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ALTERATIONS IN THE PERCEIVED SIZES OF PLANE FIGURES AS A FUNCTION OF BINOCULAR DISPARITY

by

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ABSTRACT

ALTERATIONS IN THE PERCEIVED SIZES OF PLANE FIGURES

AS A FUNCTION OF BINOCULAR DISPARITY

by

Carl Cay Semmelroth

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When figures are viewed stereoscopically and their binocular retinal disparity is varied their perceived sizes change (micropsia-macropsia) as well as their apparent depth (stereopsis). This paper contains a quantification of the relationship between binocular disparity and perceived size for several shapes and sizes of plane figures. This relationship is found to be different for circles than for straight lines and squares. Binocular disparity was also found to have an effect on perceived size over and above the effect which would be predicted on the basis of fusional convergence alone. In a separate experiment, the effect of binocular disparity on apparent depth is found to be the same for circles, straight lines and squares. A staging of the sensory transformation of retinal size, oculomotor effects and the effect of apparent distance is hypothesized. The results are then seen as consonant with data of Stevens and others that indicate that the psychophysical function relating physical and perceived magnitude is different for line length and circle area.

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CHAPTER I

INTRODUCTION

The determinants of visually perceived size may be grouped into three types: 1) the size and shape of the retinal image, 2) the apparent distance of the object, and 3) oculomotor cues, i.e., convergence and accommodation. The size of the retinal image is ordinarily assumed to be constant, given a constant visual angle. This assumption is not quite true given changes in accommodation and for other reasons (see Appendix I). However, it is warranted for the conditions of the studies reported here. Hence, the present attempt to reconstruct the sequence of events which constitute size perception will start with a linear size transformation between object size (visual angle) and retinal size. Thus, we may study the relation between perceived size and retinal size in a scaling experiment in which the object size is varied and in which the effect of apparent distance and oculomotor cues are kept constant.

When this scaling experiment is done, the results differ according to whether the stimuli used are two dimensional figures, such as circles or essentially one-dimensional straight lines. Stevens (1957, 1961a, 1961b) presents convincing evidence for the thesis that the relation between perceived and physical magnitude is a power law. Therefore, it is convenient to summarize the results of magnitude estimation studies on length of line and figural area in terms of the exponent of the power function which best fits these data. An exponent of 1.0 means that ratios between physical stimuli are reported veridically by observers, i.e., a line which is physically twice as long as another line is report-

ed twice as long. An exponent which is different from 1.0 means that the ratios between physical stimuli are not reported veridically, i.e., an exponent of 0.5 would mean that a stimulus which is physically 9 times stronger than another stimulus would be reported to be only 3 times ($9^{.5}$) as strong by an observer. In addition an exponent of 1.0 represents a linear relation between physical size and reported size whereas any other exponent represents a departure from linearity.

The power function exponent for length of line has been found to be 1.10 (Stevens, 1957); 1.00 (Teghtsoonian, 1965); .80-1.20 (Kunnapas, 1958); 1.11 (Ekman and Junge, 1961); 1.00 and .97, "longness" and "shortness" respectively (Stevens and Guirao, 1963).

The power function exponent for areas has been found to be .9-1.15 (Stevens, 1957) and .91-1.06 for squares and circles (Ekman and Junge, 1961). However, Teghtsoonian (1965) found an exponent of .76 for circles when observers were asked to estimate "apparent size" while finding an exponent of 1.03 for circles when observers were asked to estimate "objective area". Further, she obtained the same exponent (.81) with either set of instructions (apparent or objective) when stimuli were irregular polygons. The irregular polygons presumably deprived observers of the opportunity to use common linear dimension such as diameter or length of side for making "objective area" estimations.

Since an exponent other than 1.0 represents a nonlinear relationship, the relation between retinal size and perceived size does not appear to be linear, at least for two-dimensional figures with curved (circles) or irregular sides. There may be a linear or near linear relation between length of line and perceived length, although the

effect of segmenting a line on its perceived size may be interpreted to mean the sensory function for straight lines may not be precisely linear either (see Appendix II).

Given the nonlinearity of the relation between retinal size and perceived size, it becomes crucial to order the effects of apparent depth and convergence on perceived size with respect to the sensory transformation. In examining this problem below, we will see that it arises because the sequence of operations, i.e., multiply then raise to some power v.s. raise to some power and then multiply, affects the outcome of the interaction.

Figure 1 shows one hypothetical sequence of events for the interaction of the various determinants of perceived size.

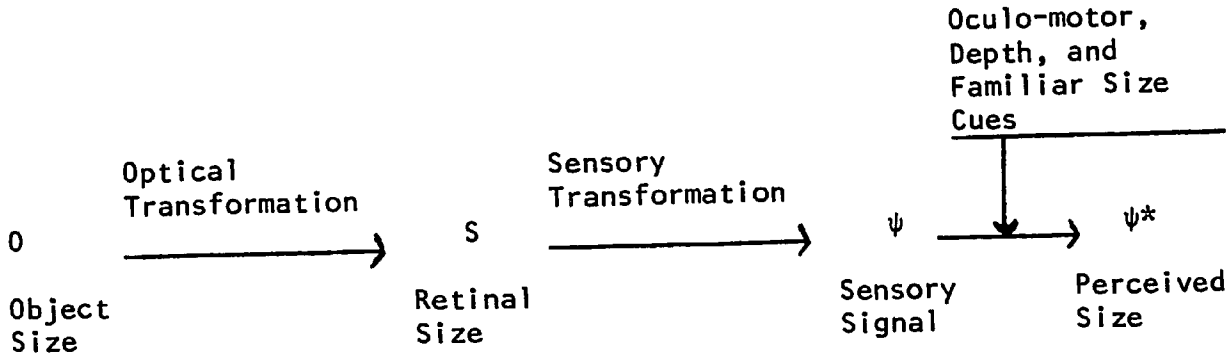


Figure 1

One hypothetical sequence of events in the perception of size

Sternberg (1966) points out the significance of the nonlinearity of perceptual size with respect to the possible theories of interaction between size and distance. He evaluated four possible orders of interaction. The four orders are generated by consideration of which of two kinds of distance (physical distance or sensory transformed distance) interacts multiplicatively with which of two kinds of size (object size

or sensory transformed size). He derives support for a theory which has transformed distance interacting with retinal size. This result is interesting since it implies that veridical information about retinal image size exists in the sensory system. It was pointed out above that length of straight lines may in fact be responded to nearly veridically which suggests the possibility that transformed (apparent) distance interacts with linear aspects of the visual scene the product of which gets transformed by an area transformation to become perceived size. In any case, there are a multitude of possible orders of interaction between the various determinants of perceived size among which is also the possibility that the sensory transformations for size and distance may be, themselves, multistaged. The sensory transformations may have a component which operates on a logarithmic basis while still operating over-all on the basis of a power law (Mac Kay, 1963; Milsum, 1966).

The effect of convergence on perceived size has been assessed by Heinemann, Tulving and Nachmias (1959). They used a 1° circular target and found approximately 25% change in perceived size with a change in convergence distance from 4 meters to 25 cm. They were able to show that this effect is independent of accommodation changes or apparent distance changes. (This study is summarized in Appendix III along with a short historical sketch of the work on the effects of stereopsis and convergence on perceived size). If Figure 1 were a representation of the sequencing of size transformation and oculomotor effects, Heinemann et al. would have gotten a different result if they had used straight lines as stimuli rather than circles. An examination of why this would be the case will serve to introduce the experiments reported in

Chapters II & III concerning the effects of binocular disparity (stereopsis) on perceived size.

Let S represent the retinal size of an object. Let ψ represent the size of a sensory signal. Let C represent the magnitude of influence on size due to convergence. Let ψ^* be perceived size.

Figure 2 represents two objects (circles or lines) of different retinal size, S_1 and S_2. They are matched in perceived size, i.e., ψ_1^* is equal to ψ_2^* because an observer has adjusted the physical size of S_1 so that the differential contribution of convergences C_1 and C_2 to ψ^*_1 and ψ^*_2 are just balanced by the differential contribution of S_1 and S_2 to ψ_1^* and ψ_2^*. That is to say S_1 and S_2 look the same size despite the fact they are different in physical size (visual angle) because of the balancing of convergence effects C_1 and C_2.

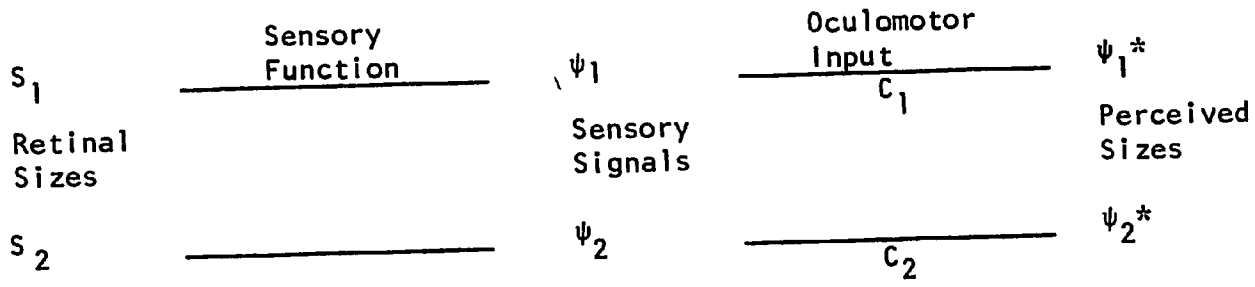


Figure 2

Representation of hypothetical events when two figures are matched in size given a different angle of convergence for each figure.

If we let the sensory function be a power function, $\psi = S^n$ for circles and $\psi = L^m$ for lines, and further assume that C in the above representation acts in multiplicative way on ψ then for a match involving circles, ψ_1^* and ψ_2^* turn out to be:

$$\psi_1^* = C_1 S_1^n \text{ and } \psi_2^* = C_2 S_2^n$$

while for a match involving lines ψ_1* and ψ_2* are:

$$\psi_1^* = C_1 L_1^m \text{ and } \psi_2^* = C_2 L_2^m$$

By definition of the task, ψ_1* is set equal to ψ_2*, in each case then

$$C_1 S_1^n = C_2 S_2^n$$

and

$$C_1 L_1^m = C_2 L_2^m$$

Thus, for some given combination of convergence effects, C_1 and C_2:

$$C_1/C_2 = S_2^n/S_1^n$$

and

$$C_1/C_2 = L_2^m/L_1^m$$

which yields

$$(S_2/S_1)^n = (L_2/L_1)^m \qquad (1)$$

If n and m are different, as data from magnitude estimation studies suggest that they are, then the effect of convergence on size matches would be different for lines than it is for circles, since in order for the equality in equation (1) to hold, with n and m different, S_2/S_2 must be unequal to L_2/L_1.

We could make the same argument for size-matching experiments where physical distance rather than convergence is manipulated except for one very important qualification. Physical distance does not have just one proximal cue which varies with it. Therefore, it is desirable to specify some quantifiable and manageable distance cue if we want to be able to make any assumptions about equalizing its effect on two different shaped stimuli.

Binocular disparity is an easily managed and quantifiable distance cue. Although it is often overlooked, there is a definite perceived

size change which takes place when an object viewed stereoscopically changes its apparent depth as a result of a change in binocular disparity. Wheatstone (1838) noticed this size change. However, as noted in Appendix III, it is not entirely clear whether this size change is the result of the apparent distance change in stereopsis or to fusional convergence changes which also take place in stereopsis or to a combination of the two.

Experiment I was designed to quantify the effects of binocular disparity on perceived size. This was done for various kinds of stimuli with the expectation that differences in sensory function for different shaped stimuli might reflect themselves in the relation between disparity and perceived size. Experiment II was designed to check on whether a given amount of disparity has an equal depth effect on various shaped objects.

CHAPTER II

EXPERIMENT I

This study was designed to determine the effect of binocular disparity on perceived size. Of particular interest was whether this effect is different for area than for length of line or lateral distance.

Method

Apparatus. - A mirror stereoscope was used to display stimulus materials separately to the left and right eyes. Visual distance to the plane containing stimuli was 49 cm. The stereoscope was inclined in such a way that observers could lean forward and look down--55° from horizontal--into the instrument while seated.

The two sets of front surface mirrors which provided separate fields of view were enclosed in a box with a head rest attached. Two screens, each containing a rectangular viewing aperture, one for each field, were attached to this box so that the views of the stimulus fields were each limited by a rectangular field. These screens were located at a visual distance of 29 cm. from the eyes. The field formed by each screen was 19°45' visual arc high by 21°40' visual arc wide. Each screen was adjustable laterally so that the edges of the fields in each eye could be made to coincide with corresponding points in the left and right stimulus planes regardless of the interpupillary distance of the observer.

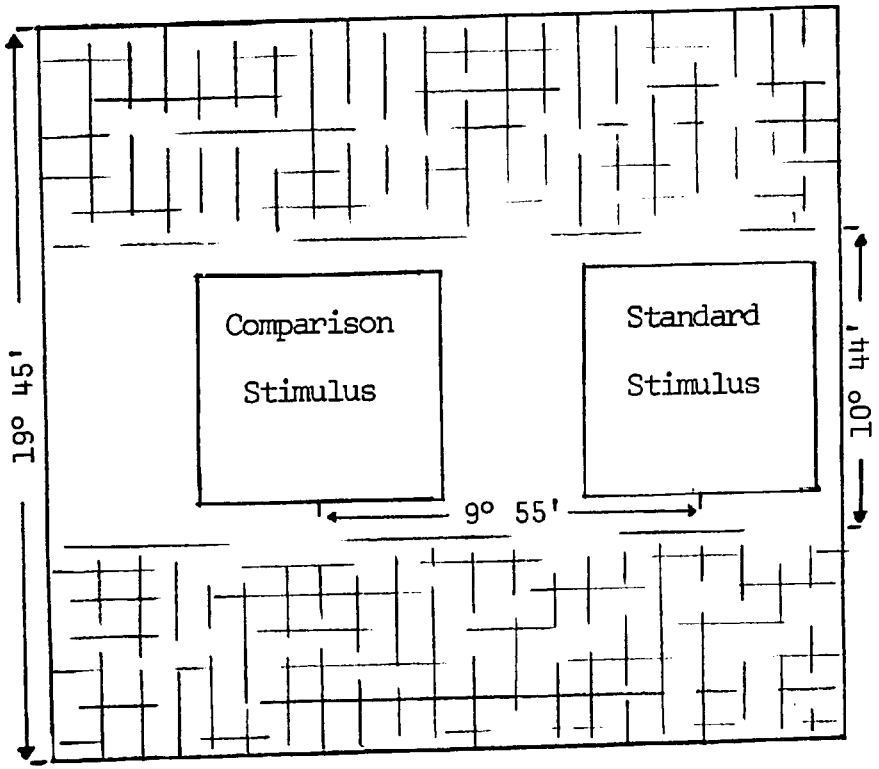
Stimulus materials. - Stimuli were constructed such that each monocular field consisted of a standard stimulus on the right and a comparison stimulus on the left. Above and below the standard and comparison stimuli were "random" vertical and horizontal cross-

hatching. Figure 3 is a representation of the stimulus fields presented to the left and right eye.

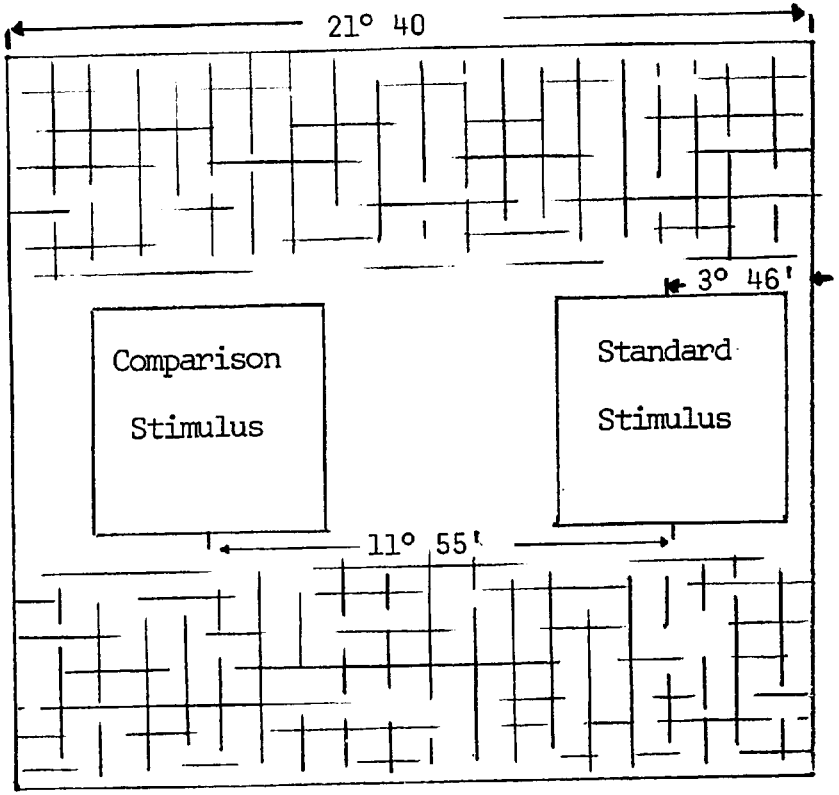
The standard stimuli and cross-hatching surround were fixed and identically located with respect to one another in the two half-images. The right field was adjustable by the observer so that the observer could shift the comparison stimulus horizontally, thus producing varying degrees of crossed or uncrossed binocular disparity. Figure 3 illustrates a state of adjustment in which there exists 2° of disparity. (The stimuli in the left field are 9°55' apart while those in the right field are 11°55' apart.) By varying disparity observers were able to vary the apparent depth of the comparison stimulus with respect to the standard stimulus and the surround. This adjustment also varied the amount of fusional convergence required while binocularly fixating the comparison stimulus. Thus while varying the apparent depth of the comparison stimulus the observers also varied the apparent size of the comparison stimulus as compared to the standard stimulus and surround.

Stimuli were constructed by drawing outline figures on black ditto masters produced by Columbia Ribbon & Carbon Co. Copies were made from these masters for left and right half-fields so that the two half-images were identical except for the relative horizontal location of the comparison stimulus within each half-field.

Twelve standard stimuli were constructed along with 12 sets of 5 comparison figures. The twelve standard stimuli are listed in Table 1. The exact dimensions of all stimuli in cm. and degrees of arc at the viewing distance used are listed in APPENDIX IV. A set of 5 comparison stimuli was constructed corresponding to each of the 12 standard stimuli. The comparison stimuli differed from the standard stimuli only in size.



Left Field



Right Field

Figure 3

Representation of right and left fields viewed in stereoscope.

Table 1

DESCRIPTION OF STANDARD STIMULI

#	Shape	Approximate dimension
1	vertical line	3 cm. long
2	vertical line	6 cm. long
3	vertically separated x's	3 cm. apart
4	vertically separated x's	6 cm. apart
5	outline circle	3 cm. diameter
6	outline circle	6 cm. diameter
7	solid circle	3 cm. diameter
8	solid circle	6 cm. diameter
9	outline square	3 cm. side
10	outline square	6 cm. side
11	solid square	3 cm. side
12	solid square	6 cm. side

Each set of 5 comparison stimuli ranged from approximately the same size as the standard to approximately 14% larger (linear extent) than the standard.

Instructions and conditions. - By grasping a sliding panel with his right hand, an observer could adjust the lateral position of the comparison stimulus in the right half-field. This continuously adjustable position determined the difference in amount of binocular disparity present for the comparison stimulus with respect to the background and edges of the field. Thus the observer could vary for himself the apparent distance and apparent size of the comparison stimulus.

