frequency components in the vertical dimension of the three rectangles, described by the function sin x/x. The arrows indicate the adapting frequencies that were used. The open arrows indicate frequencies for which grating bar width was equal to test rectangle width.

For an object, like a rectangle, with a broad frequency spectrum, adaptation to a single frequency will reduce the sensitivity of those neurons near the frequency of the adapting frequency. One may think of this as producing shifts in the central tendency of the neural response distribution on both sides of the adapting frequency away from the adapting frequency, since the relative contribution of frequencies near the adapting frequency is less. If we ask which of these opposing shifts agree with the perceived size of the object, the data answer--it is the lower one, since lower frequencies are correlated with larger sizes. Presumably the perceived size of the object will be determined by where the predominant part of the effective frequency spectrum falls. For example, if a 6 c/deg adapting grating is used with a 10

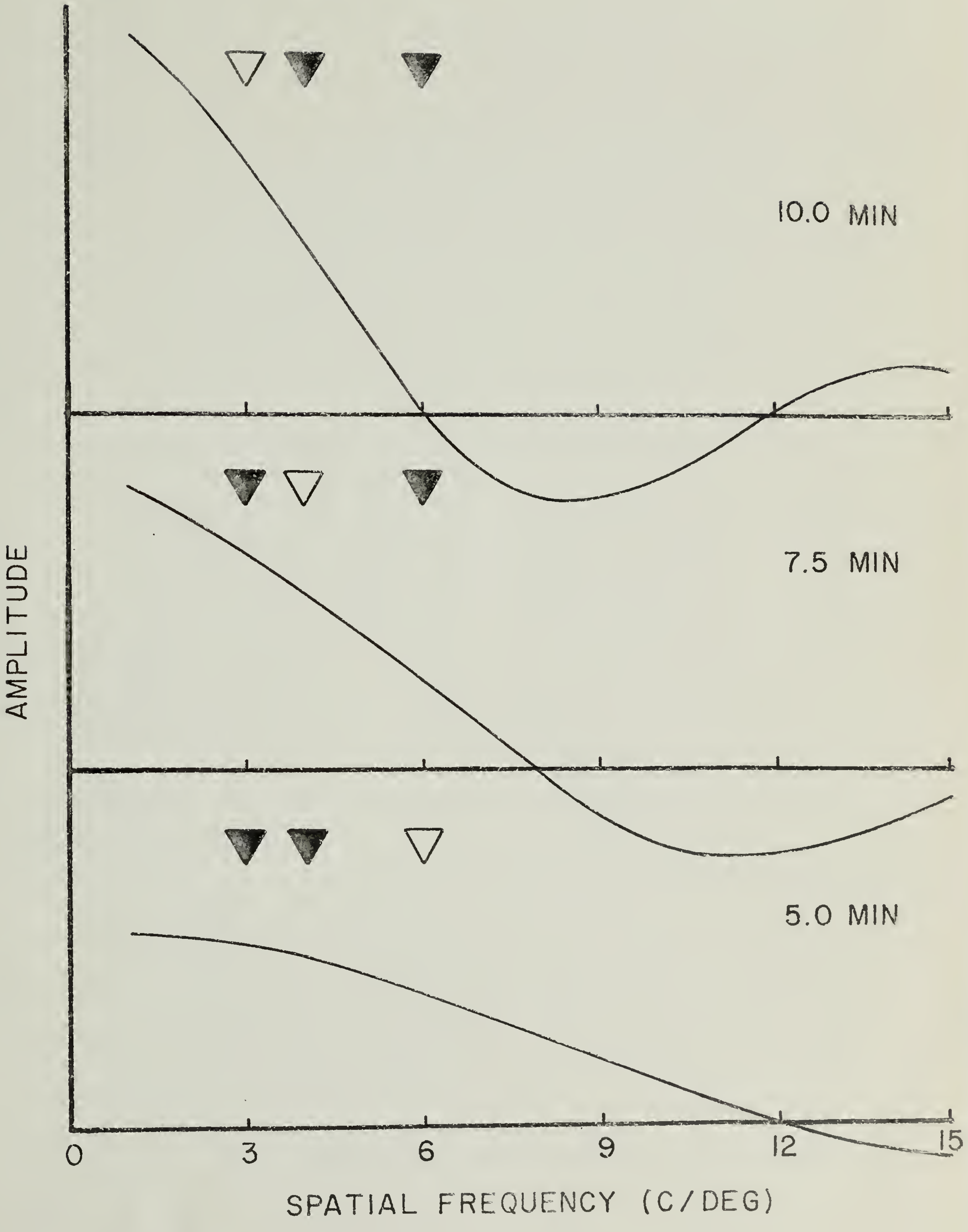
10.0 MIN
7.5 MIN
5.0 MIN
AMPLITUDE
0
3
6
9
12
15
SPATIAL FREQUENCY (C/DEG)

Figure 8

min arc rectangle, the adaptation is centered at a frequency where there is no energy in the rectangle. Nevertheless, a size increase is found. That is, it is the adaptation effect on the part of the frequency spectrum with the largest amplitudes which is perceptually significant. While most of the results may be interpreted as a dominance by the shift to lower frequencies, if adaptation to sufficiently low frequency gratings were possible, one would expect size perception dominated by shifts toward higher frequencies as well, that is, a reduction rather than enlargement of apparent size. Some of the data, at grating bar to rectangle width of ratio 2.0, do show a trend in this direction of reduced perceived size. An interpretation of this reduced size shift with a 5 min arc rectangle and a 3 c/deg grating is possible in terms of shifts in frequency channel responses to higher and lower frequencies. Adaptation to 3 c/deg produces shifts in the 5 min arc rectangle response distribution which are equally effective; that is, they balance each other and leave the perceived size of the square unaffected.

In conclusion, the results are not consistent with a size aftereffect explanation. However, the frequency channel mechanisms that Blakemore _et al_ (1970) suggest for the encoding and perception of the size of patterns having a single spatial frequency could also be involved in the encoding of size information of a single object having a multiple frequency spectrum.

Summary Abstract

Subjects were asked to identify the square in a series of solid luminous rectangles before and after adaptation to sinusoidal gratings. Both horizontal and vertical gratings were used. Adaptation to a grating produced an apparent enlargement of the rectangles on the dimension orthogonal to the bars of the grating. This effect was found when a single grating bar was narrower, equal in size, or wider than the rectangle. Blakemore _et al_. have shown that adaptation to a sine wave grating produces shifts in the perceived frequency of gratings of similar frequency to that of the adapting grating. The shift in perceived frequency is away from the adapting frequency. This finding suggests that the size encoding mechanisms these authors proposed for patterns having a single spatial frequency could be involved in the encoding of size information in patterns having a multiple frequency spectrum. That the gratings always led to apparent widening of the rectangles may be attributed to the preponderance of effective stimulus energy at frequencies lower than those of the set of gratings used.

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