Each of 20 conditions consisted of pairing 5 various sized comparison stimuli with a standard stimulus. Observers were asked to make the comparison stimulus match the standard stimulus in some aspect of size.

The 20 conditions are characterized in Table 2. The first 12 conditions consisted of having observers make essentially null size (lateral distance or length) matches since comparison stimuli and standard stimuli were the same shape.

Conditions 13 through 16 consisted of having observers match the length of lines with a linear dimension of a solid figure, i.e., the diameter for a circle, the length of a side for a square. Conditions 17 and 18 consisted of having observers match the circle diameters with the length of a side of squares. Conditions 19 and 20 consisted of observers making area matches between circles and squares.

Observers. - Four females (D.H., S.S., J.H. and A.C.) age 20-24 and one male (D.W.) age 37 served as observers. All observers had normal uncorrected vision except J.H. and A.C. who were mild myopes corrected to 20-20. J.H. wore spectacles during the experiment and A.C. wore contact lenses. Interocular distances were: D.H. - 5.60 cm.; S.S. - 5.70 cm.; J.H. - 6.43 cm.; A.C. - 5.75 cm.; D.W. - 6.35 cm.

Design. - Each condition was tested 10 times for each observer. Each condition involved matching 5 different sized comparison stimuli with a given standard stimulus. Thus each observer made a total of 1000 size matches.

Order of presentation for each observer was determined as follows.

1) The 20 conditions were randomized 5 times, each time without replacement.

Table 2

DESCRIPTION OF CONDITIONS FOR EXPERIMENT 1

Condition	Standard	Comparisons	Instruction
1	3 cm. line	lines	same length
2	6 cm. line	lines	same length
3	3 cm. separated X's	separated X's	same separation
4	6 cm. separated X's	separated X's	same separation
5	3 cm. outline circle	outline circles	same size
6	6 cm. outline circle	outline circles	same size
7	3 cm. solid circle	solid circles	same size
8	6 cm. solid circle	solid circles	same size
9	3 cm. outline square	outline squares	same size
10	6 cm. outline square	outline squares	same size
11	3 cm. solid square	solid squares	same size
12	6 cm. solid square	solid squares	same size
13	3 cm. line	solid squares	line equal side of square
14	3 cm. solid square	lines	line equal side of square
15	3 cm. line	solid circles	line equal diameter of circles
16	3 cm. solid circle	lines	line equal diameter of circles
17	3 cm. solid circle	solid squares	diameter equal side
18	3 cm. solid square	solid circles	diameter equal side
19	3 cm. solid circle	solid squares	same area
20	3 cm. solid square	solid circles	same area

2) The 5 comparison stimuli per condition were ordered randomly among themselves for each of the 100 conditions listed above. Together this ordered the first 500 trials.

3) The second 500 trials consisted of the first 500 trials in reverse order.

A different order of presentation was generated for each observer.

Data were gathered in 20 sessions for each observer spread over approximately 4 weeks. Each session consisted of 50 trials and lasted approximately 1 hour.

Procedure. - At the beginning of every new condition, i.e., every five trials, the observer was given the appropriate instruction for the particular match being made, e.g., "Make the line the same length as the diameter of the circle." Also at the beginning of each new condition the observer checked the edges of the field in each monocular field, making sure each edge was lined up on corresponding points in the two fields.

The observer indicated to the experimenter when he or she had made a satisfactory size match. The experimenter then measured the distance between the comparison stimuli in the two half-fields using a steel rule calibrated in .5 mm. While this measurement was being made the observer either closed his eyes or leaned back from the stereoscope as he wished.

Results and Discussion

Mean and standard error of the mean disparity settings were calculated for each comparison stimulus in each condition for each observer. These values are listed in APPENDIX V.

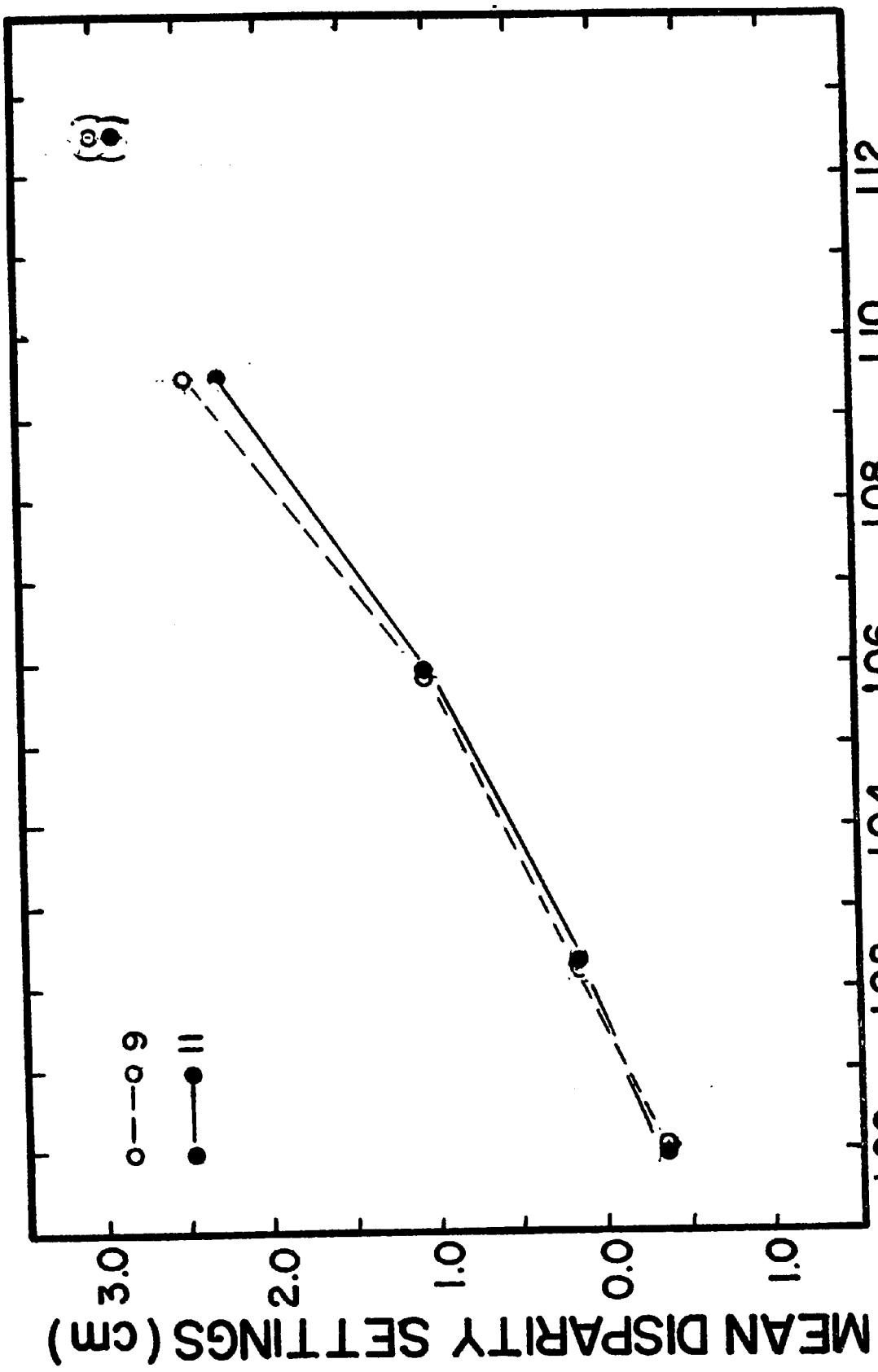


Figure 4

Mean disparity settings for condition 9 (small outline square standard-outline square comparisons) and condition 11 (small solid square standard-solid square comparisons).

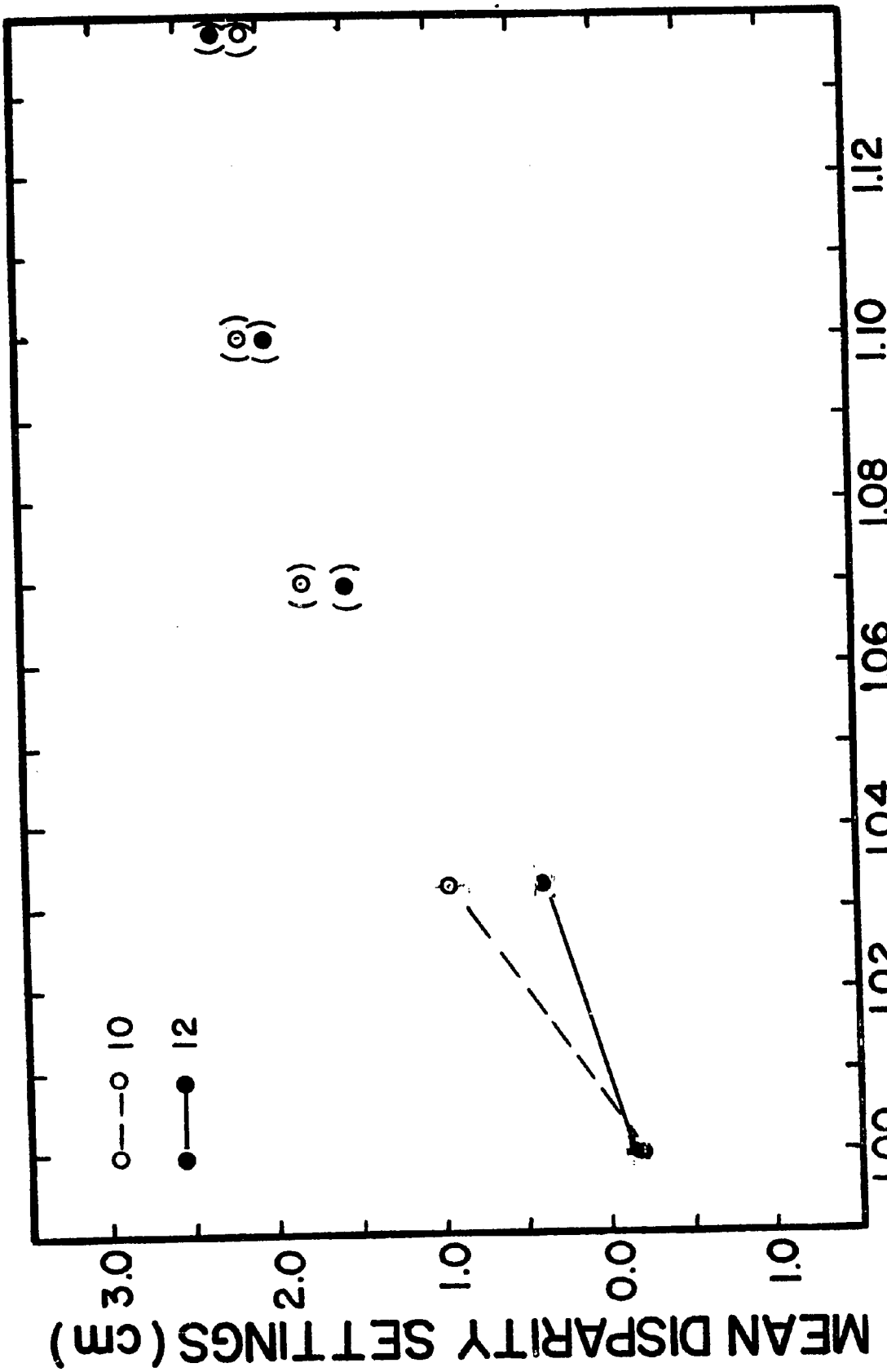


Figure 5

Mean disparity settings for condition 10 (large outline square standard-outline square comparisons) and condition 12 (large solid square standard-solid square comparisons.)

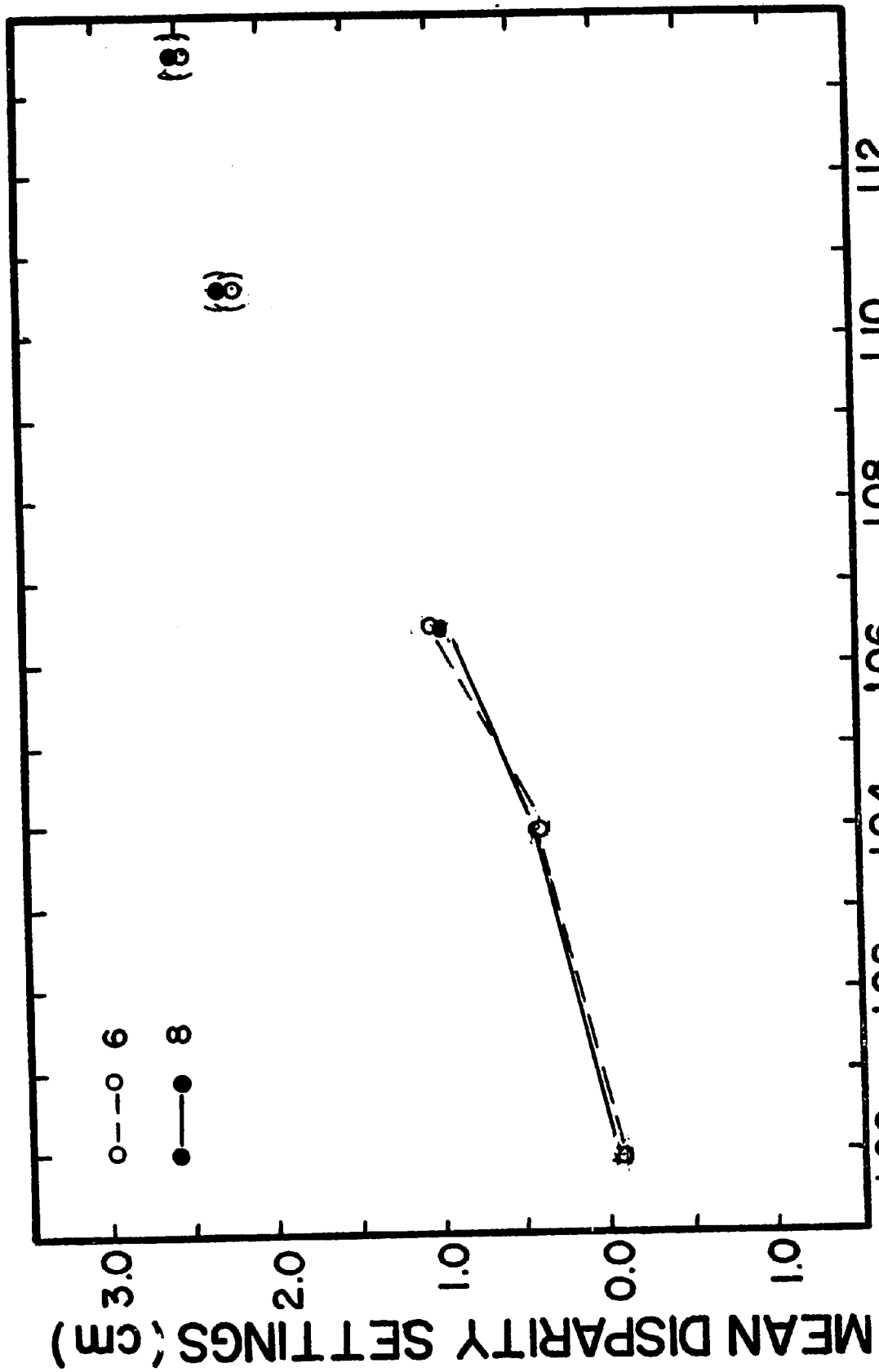


Figure 6

Mean disparity settings for condition 6 (large outline circle standard-outline circle comparisons) and condition 8 (large solid circle standard-solid circle comparisons).

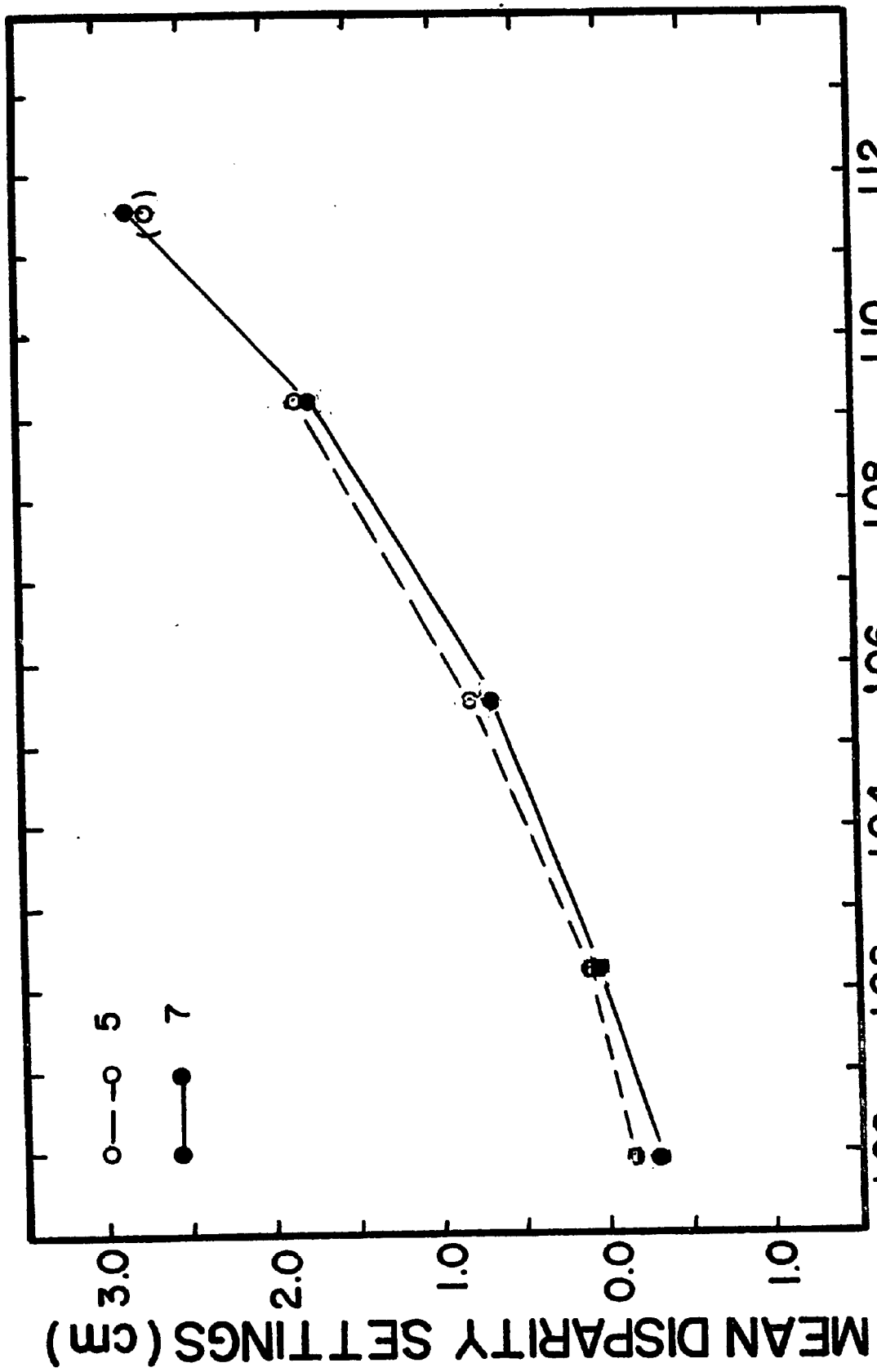


Figure 7

Mean disparity settings for condition 5 (small outline circle standard-outline circle standard) and condition 7 (small solid circle standard-solid circle comparisons).

Grand means (across observers) were calculated for each comparison stimulus in each condition. These values are presented in Figures 4-21 and discussed below. The ordinate in each of these figures is amount of disparity in centimeters at the the field distance of 49 cm. The abscissa is the ratio of the linear extent of the comparison and standard stimuli as measured in the field plane. These ratios are extremely close to the visual-angle ratios which they present to the eyes.

In addition to grand means, Figures 15, 16, 18, 19, and 20 contain means and standard error of each mean for a representative observer (D.W.). These values furnish both an opportunity to see the kind of variability present in individual observer data and also to indicate the presence of consistent differences (across size ratios) in individual data which are present in the group mean data presented in these particular Figures.

Overall result. -Perceived size is definitely affected by disparity. This result can be clearly seen in all Figures 4-21. The sizes of the standard errors as well as the observers' reports indicate that the task of trading off perceived size for disparity is a readily "do-able" task and yields reliable data.

Solid versus outline stimuli. -Do outline and solid stimuli change their perceived size at different rates with increasing disparity? We shall examine two extremes of contrast: outline figure versus a filled (solid) negative contrast figure. Any effect of these two extremes on the amount of disparity used to make size matches between different sized figures may be seen in Figures 4, 5, 6, and 7. (Points contained in parenthesis are based upon incomplete data which were obtained when one or more observers on one or more trials could not produce enough disparity to make the size match. Thus, these points are biased toward zero disparity.)

Figures 4 and 5 compare solid and outline squares, small and large respectively. Conditions 9 and 11 fall right on top of one another in Figure 4. That is, solid squares and outline squares yield equivalent results. Data for large squares-- conditions 10 and 12-- were quite incomplete. This resulted from the encroachment of the comparison figure on the edge of the field when a large amount of disparity was required by an observer to make a size match. Unfortunately the observer was able to reduce the perceived width of the comparison square because of this encroachment and the experimenter was unaware for some time of the fact that some observers were continuing to make a size match under these conditions. Consequently, the results from conditions 10 and 12 should probably be disregarded.

This conclusion (that conditions 10 and 12 give spurious results) is strengthened by the results for condition 6 (large outline circles) and condition 8 (large solid circles) which are compared in Figure 6. The large circles did not change their width when they encroached on the border of the field, i.e., they remained circles rather than becoming truncated whereas the squares maintained their height and became narrower thus becoming rectangular under the same conditions. Figure 6 shows that there was no difference between solid and outline large circles.

Figure 7 shows the results for small outline circles (condition 5) and small solid circles (condition 7). With the exception of one point, these values all fall very close together.

It may be concluded from the results displayed in Figures 4, 5, 6, and 7 taken as a whole that there is no difference in the amount of disparity required to make size matches as a result of the figures being outline or solid two dimensional figures.

Distance between points vs. straight lines. - Do open and closed linear extents change their apparent separation (length) with increasing disparity at the same rate? Analogous to the solid vs. outline distinction made above for two-dimensional figures is a distinction between the distance formed by the vertical separation of two points which were indicated to observers by x's and distance filled by a straight line.

Figures 8 and 9 show the results for distance vs. straight lines for small and large figures, respectively. There are various ways to measure the distance between two X's. One way is to measure the distance between similar points on the stimuli (X's). This measurement is used as the independent variable (abscissa) for plotting condition 3 in Figure 8 and condition 4 in Figure 9. In terms of this representation, the results indicate a difference in the amount of disparity required for matching distances as opposed to straight lines.

However, when the distances between X's are measured between the outer points of intersection of the two lines forming each X, and these measurements are used as the independent variable, as in condition 3' and 4' of Figures 8 and 9, there is no significant difference between the amounts of disparity required for lateral distance matches as opposed to length of line matches. The results suggest that straight lines change their length given changes in disparity at the same rate as the distance between points changed (when distance is measured from the outside dimensions of the points marking off the distance).

Effect of absolute size. - Does the absolute size of the comparison and target stimuli have an effect on the rate at which figures change their perceived size with increasing disparity? Figures 10 and 11 allow a comparison between condition 7 and 8 (small and large circles) and between conditions 11 and 12 (small and large squares). The results for

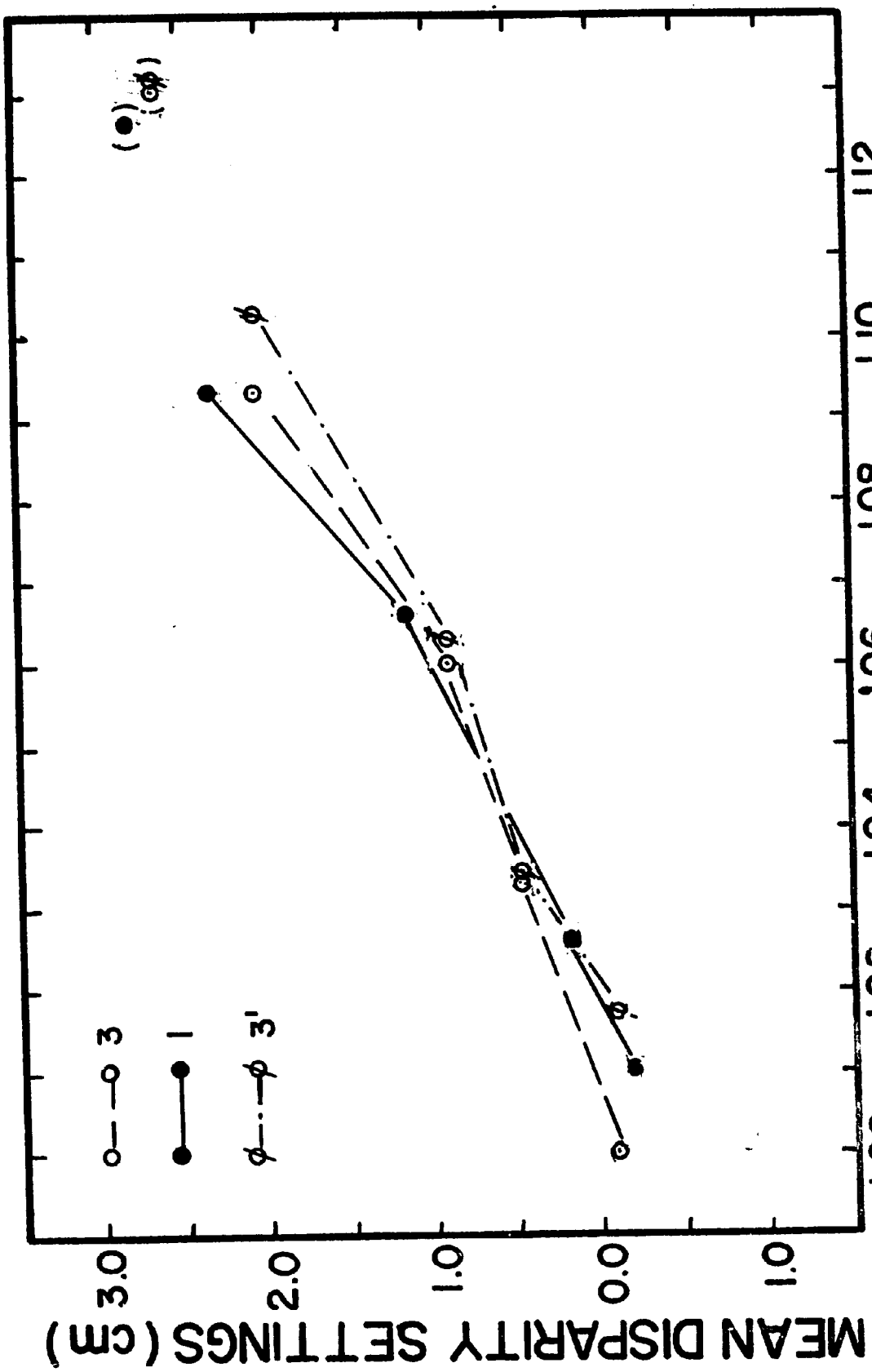


Figure 8

Mean disparity settings for condition 1 (short line standard-line comparisons) and condition 3 with X separations measured in 2 ways.

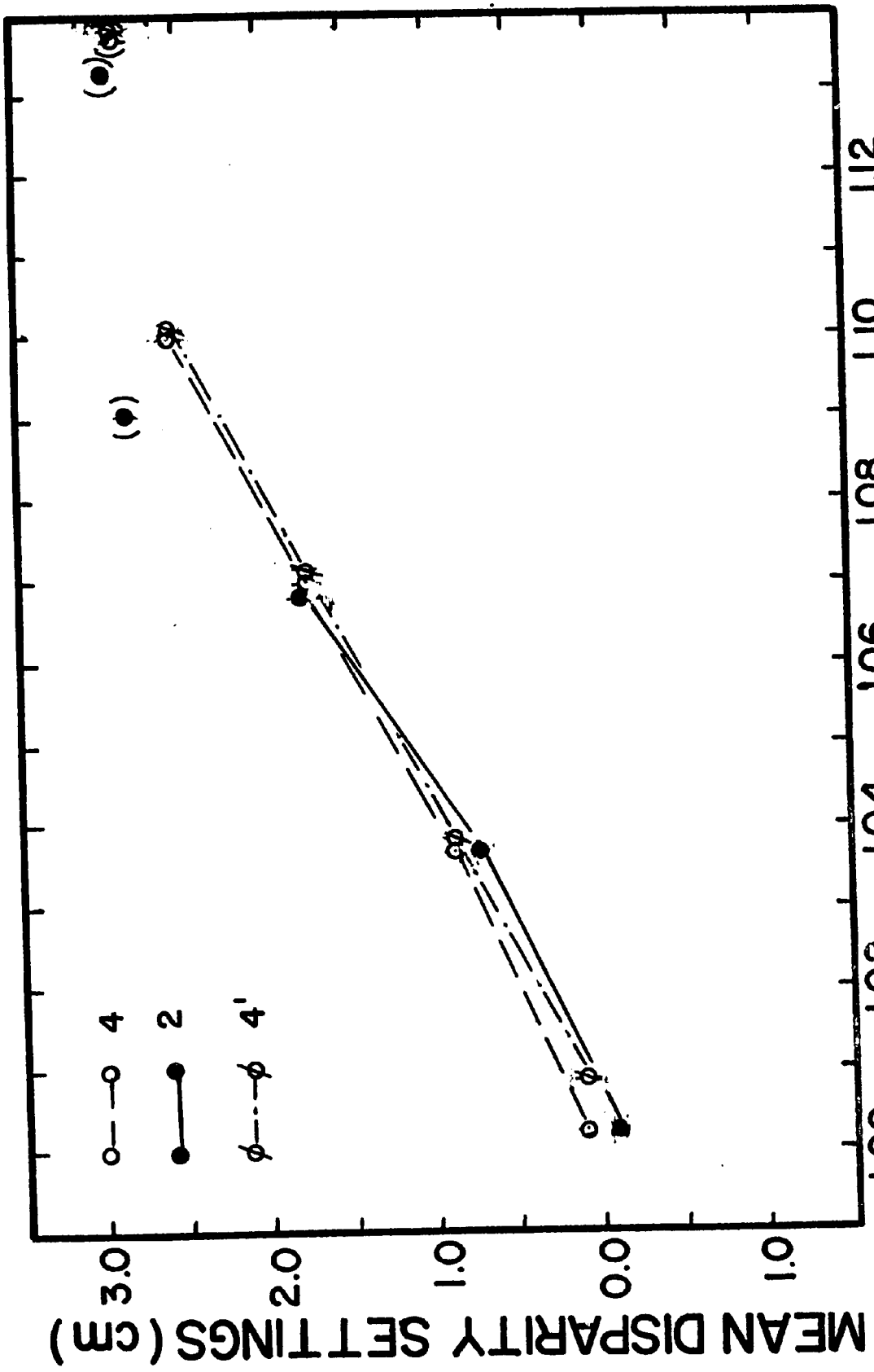


Figure 9

Mean disparity settings for condition 2 (long line standard-line comparisons) and condition 4 with X separations measured in two ways.

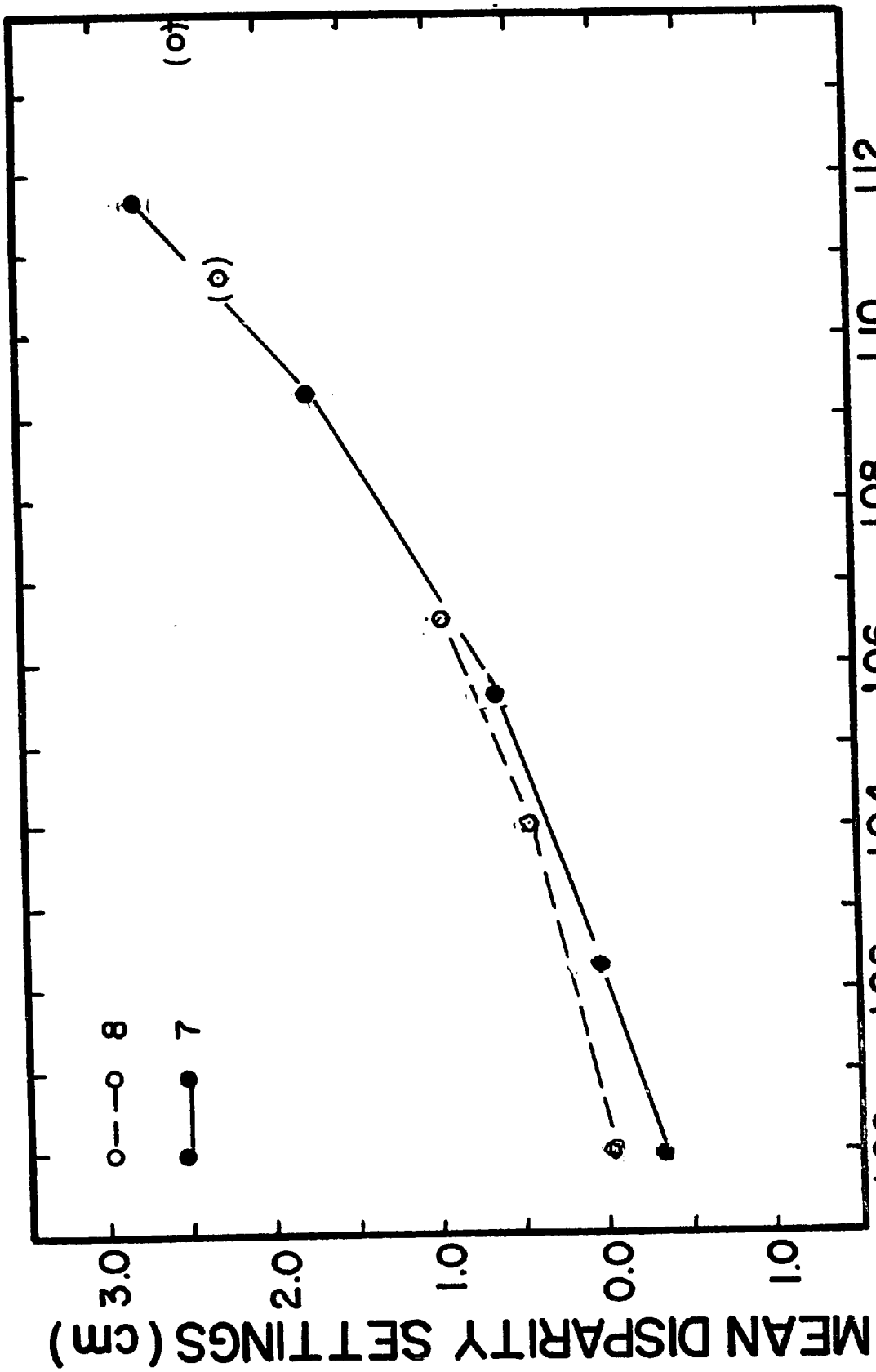


Figure 10

Mean disparity settings for condition 7 (small solid circle standard-solid circle comparisons) and condition 8 (large solid circle standard-solid circle comparisons).

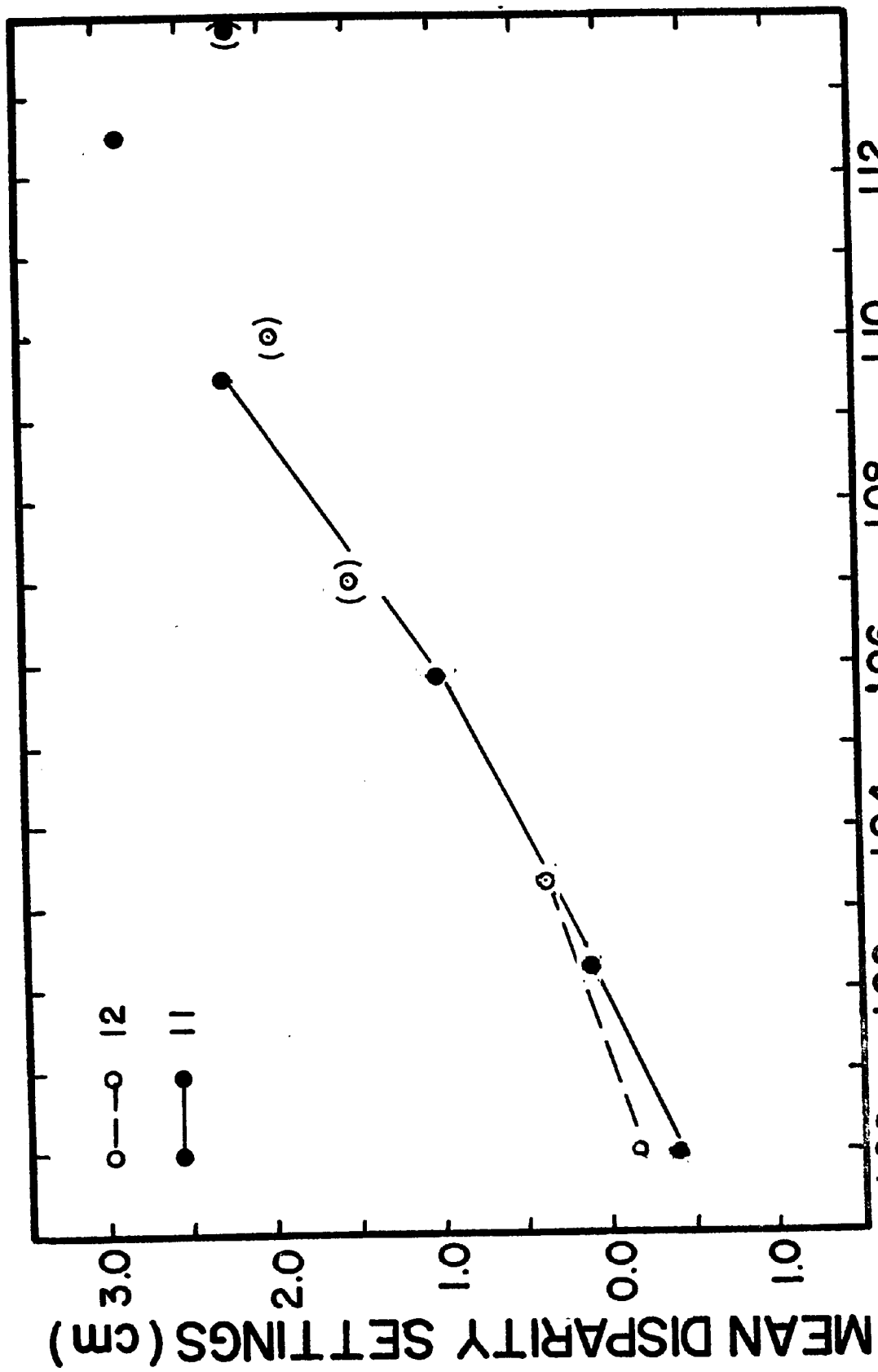


Figure 11

Mean disparity settings for condition 11 (small solid square standard-solid square comparisons) and condition 12 (large solid square standard-solid square comparisons).

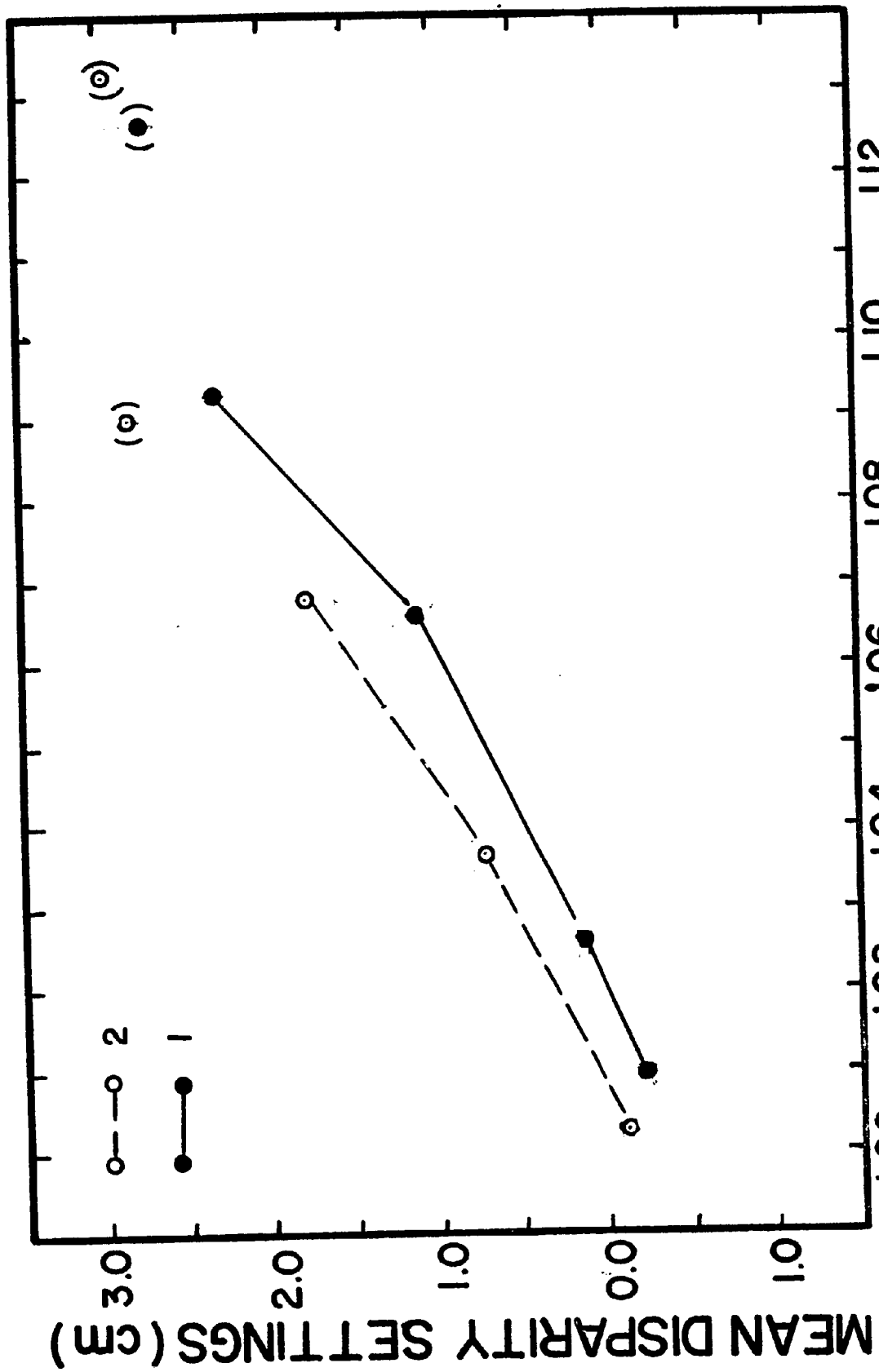


Figure 12

Mean disparity settings for condition 1 (short line standard-line comparisons) and condition 2 (long line standard-line comparisons).

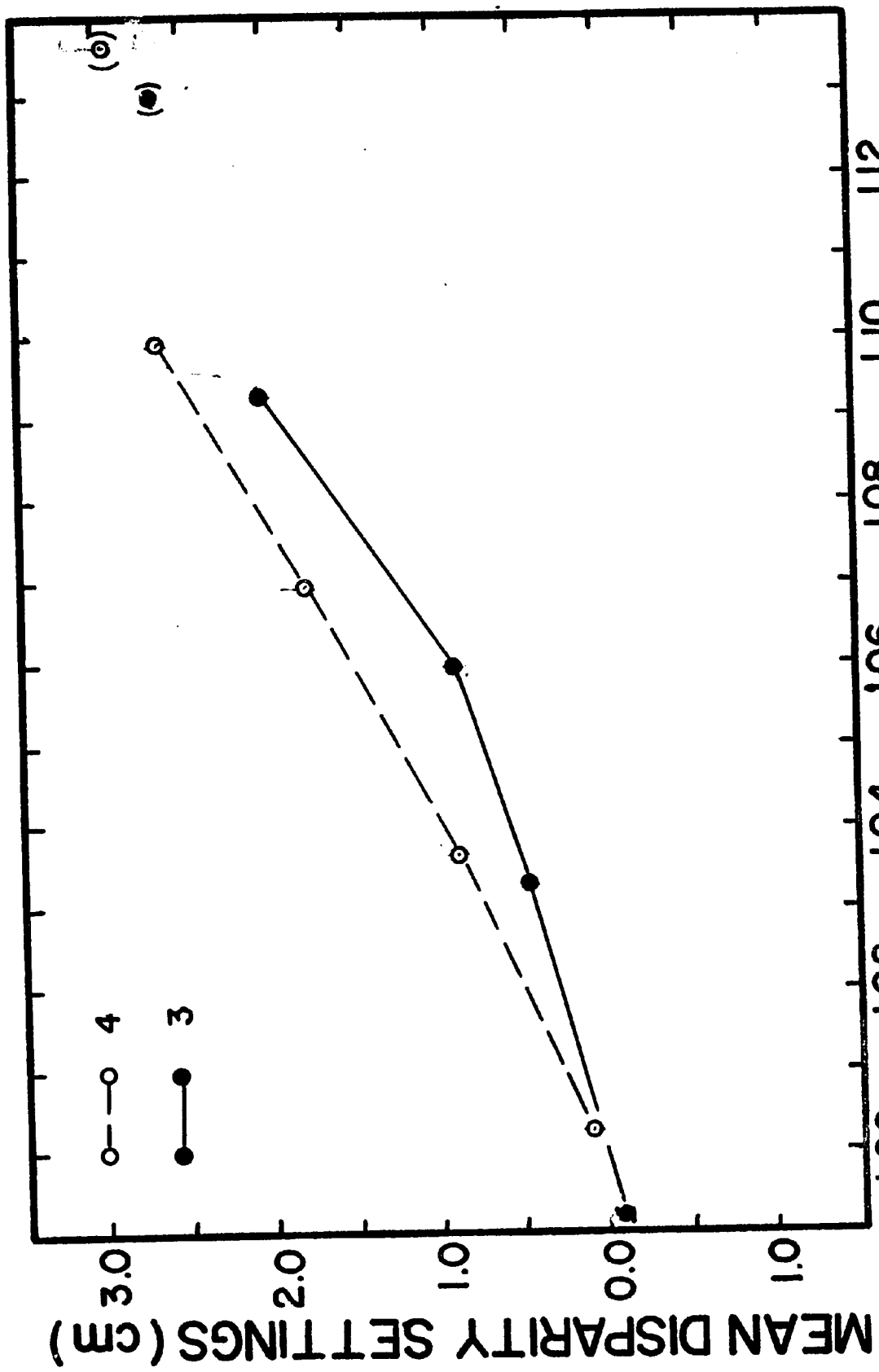


Figure 13

Mean disparity settings for condition 3 (short separation X's standard-separated X's comparisons) and condition 4 (long separation X's standard-separated X's comparisons).

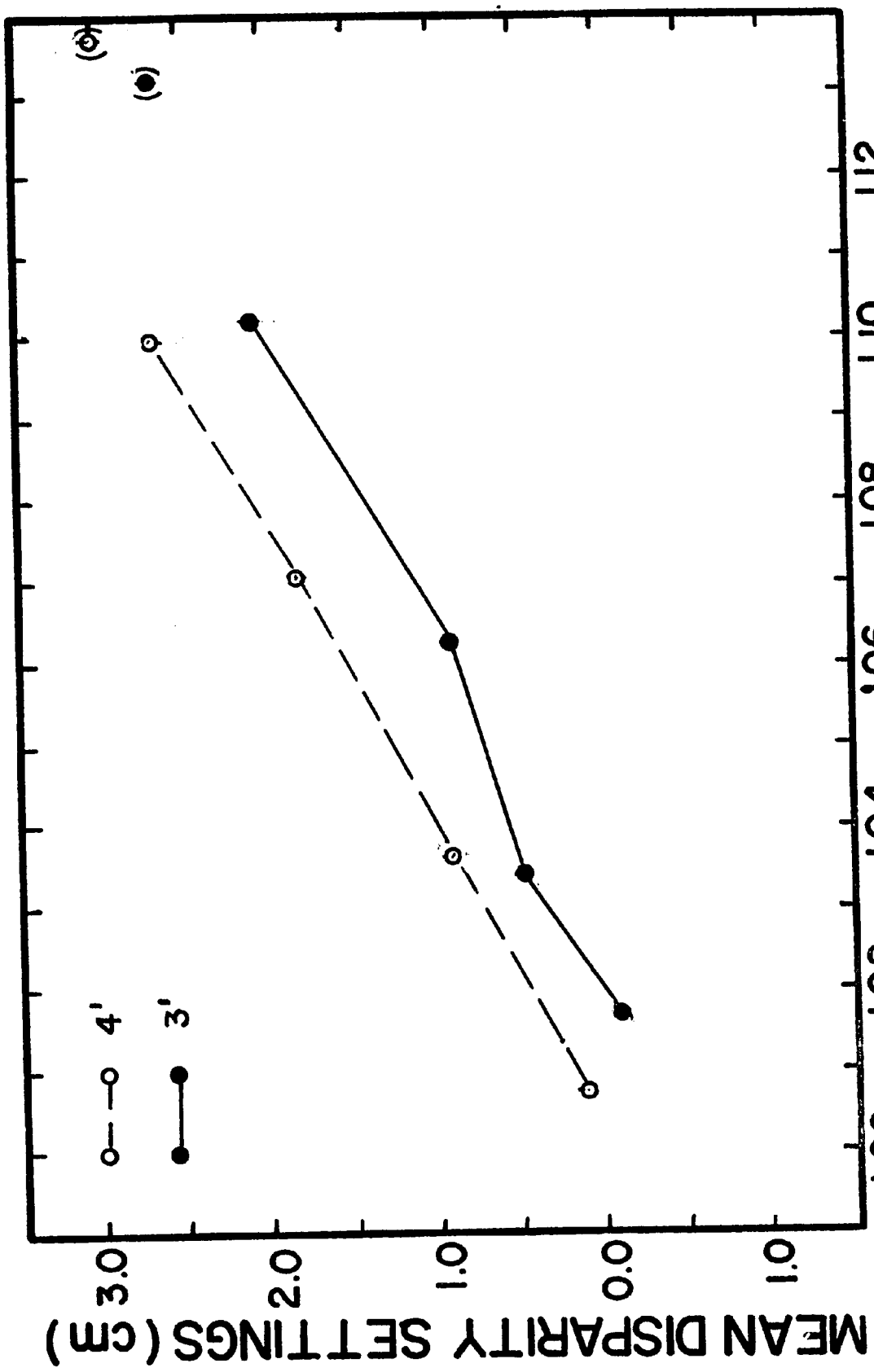


Figure 14

Mean disparity settings for conditions 3 and 4. Size measurements made from outside intersections of bars of X's.

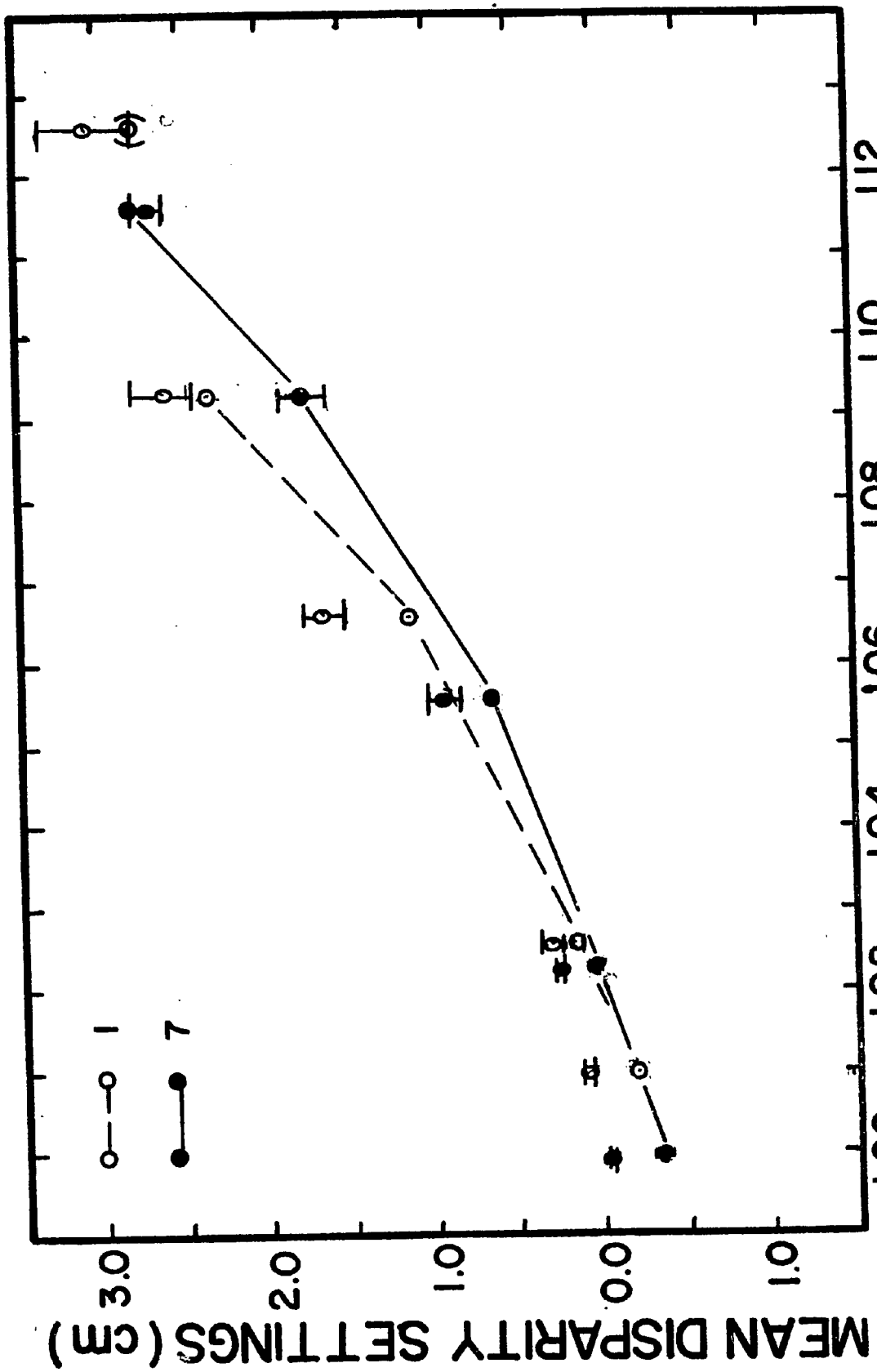


Figure 15

Mean disparity settings for condition 1 (short line standard-line comparisons) and condition 7 (small solid circle standard-solid circle comparisons). Unconnected points represent means and standard errors of observer D.W.

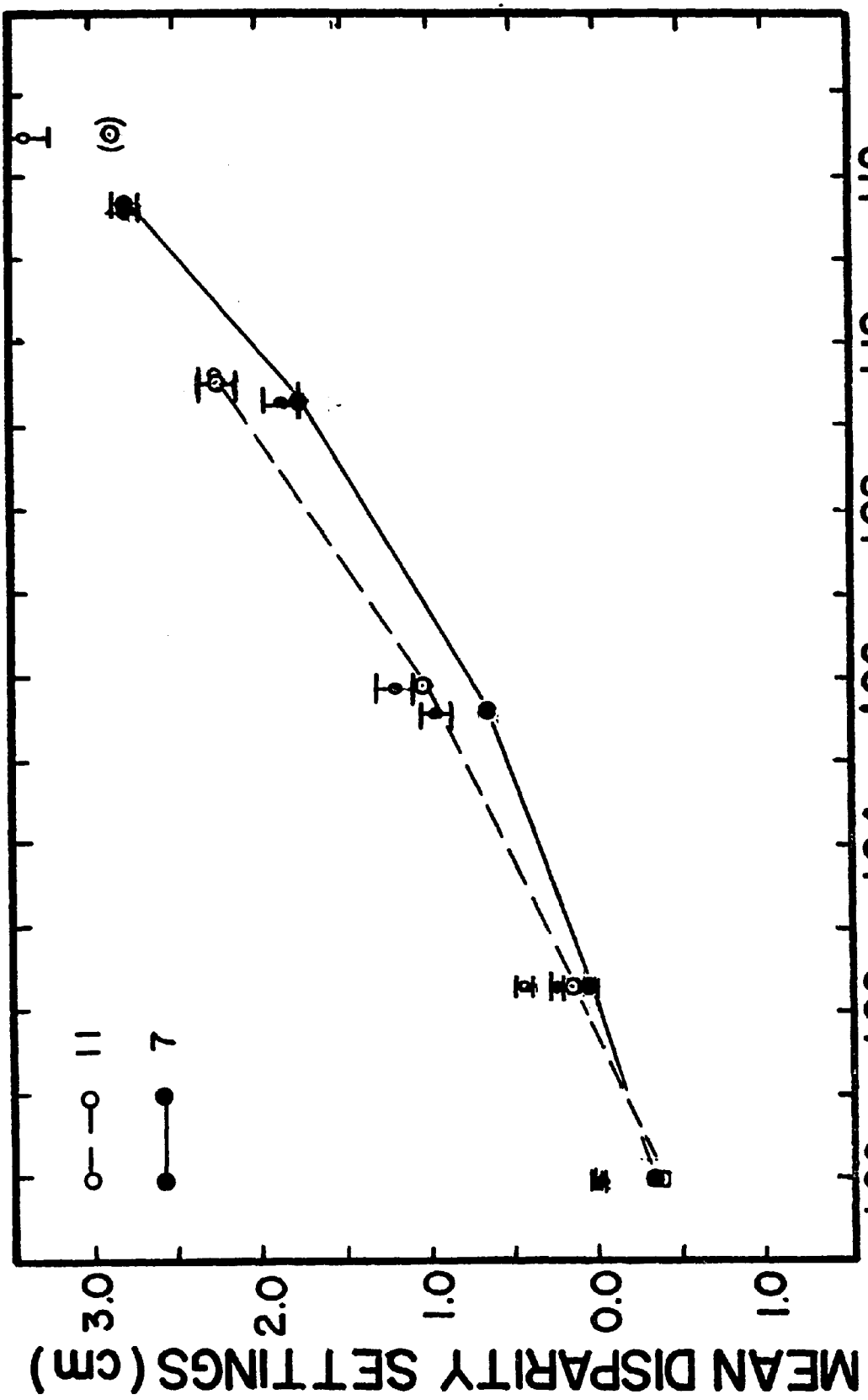


Figure 16

Mean disparity settings for condition 7 (small solid circle standard-solid circle comparisons) and condition 11 (small solid square standard-solid square comparisons). Unconnected points represent means and standard errors of observer D.W.

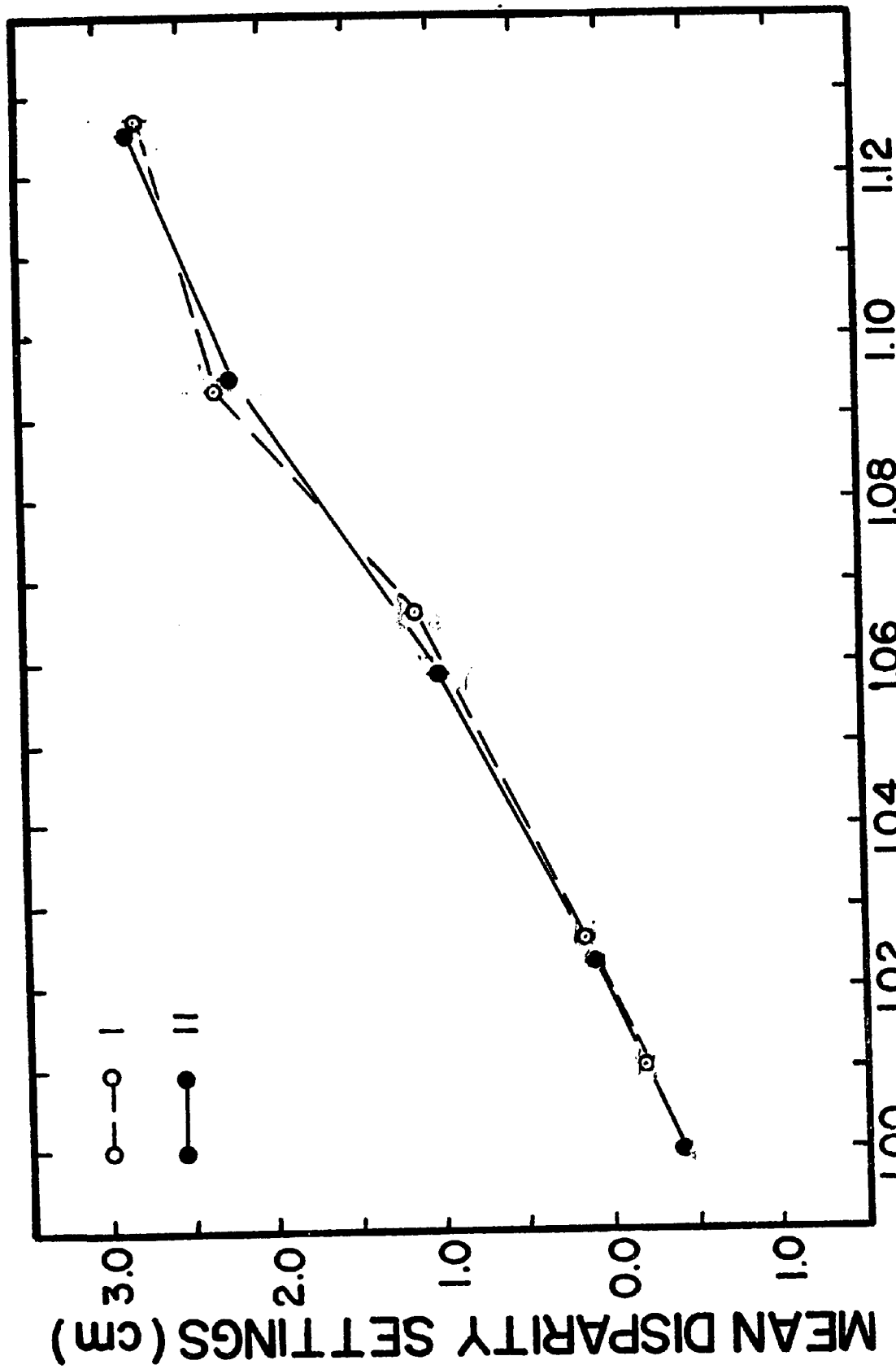


Figure 17

Mean disparity settings for condition I (short line standard-line comparisons) and condition II (small solid square standard-solid square comparisons).

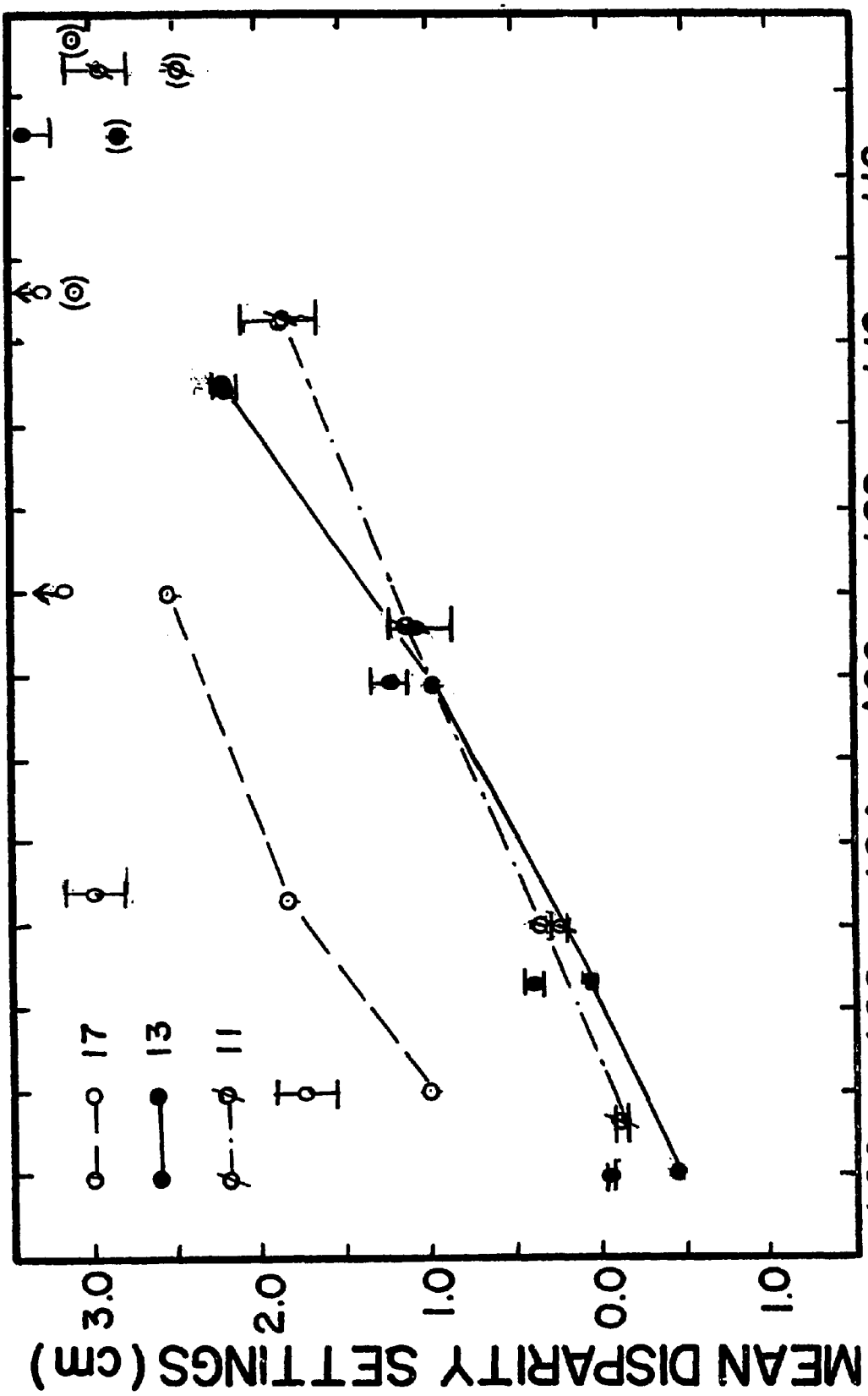


Figure 18

Mean disparity settings for condition 11 (small solid square standard-solid square comparisons), condition 13 (short line standard-solid square comparisons) and condition 17 (small solid circle standard-solid square comparisons). Unconnected points represent means and standard errors of observer D.W.

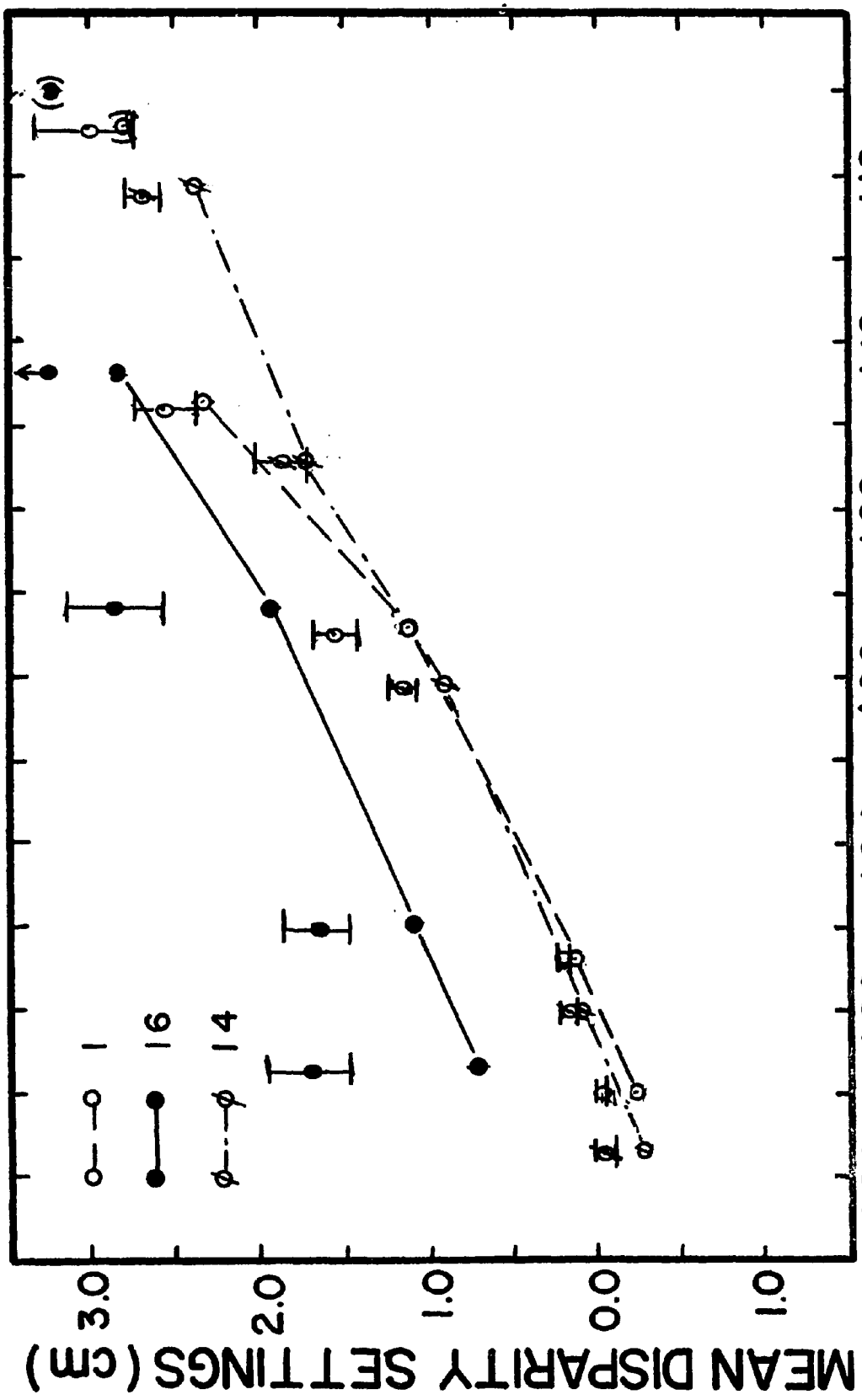


Figure 19

Mean disparity settings for condition 1 (short line standard-line comparisons), condition 14 (small solid square standard-line comparisons) and condition 16 (small solid circle standard-line comparisons).
Unconnected points represent means and standard errors of observer D.W.

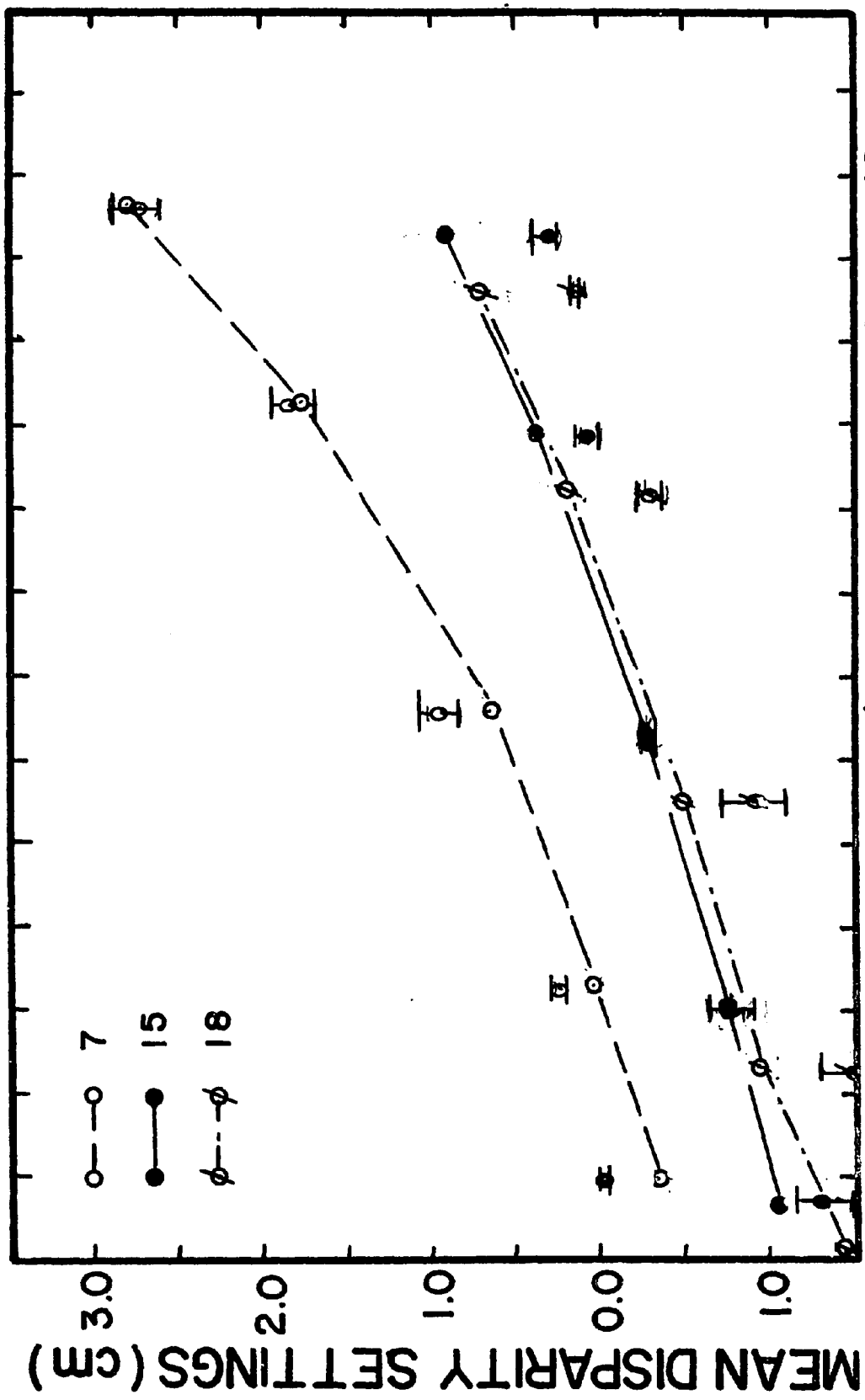


Figure 20

Mean disparity settings for condition 7 (small solid circle standard-solid circle comparisons), condition 18 (small solid square standard-solid circle comparisons), and condition 15 (short line standard-solid circle comparisons.)
Unconnected points represent means and standard errors of observer D.W.

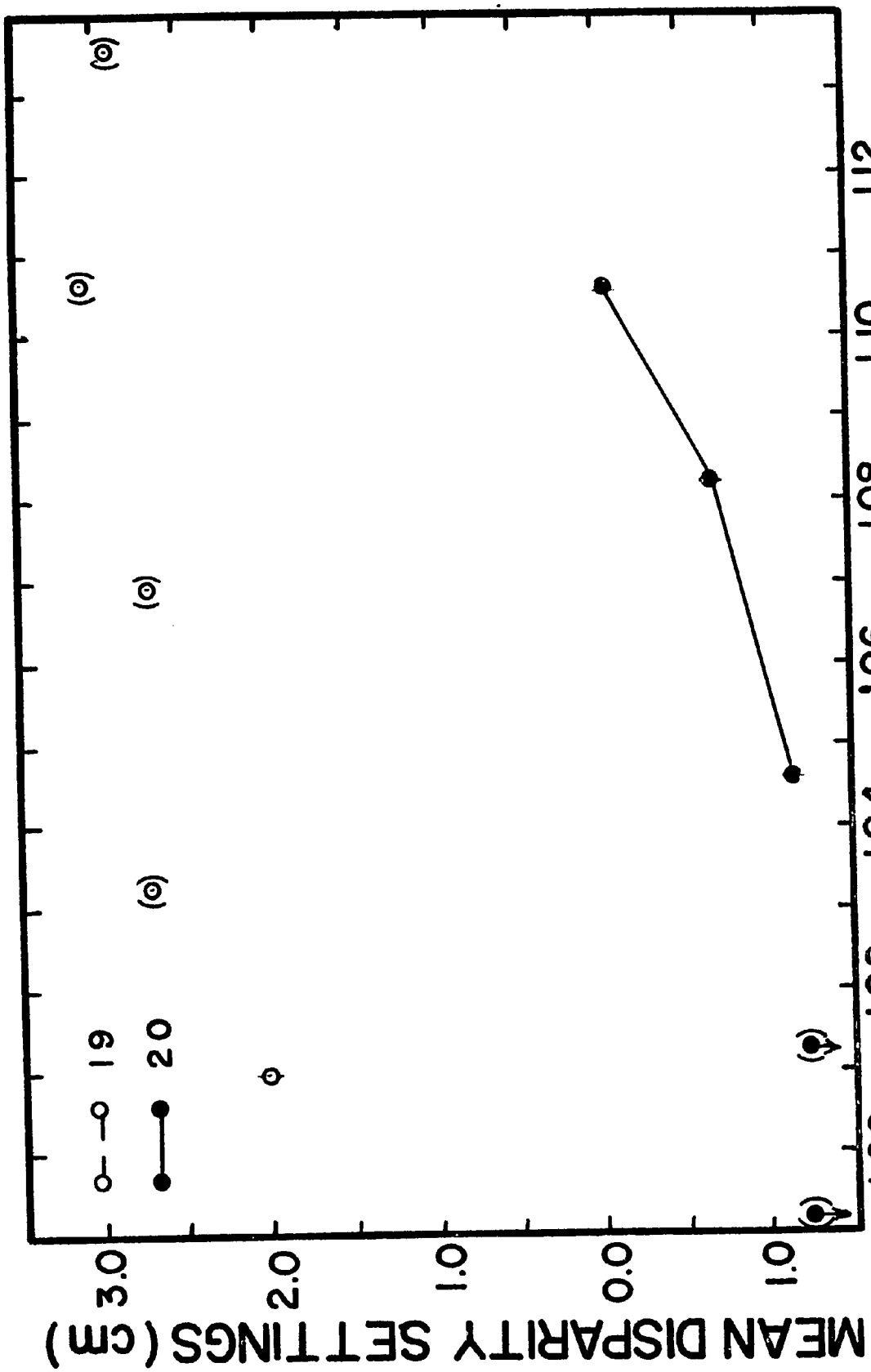


Figure 21

Mean disparity settings for condition 19 (small solid circle standard-solid square comparisons; area match instruction) and condition 20 (small solid square standard-solid circle comparison; area match instruction).

small and large squares in Figure 11 must remain questionable because of the incompleteness and probable inaccuracy of the data on large squares for reasons cited above. However, the sparse results for circles shown in Figure 10 seem to indicate a difference in rates at which the apparent size of large and small circles grow with increasing disparity.

The results for large and small straight lines in Figure 12 show a definite displacement between them. This displacement appears to be a difference in intercept rather than a difference in rate of change. Figure 13 appears to exhibit a difference in rate of growth between large and small distances between x's. But when the distance results from conditions 3 and 4 are plotted using the outside dimensions mentioned above, the apparent rate of growth difference between conditions 3 and 4 changes into what looks like an intercept difference. This replotting may be seen in Figure 14.

Effect of shape. - Do stimuli of different shapes change their perceived size at different rates with increasing disparity? Comparisons among condition 1 (small line matched with lines), condition 7 (small solid circle matched with solid circles), and condition 11 (small solid square matched with solid squares) afford an opportunity to determine if different shapes change their apparent size at different rates given changes in disparity.

Figure 15 appears to show that circles change apparent size at a different rate than straight lines with changes in disparity. Figure 16 shows a similar differential effect for squares and circles. Figure 17 shows that straight lines and squares act in the same way.

The contrast between lines and squares versus circles and lines or squares is further illustrated in Figures 18, 19, and 20. Figure 18

shows that condition 13 (solid squares matched with a standard line) and condition 11 (solid squares against solid squares) indicate similar findings, but condition 17 (sides of solid squares compared with the diameters of a standard circle) showed different results.

Figure 19 shows condition 16 (lines against a standard circle) standing apart from condition 1 (lines against a standard line) and condition 14 (lines against a standard square). Figure 20 also shows condition 7 (circles matched with circles) to be different from both condition 15 (circles matched with standard line) and condition 18 (circles matched with standard square). Figure 20 is of particular interest because of the similarity in results between conditions 15 and 18. The similarity in the result of matching circle diameters against the side of a standard square (condition 18) to the result of matching circle diameters to a standard straight line again emphasizes the similar behavior of squares and straight lines, while underlining the different behavior of circles.

The results for conditions 19 and 20 are presented in Figure 21. Observers were asked to match squares and circles in area in these two conditions. Unfortunately, both as a result of the large physical area difference between circles and squares and the observers further propensity for seeing the squares as even larger than they were relative to the circles, observers could not produce enough disparity to make many of the matches.

Variance differences among different size comparisons. - Increasing standard errors with increasing comparison size matches may be seen in almost any of the Figures 4-21 reflecting increases in variance. A comparison of variances among conditions (outline versus solid stimuli,

large versus small stimuli, lines versus squares etc.) failed to show a significant difference in variance.

Experiment I Summary

The major results of Experiment I may be summarized as follows:

1. By varying the field disparity of one of two stimuli observers can make consistent null matches between stimuli which have different retinal sizes.
2. The amount of disparity required to make a null size-match is not influenced by whether the stimulus is an outline figure or a solid two-dimensional figure.
3. The amount of disparity required to make a null length-match is not different for a straight line or an "empty distance marked off by two X's".
4. Absolute size of two-dimensional figures and absolute length of lines and distances appears to influence the amount of disparity required to make a null match between two stimuli with the same physical size ratio. However, absolute size does not appear to change the slope or form of the function at least for length of line and distance.
5. The effect of disparity on the perceived size of squares is the same as the effect of disparity on the perceived length of lines.
6. The effect of disparity on the perceived size of circles is different from its effect on the perceived size of squares and perceived length of lines.

CHAPTER III

EXPERIMENT II

In Experiment I observers experienced apparent distance (depth) change as well as apparent size change of stimuli with changes in disparity. Different amounts of disparity were required for squares or lines and circles as well as different amounts for large and small circles. Were these differences accompanied (or caused) by differential depth effects for these stimuli? If they were, then one might expect those conditions in Experiment I which exhibited differential size effects (with given amounts of disparity) to also produce differential depth effects.

Also of interest was whether or not the relatively small size differences between comparison and standard stimuli in various conditions of Experiment I were traded off at all for depth changes. It is possible that observers could experience a small size difference as a depth difference instead of or in addition to an apparent size difference.

Accordingly, Experiment II was designed to determine if the various kinds of stimuli used in Experiment I produce differential depth effects given some amount of disparity. Also, it was designed to determine if small differences in physical size between standard and comparison are traded off for differences in apparent distance.

Method

Apparatus. - Apparatus was the same as that used for Experiment I.

Stimulus materials and procedure. - One set of fields, one for each eye, was constructed. It was exactly like that used in condition 7 of Experiment I except that the standard stimulus (solid 3 cm. circle) in

the right half-field was shifted 1 cm. to the left (nasally). This resulted in 1 cm. crossed disparity between the two half-images of the standard stimulus, consequently the standard stimulus appeared somewhat in front of the background to the observers. Comparison stimuli consisted of the smallest comparison stimulus from each condition 1-6 and 8-12 in Experiment I. In addition all 5 comparison stimuli from condition 7 (small solid circles) were used in Experiment II making a total of 16 comparison stimuli.

Instructions and conditions. - Observers were instructed to adjust the comparison stimulus so that it appeared to be at the same distance, i.e., in the same plane, as the standard stimulus.

Each condition consisted of pairing one comparison stimulus from Experiment I with the small solid circle standard stimulus which remained the same across all conditions. The 16 conditions are enumerated in Table 3 along with the dimensions of the comparison stimuli.

Observers. - The same five observers served who served in Experiment I.

Design. - Each condition was repeated for each observer 10 times. Order of presentation of conditions was randomized without replacement for the first half (80) of the trials for each observer. Order of presentation of the second 80 trials was determined by reversing the first-half sequence for each observer.

Data for Experiment II were gathered in two equal sessions for each observer after Experiment I had been completed. Each session lasted approximately 90 minutes.

Procedure. - Procedure for Experiment II was essentially the same as that used in Experiment I except that there was no change of standard

stimulus and field required between conditions.

Results and Discussion

Means and sums of squares for each observer on each condition are contained in APPENDIX VI. Grand means (across observers) and variances are given in Table 3.

Outline vs. solid figure. - Six comparisons betwen conditions are relevant to whether or not solid and filled figures require different amounts of disparity in order to appear at the same apparent distance. These are between conditions 11 and 13 (small squares), 14 and 12 (large squares), 1 and 6 (small circles), 8 and 7 (large circles), 10 and 16 (long line and distance), and conditions 15 and 9 (short line and distance). The differences between these conditions are neither consistent in direction (with respect to whether or not the solid figure requires more or less disparity than the outline figure) nor are any of these differences large enough to produce a t value significant at or beyond p= .05.

Large vs. small figures. - Six comparisons between conditions are relevant to whether or not large and small figures require different amounts of disparity in order to appear at the same apparent distance. These are conditions 1 and 8 (filled circles), and 6 and 7 (outline circles), 11 and 12 (filled squares), 13 and 14 (outline squares), 9 and 10 (lines) and conditions 15 and 16 (distances). The differences between the means for these pairs of conditions are not consistent in direction. One difference--between the small and large filled squares--does yield a t value which is significant. However, given the fact that this is one

t value which is significant out of a total of 15 t tests which were made-including the 12 above and 3 below-it is difficult to attach much importance to it.

TABLE 3

DESCRIPTION OF CONDITIONS, MEAN DISPARITY IN CM. AND VARIANCES FOR EACH CONDITION IN EXPERIMENT II

Condition	Comparison Stimulus	Mean disparity	Variance
1	3.01 cm. solid circle	.9878	.030633
2	3.08 cm. solid circle	.9904	.025340
3	3.18 cm. solid circle	1.0220	.012780
4	3.29 cm. solid circle	1.0056	.021337
5	3.36 cm. solid circle	.9738	.016768
6	3.01 cm. outline circle	.9414	.041180
7	5.96 cm. outline circle	.9528	.030736
8	5.96 cm. solid circle	.9636	.015771
9	3.05 cm. line	1.0256	.022397
10	6.02 cm. line	1.0776	.043230
11	3.04 cm. solid square	1.0270	.029337
12	6.02 cm. solid square	.9356	.040841
13	3.04 cm. outline square	.9728	.035436
14	6.02 cm. outline square	.9624	.024494
15	3.00 cm. separated X's	1.0368	.034474
16	6.00 cm. separated X's	1.0032	.080130

Shape. - The three conditions of particular interest because they yielded differences in Experiment I in the amount of disparity required to make size matches were conditions 1 (filled circles), 9 (line) and 11 (square). No significant difference was found among these three means in Experiment II.

TABLE 4

ANALYSIS OF VARIANCE: CONDITIONS 1-5 IN EXPERIMENT II

Source	df	MS	F
Between	4	.017	.78
Within	245	.022	

Effects of small size differences on disparity. - Conditions 1-5 were subjected to an analysis of variance. The results of that analysis appear in Table 4. These results give no apparent reason for saying that distance and size were traded off under the conditions of Experiments I or II.

Experiment II Summary

The amount of disparity required to produce a particular distance change appears to be unrelated to whether or not the figure is a straight line, an "empty" distance, filled or unfilled. It also appears to be unrelated to either the shape of the figure or whether the comparison figure is close in size to the standard stimulus which is marking the distance to be produced.

It is probable that absolute size is also unrelated to the amount of disparity required, but the results of Experiment II leave that question open.

CHAPTER IV

DISCUSSION

The major points to be discussed are: 1) Do individuals consistently reflect the group results in Experiment I? 2) How does the magnitude of size change given changes in disparity in Experiment I compare to the size change produced by convergence as measured by Heinemann et al.? Compared to what an ideal observer would do? 3) How might the difference in results between large stimuli and small stimuli in Experiment I be accounted for? 4) Are the results on lines, circles, and squares consistent with the speculation in Chapter I concerning a hypothetical sequencing of size transformation and stereoscopic effects?

Figures 22 through 26 show data from individual observers in Experiment I. These data are represented in such a way that they are relevant to both points 1 (individual observer agreement with group results) and point 2 (comparison of results with convergence effects and ideal observer).

The abscissa in these figures represents the size ratio between the comparison stimulus and standard stimulus just as the figures in Chapter II. However, these ratios are corrected by adding to or subtracting from the size of the standard so that the standard to comparison size ratio was 1.0 at zero disparity. The ordinate represents the reciprocal of the convergence distance. This value is calculated from the observer's interocular distance and the placement of the stimuli in the two fields of the stereoscope. The origin of the functions differ across observers (among Figures 22-26) reflecting the fact that the observers have different interocular distances while the position of the standard stimuli were fixed. This means that slightly different amounts of convergence

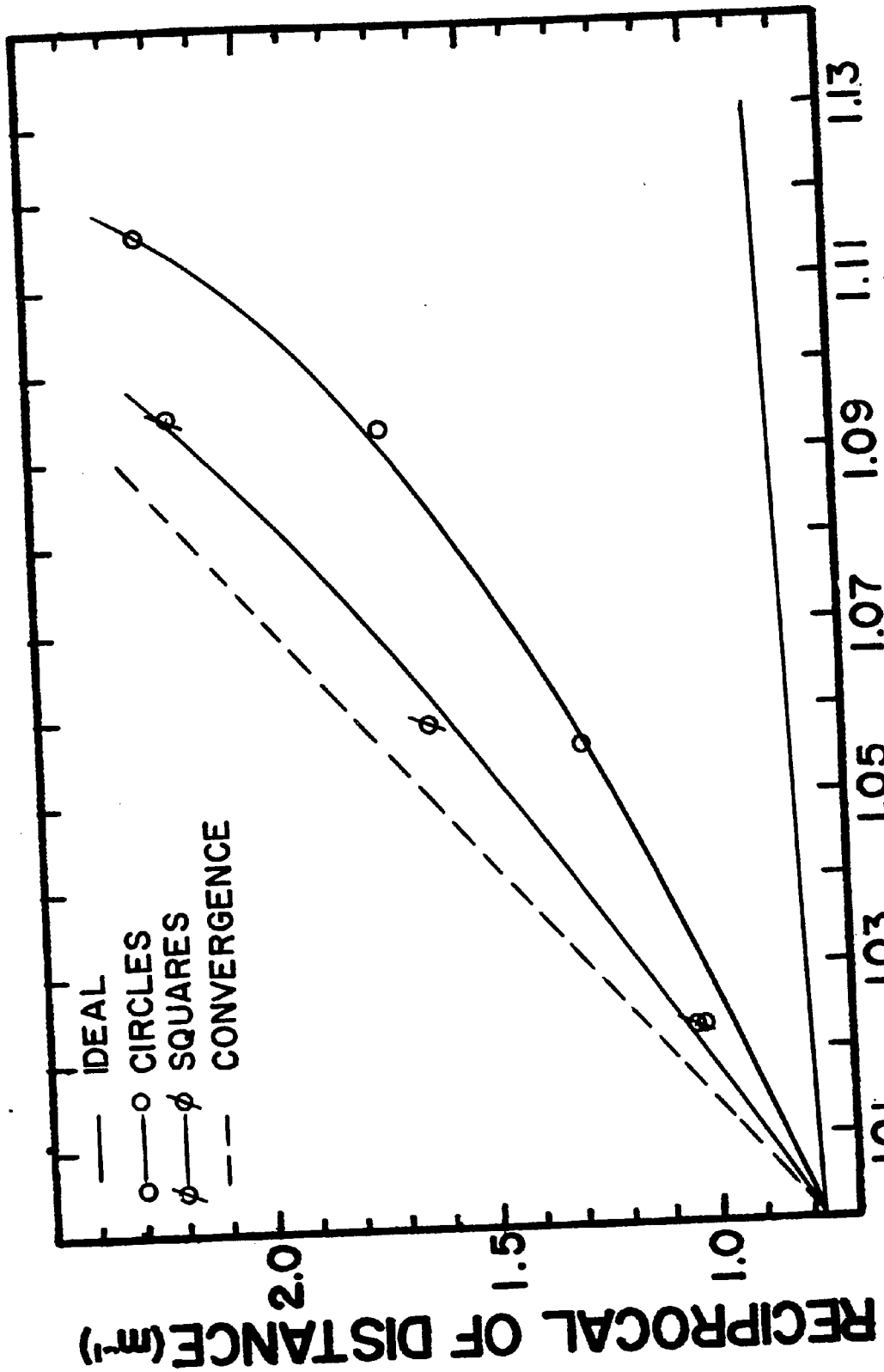


Figure 22

Observer - D.H. Comparison of data for squares, circles, an ideal observer and data expected on the basis of convergence alone.

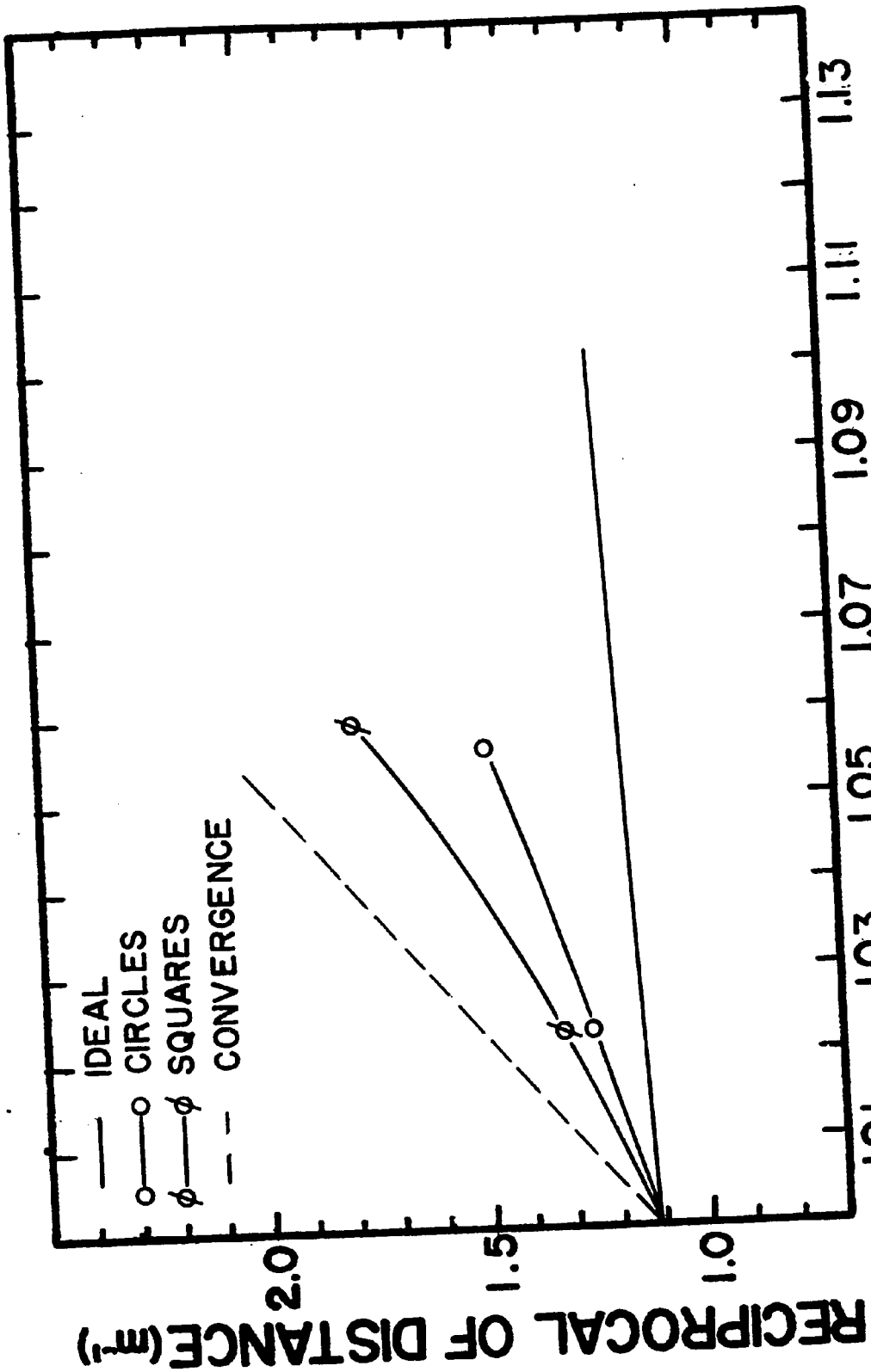


Figure 23

Observer - A.C. Comparison of data for squares, circles, an ideal observer and data expected on the basis of convergence alone.

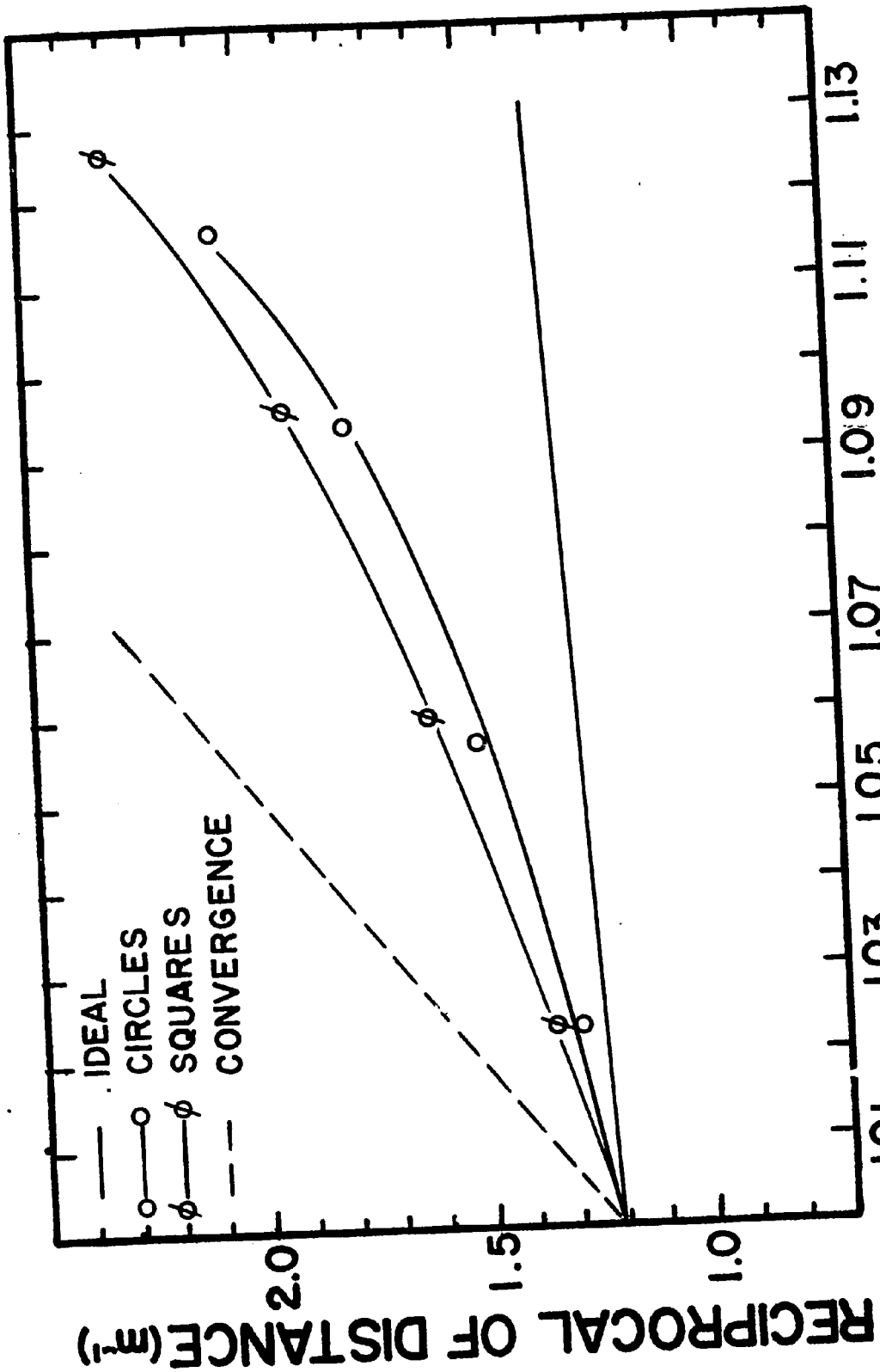


Figure 24

Observer - D.W. Comparison of data for squares, circles, an ideal observer and data expected on the basis of convergence alone.

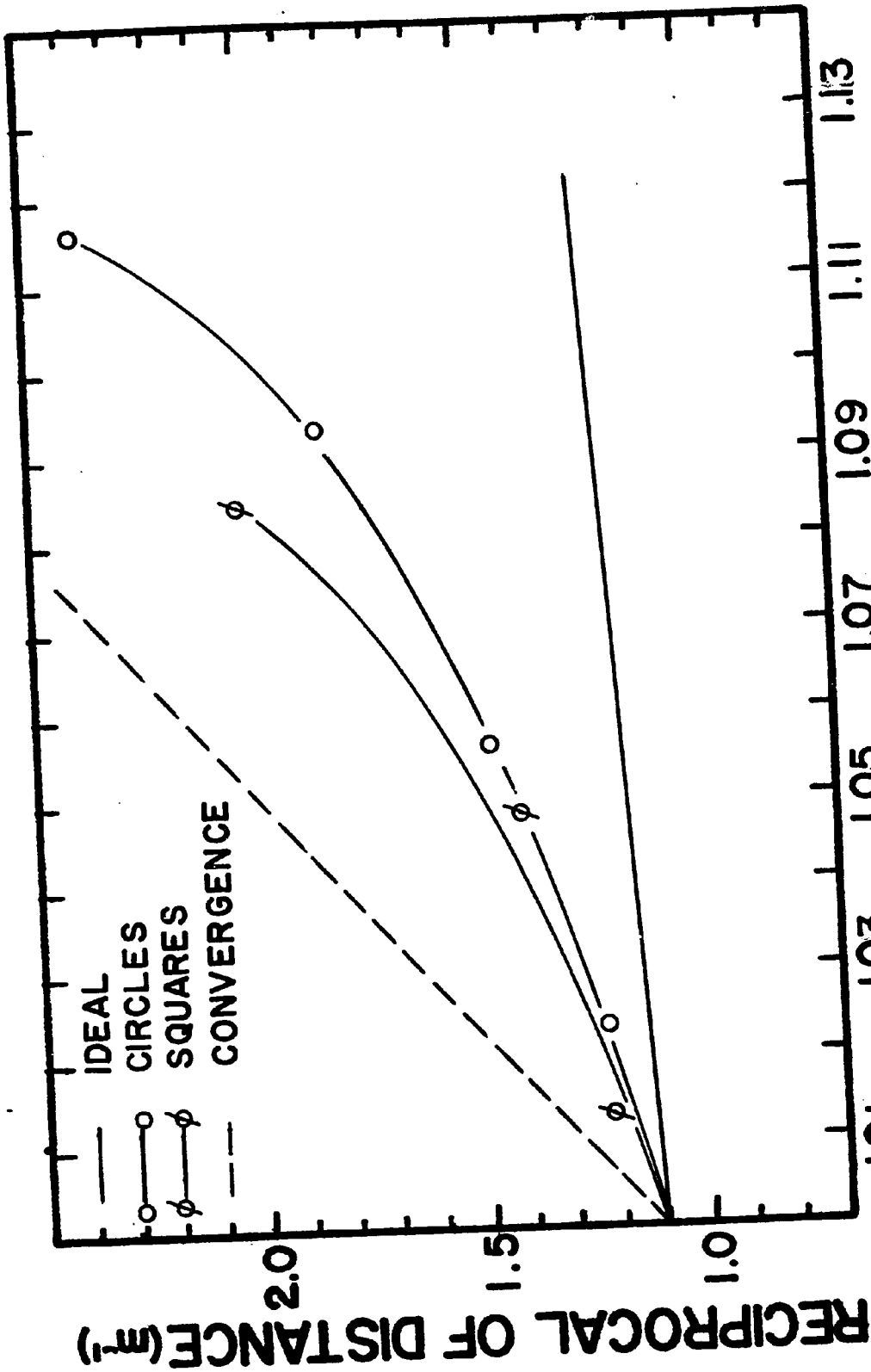


Figure 25

Observer - J.H. Comparison of data for squares, circles, an ideal observer and data expected on the basis of convergence alone.

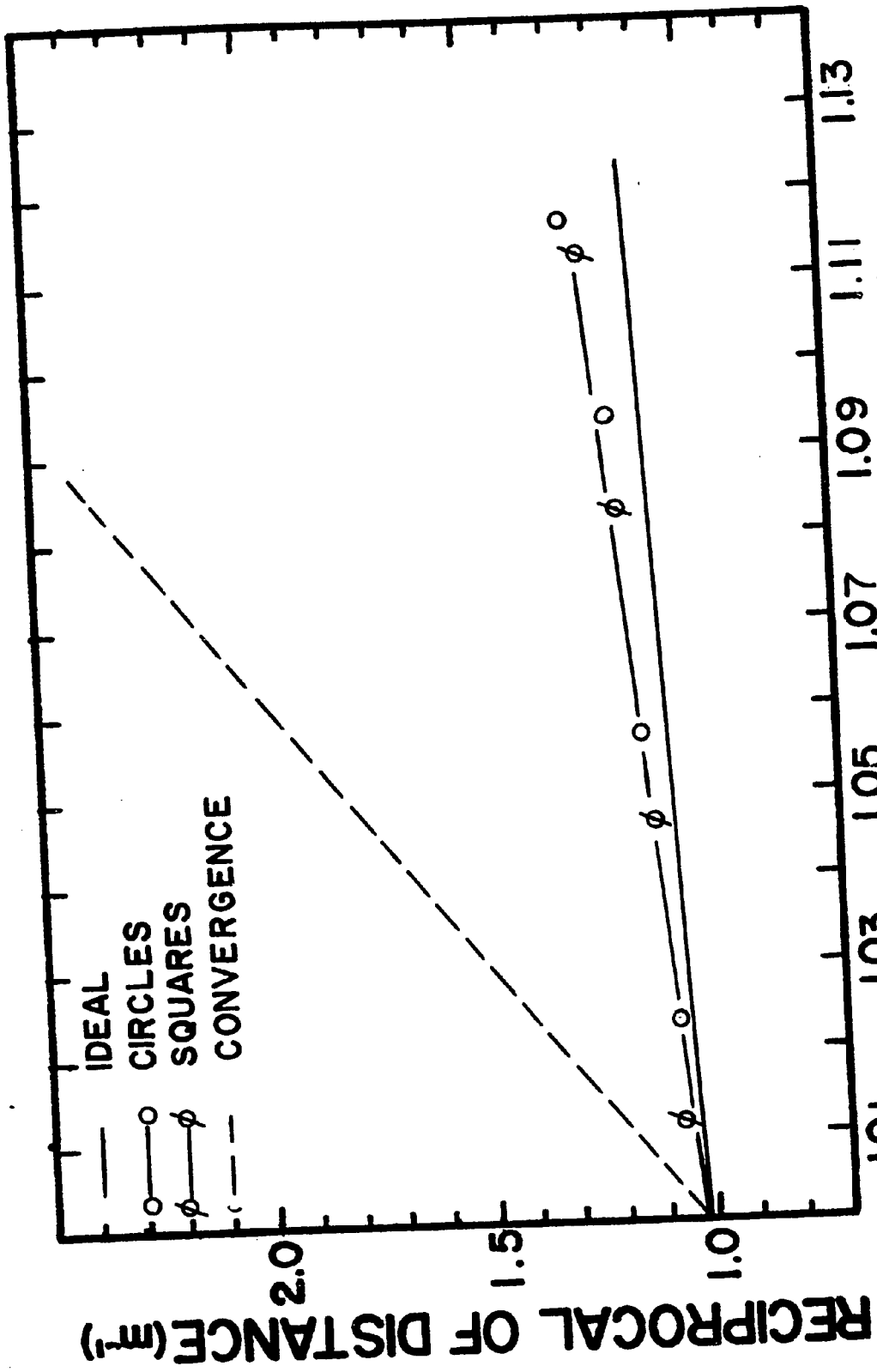


Figure 26

Observer - S.S. Comparison of data for squares, circles, an ideal observer and data expected on the basis of convergence alone.

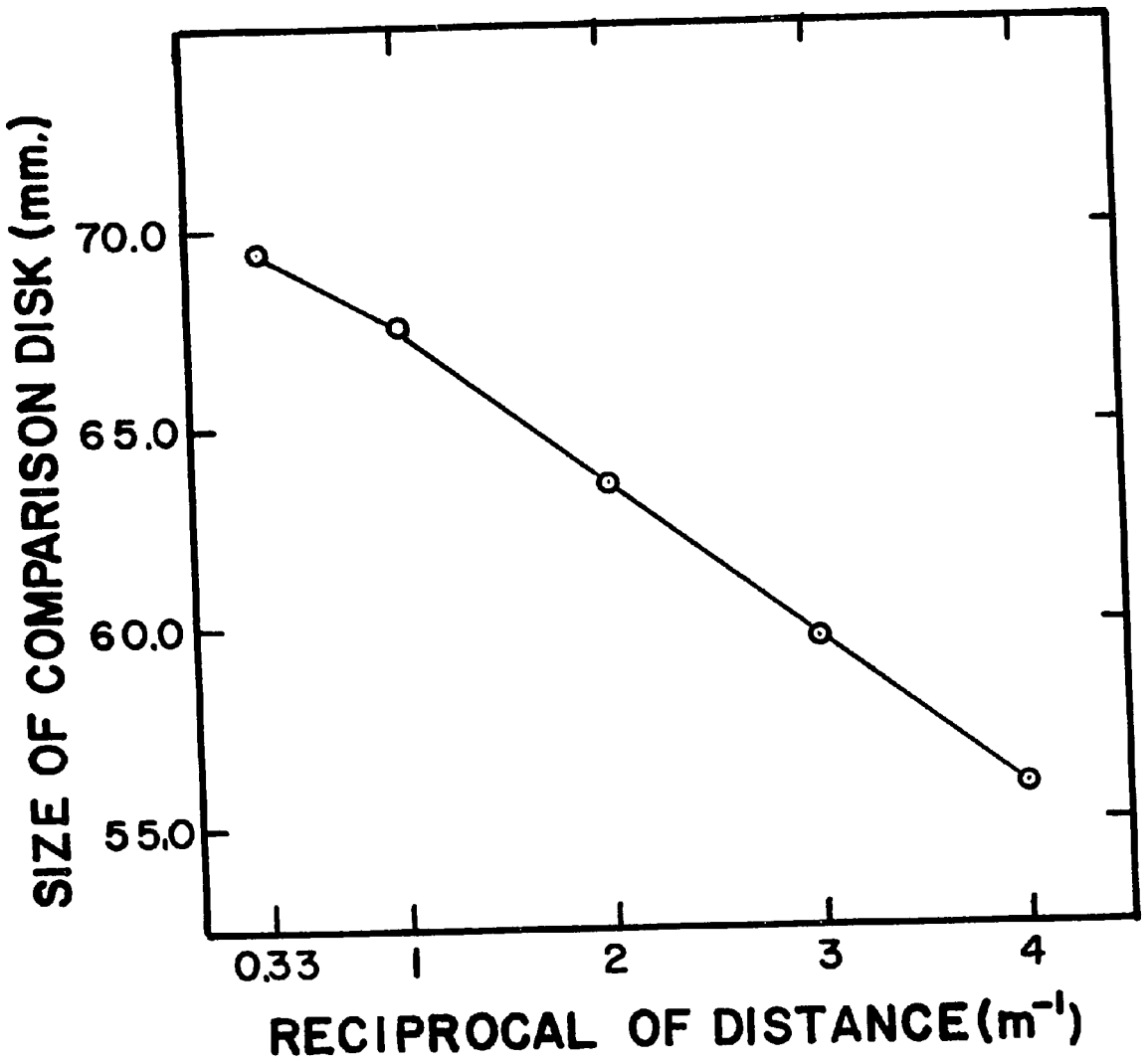


Figure 27

The perceived size of a 1° disk as a function of the reciprocal of its distance. Taken from Heinemann et.al. (1959).

were required to fuse the standard for different observers. The optical distance of all stimuli stayed constant at approximately 1/2 meter. Since the ordinate scale unit is the reciprocal of distance in meters it is easily seen that the task requires most observers to maintain their accommodative state while convergence varies through what would in the natural (nonstereoscope) viewing situation result in approximately 1 diopter change in accommodation. Thus, increases in the disparity of the comparison stimulus represented decreases in the dissonance between accommodation distance and convergence distance up to 2.0 on the ordinate.

If observer's accommodation were completely determined by the convergence distance (which is unlikely) rather than the constant optical distance accommodation would have changed 1 diopter at most. This would produce an insignificant retinal size change relative to the 10-12% perceived-size changes which were found.

As can be seen in Figures 22-25, the difference in results for circles and squares for grouped data (see Figure 16) is exhibited by each of these 4 observers. Figure 26 (observer SS) does not exhibit a difference between circles and squares. However this observer's data, are quite different in another respect also, i.e., the effect of disparity on perceived size is very much greater for her than it is for the other observers. (It should be noted that a lower slope in these figures means a greater perceived-size change per unit disparity.) In fact, her data fall surprisingly close to a line which would be predicted if an ideal range finder were performing the task. This is the line pictured for each observer, representing the physical object sizes which would give retinal sizes equal to that of standard stimulus at the convergence distances represented on the ordinate. That is, if a standard stimulus

is at a convergence distance of 1 meter then a comparison stimulus at a convergence distance of 90 cm. which has the same visual angle as the standard would have to be physically .9 the size of the standard if the distances and sizes were seen veridically. It should be pointed out that this line would have a slope of 45° if the axes had the same scale units. The facts about SS's data to be noted here for future reference are that her data fall close to this line meaning that she made the size matches by trading off distance and size almost perfectly. However, this meant she needed very little convergence change to make these matches (compared to the other observers) and she was the only observer whose data exhibited no difference between squares and circles.

Aside from a comparison with what an ideal observer would do, we can also compare these data with the data of Heinemann et.al. Heinemann's data, seen in Figure 27, were generated by having observers match a standard stimulus which was at 4 meters with comparison stimuli at various convergence distances in to 25 cm. As pointed out in Chapter 1, Heinemann allowed only convergence to influence the observers' perceived size matches. Because his grouped data are extremely linear from 1 meter in, it seems reasonable that we can pick values off his size matching function and plot the ratios of these values on our coordinates. The upper line on Figures 22-26 is the result of this inference from Heinemann's data. As such, it represents the size matching function which would have been expected from the observers in Experiment I if the size matches were governed by the effect of convergence changes alone, i.e., with no contribution from changes in apparent distance.

As can be seen, the data fall between what would be expected from convergence alone and what would be expected if distance were taken fully into account. It is likely, therefore, that apparent distance and

convergence both had an effect on the size matches. (SS is probably an exception since she used very small amounts of disparity--thus very little convergence change took place).

How might we account for the difference in results between large stimuli and small stimuli in Experiment I? Differential amounts of disparity were required to match large stimuli vs. those amounts required to match small stimuli as can be seen in Figure 12. These results might be explained by the fact that retinal size is known to influence convergence (Ittelson and Ames, 1950). Differences in convergence may be responsible for what appears to be a constant difference between the amounts of disparity required to match large figures and those amounts of disparity required to match small figures. If this is the explanation then one might expect to find some depth difference in Experiment II between large and small figures resulting from differences in retinal disparity which might be expected to accompany the change in convergence. Although there is one "significant difference" in Experiment II to this effect, it is hardly conclusive as was noted in Chapter III.

In Chapter I it was speculated that differences in sensory function for different shaped stimuli might reflect themselves in the relation between disparity and perceived size. We have seen that the effect of disparity on the perceived size of circles is different from its effect on the perceived size of squares and lines. The question is: can this difference be sensibly interpreted as being consistent with the speculations in Chapter I?

Two considerations bear on this question. 1) Is the difference in the right direction? 2) Is the difference of suitable magnitude?

Figure 28 shows the mean data of 5 observers for squares, lines and circles. The ordinate is again the reciprocal of the convergence

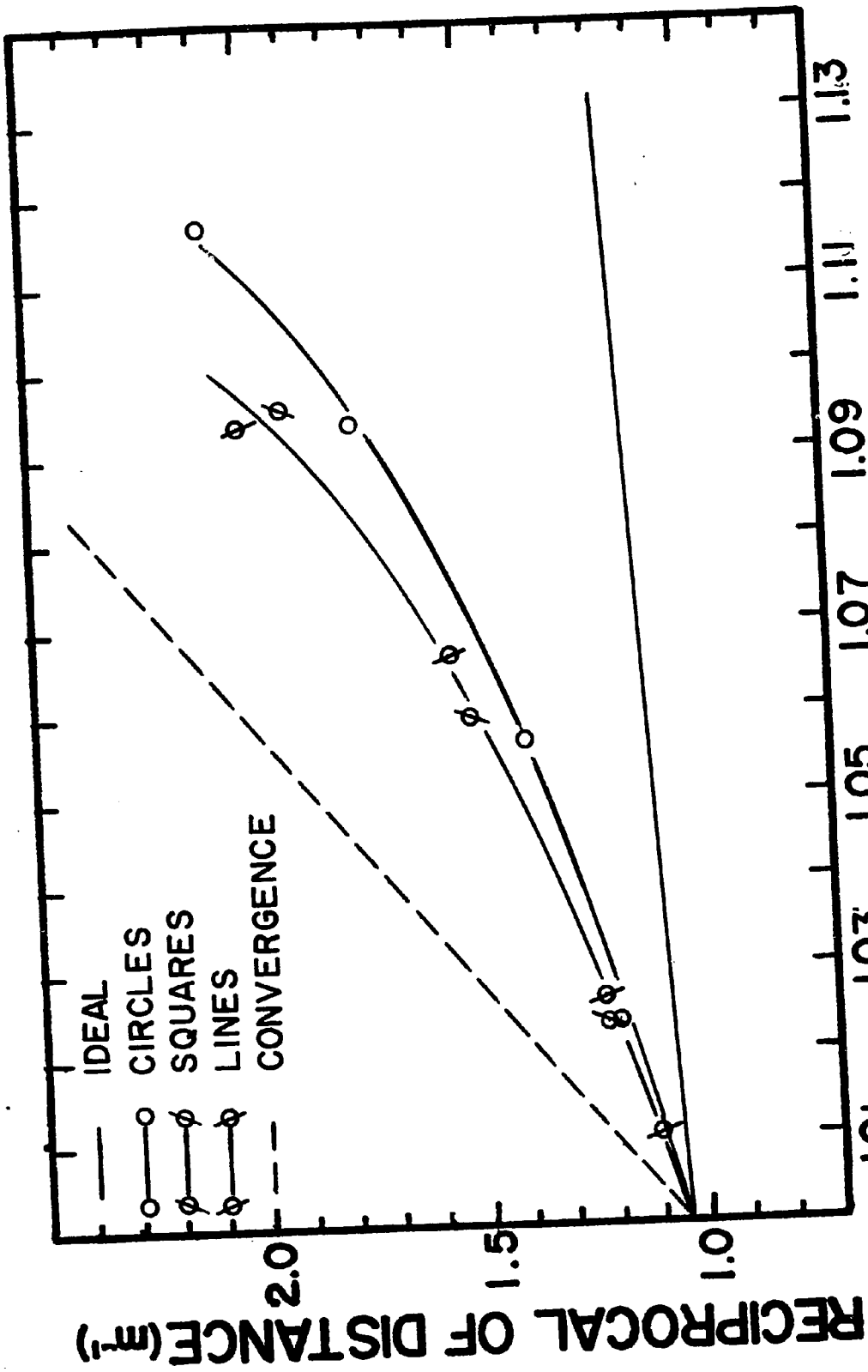


Figure 28

All observers. Comparison of data for squares and line with circles.

distance. The origin for each of the functions was calculated on the basis of the mean interocular distance for all observers. The solid lines which are drawn through the circle data and the line and square data are visually fitted lines.

The relation between these two functions may be investigated as follows. Equation (1) in Chapter I says that if the effect of convergence and/or apparent distance operates after the sensory transformation, then for a given value of convergence and/or distance:

$$(S_2/S_1)^n = (L_2/L_1)^m$$

where S and L are two differently shaped stimuli with sensory power functions described by exponents n and m respectively, and where S_2/S_1 and L_2/L_1 are size ratios of these stimuli when a perceptual match has been accomplished.

By taking S as circles and L as lines and squares we can try different values of n and m to see if the difference between these two functions is in the right direction and approximately the right size which we would predict from estimates of n and m taken from magnitude estimation studies.

If we take the sensory function for lines to be close to a linear function then we might assume that m= 1. Given m= 1, n= .87 would satisfy the data in Figure 28. This exponent (.87) is in good agreement with the exponent from magnitude estimation studies cited in Chapter I. If we reduce our assumed m to .95 which the argument in Appendix II suggests, then n= .82 would satisfy the data in Figure 28.

As mentioned above, these predictions of n from m, given the data from Experiment I, are made by assuming that either the oculomotor or the apparent distance changes, induced by changes in disparity, act on transformed size. This gives us reason to suppose that one or the other

of these effects does act on transformed size. Do we have any reason to suppose that both do?

The data of observer SS do not show a difference between circles and squares. As noted above, she experienced large apparent distance changes and very little convergence change. This might be interpreted to mean that apparent distance acts on physical (or some linear function of physical) size just as Sternberg suggests, and that the differences between circles and squares in Figure 28 is produced by convergence alone.

Thus, a hypothetical sequence of events in the perception of size which would be consistent with the data of all 5 observers is seen in Figure 28.

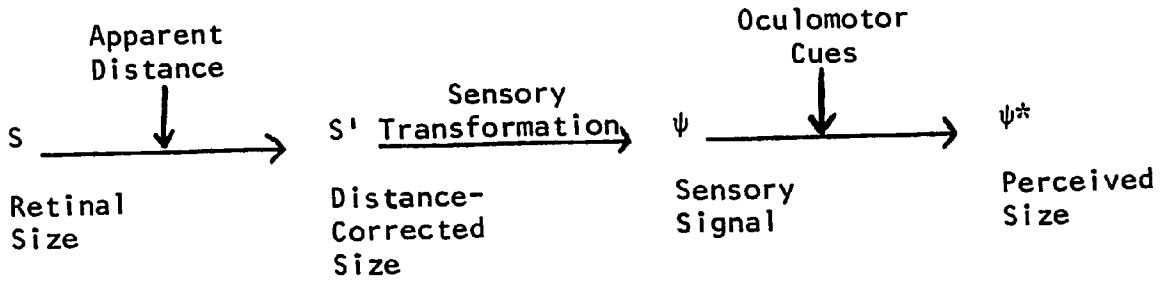


Figure 28

An hypothetical sequence of events in the perception of size which is consistent with results of Experiment I.

In conclusion, we find that the results of Experiment I show a difference between the amount of disparity required for size matching of circles and that required for lines and squares. This difference is anticipated by an hypothesis of size perception which has sensory transformed size interacting with oculomotor influences on perceived size. The size and direction of this difference are also consonant with data from previous studies using magnitude estimation techniques.

APPENDIX I

The retinal-image size (proximal-stimulus size) varies with the visual angle of the object (distal stimulus) which is being imaged. However, consideration of the structural characteristics of the eye make it seem unlikely that the effective retinal stimulus is exactly linear with respect to visual angle under all conditions.

First, because of the curved surface of the retina and the fact that the center of curvature of the retina does not coincide with the nodal point of the eye (Bennett and Francis, 1962), there is a certain amount of oblique aberration present. Second, since the center of rotation of the eye (Park and Park, 1933) does not coincide with the optical center of the eye, successive fixations produce movement of the optical center of the eye as well as the retina in relation to the distal stimulus. This non-coincidence results in progressive exaggeration of the angular movement of an object on the retina relative to the angular change of fixation with decreasing distance of the distal stimulus. Consequently, the size of the saccadic movement required to fixate a peripheral object at a constant eccentricity varies somewhat with the distance from the observer to the object. Since saccades are essentially "ballistic" movements, i.e., their direction and distance are determined before they begin, this mismatch between objective world angle and ocular movement angle must either be corrected for perceptually before the movement or result in missing the target. The mismatch is probably insignificant beyond 1 meter. However, it does alter the alignment of objects which are close to the eye with objects anywhere more distant when eye movements take place.

APPENDIX I - concluded

A third structural characteristic of the eye which detracts from an exactly linear relationship between visual angle and size of the retinal stimulus is accommodation. The size of a sharp retinal image (y') is given in mm by the product of the object focal length of the eye (f) in mm and the visual angle of the source (u) in radians (Le Grand, 1968).

$$y' = fu$$

The object focal length of the eye is given in meters by the reciprical of the total dioptric power of the eye. Le Grand's Theoretical Eye has a power of 59.9404 D and 67.6767 D unaccommodated and accommodated respectively. Thus the size of a sharp 1° retinal image for the unaccommodated eye would be .2912 mm while the size of a sharp 1° retinal image for the accommodated eye would be .2579 mm. This difference represents a factor of .8857 in retinal size between the extreme states of accommodation (Wyszecki and Stiles, 1967).

APPENDIX II

One might speculate that the sensory function for length is not precisely linear. This conjecture derives from the fact that calibrated line segments are seen as longer than uninterrupted line segments of the same length (Helmholtz, 1925).

Helmholtz attributes this phenomenon to the "rule...that in all perceptions of the senses distinctly perceptible differences appear to be larger than differences of the same objective size which are only vaguely perceived. One of the first consequences of this rule is that a graduated division of a dimension in space is easily supposed to be larger than one that is not thus divided, because the direct perception of the divisions enables us to see that the given magnitude contains so many divisions of such size more distinctly than we can do when they are not thus perceptibly marked off."

This statement comes close to saying that perceived size of space grows at a smaller ratio than physical space. That is, if small distances are more "distinctly seen" than larger ones, then perhaps the ratio between the perceived size of the larger distance to the perceived size of the smaller distance is smaller than the ratio of the two physical distances. Helmholtz cites data from Kundt who had observers bisect a distance $\overline{AE}$ with a point D. The distance was made up of segments $\overline{AB}$= 20.2 mm., $\overline{BC}$= 40.2 mm. and $\overline{AE}$= 241.9 mm. Point D was movable by the observer. For two observers (120 trials each at a distance of 338 mm.) D was put 2.68 mm. and 3.95 mm. closer to C than the actual midpoint of the line. These data are illustrated in Fig. 1. The figure shows

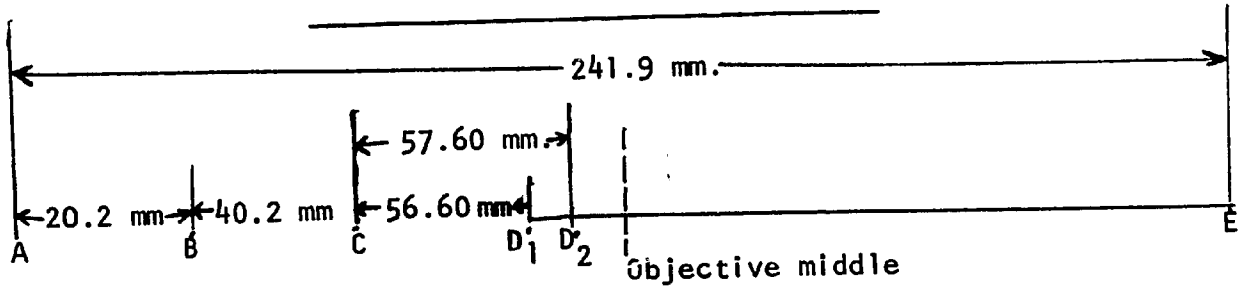


Figure 29

Representation of data from Kundt

APPENDIX II - concluded

subjective midpoint for two observers (D_1 and D_2) of a distance defined by four fixed points, A,B,C,E. Measurements made by A. Kundt, cited by Helmholtz (1925).

That these data may reflect the non-linearity of the sensory function for length (distance) may be illustrated by supposing that subjective length is governed by a power function and that the observer (say D_2) is making subjective lengths $\overline{AB}$, $\overline{BC}$, $\overline{CD}$, add up to $\overline{D_2E}$. Thus:

$$20.2^n + 40.2^n + 57.87^n = 123.6^n$$

where n is the exponent for the power function governing the relation of stimulus size to sensory size. In this case, n= .96 would account for the location of D_2. A slightly smaller exponent would be needed to account for D_1.

Smith and Milne (1909) and Smith et al. (1912) investigated the influence of margins on the bisections of lines. They found a similar effect to that of Kundt.

Thus, lines (or distances defined by end points) change their apparent length when they are segmented. One explanation for this phenomena is that the sensory function underlying length of line (or distance between points) is not precisely linear.

APPENDIX III

Wheatstone (1838) alluded to changes of the "apparent magnitude of binocular images" with changes in vergence produced with his newly invented stereoscope. Later he elaborated on this result and showed that it was still obtainable with pinhole apertures (Wheatstone, 1852), thus presumably eliminating accommodation changes as an underlying mechanism.

Judd (1897) discussed this phenomena and attributed it to "the combination of retinal images and sensations of convergence under the general law that of two objects requiring different degrees of convergence and yielding the same sized retinal images, the one requiring the greater convergence will seem smaller." He also mentioned that the object requiring more convergence also may appear nearer but he considered the effect of convergence on apparent distance weaker and not as reliable as the effect of convergence on the experience of size change.

Carr (1935) cited data of Swenson (1932) which show that the matched size of circular discs as well as judged distance decreases with both convergence and accommodation when the stimulus to accommodation and the stimulus to convergence are varied independently. Carr interpreted this to mean that either accommodation or convergence changes will produce changes in size and/or distance. However, this conclusion would seem to be unwarranted since stimulus to accommodation also influences convergence (Hofstetter, 1951).

Again, Hermans (1954) reported changes in judgements of size as a function of convergence as well as of elevation. Alpern (1962) referred to the same phenomenon as the silo-effect (smaller, in; larger, out) and noted that, in prism-vergence testing, the perceived size of the test

APPENDIX III - cont.

object diminishes and approaches the observer as a base-out prism before the eyes is increased in strength. Alpern compares these changes in apparent size with distance to those changes produced by projecting an after-image on a surface at different distances from the eye, first observed by Emmert (1881) and much studied by Young (1949, 1950, 1952a, 1952b, 1952c).

In the so-called wall paper effect, (produced by crossing your eyes while looking at a repeating design such as wall paper) objects are seen as smaller and closer with increasing convergence. Boring (1942) attributed this size change to the apparent distance change with convergence. However, Ittelson (1960) pointed out that the change in apparent distance in the wall paper effect can be accounted for by the presence of binocular disparity.

Adams (1955) showed that binocular disparity is accompanied by size change i.e., objects get smaller with increased crossed disparity. This effect was also reported using random letter stereograms (Bunge and Bechtoldt, 1967) and it was attributed to an effect on apparent size by changes in apparent distance. Also Gulick (1967) had observers judge the linear sizes of squares viewed stereoscopically with different degrees of corssed disparity, using a magnitude-estimation technique. He related judged height and width to decreases in judged distance resulting from increased crossed disparity.

Despite this apparent relationship between perceived size and perceived distance in the wall paper effect and stereopsis, it is probable that in fact there is some decrease in perceived size due to increased convergence in these two phenomena. Heinemann, Tulving and

APPENDIX III - cont.

Nachmias (1959) in a series of experiments showed that:

(1) With monocular observation through an artificial pupil, size matches were governed by retinal size alone.

(2) With monocular observation and natural pupil, the matched sizes of a series of 1° disks increased with distance. Thus when accommodation was allowed to operate, apparent size increased with decreasing accommodation.

(3) Under the above conditions, judgments of distance in general were such that physically closer targets (hence perceptually smaller) were seen as farther away than physically more distant targets. (Thus smaller-out; larger-in). Consequently, one can assume that perceived distance change is not what produced the size change in 2 above. Rather the size change must have been directly due to either accommodation changes or convergence changes accompanying these accommodations changes.

(4) With binocular observation of a fixation point-but only monocular observation of the target discs-apparent size increased with physical distance. Further it increased in almost precisely the same way when accommodative and pupillary adjustments were prevented by the application of homatropine to the observer's eyes. Consequently the results in 3 above were probably due to the convergence change accompanying accommodation changes.

Thus, it would seem that convergence alone is enough to decrease apparent size. But when increased convergence is a result of disparate retinal stimuli, i.e., fusional convergence, a decrease in size result-

APPENDIX III - concluded

ing from decreased fusional convergence is accompanied by decreased perceived distance resulting from increased crossed disparity. In this case both the decreased apparent distance and fusional convergence probably contribute to the decreased size.

APPENDIX IV

DIMENSIONS OF STIMULI BY CONDITION IN EXPERIMENT I

Condition	Stimuli		° of arc
1	Standard:	3.02 cm. line	3° 32'
	Comparisons:	3.05 cm. line	3° 34'
		3.10 cm. line	3° 37'
		3.22 cm. line	3° 46'
		3.30 cm. line	3° 52'
		3.40 cm. line	3° 59'
2	Standard:	6.0 cm. line	7° 1'
	Comparisons:	6.02 cm. line	7° 2'
		6.22 cm. line	7° 16'
		6.41 cm. line	7° 30'
		6.60 cm. line	7° 43'
		6.79 cm. line	7° 56'
3	Standard:	3.00 cm. separated X's	3° 30'
	Comparisons:	3.00 cm. separated X's	3° 30'
		3.12 cm. separated X's	3° 39'
		3.20 cm. separated X's	3° 44'
		3.30 cm. separated X's	3° 52'
		3.42 cm. separated X's	4° 0'
4	Standard:	5.98 cm. separated X's	7° 0'
	Comparisons:	6.00 cm. separated X's	7° 1'
		6.20 cm. separated X's	7° 15'
		6.40 cm. separated X's	7° 29'
		6.58 cm. separated X's	7° 42'
		6.80 cm. separated X's	7° 57'
3'	Standard:	3.05 cm. between X's	3° 34'
	Comparisons:	3.10 cm. between X's	3° 37'
		3.15 cm. between X's	3° 41'
		3.24 cm. between X's	3° 47'
		3.36 cm. between X's	3° 56'
		3.45 cm. between X's	4° 2'
4'	Standard:	6.02 cm. between X's	7° 2'
	Comparisons:	6.07 cm. between X's	7° 6'
		6.24 cm. between X's	7° 18'
		6.45 cm. between X's	7° 33'
		6.63 cm. between X's	7° 45'
		6.85 cm. between X's	8° 1'

APPENDIX IV- cont.

Condition	Stimuli		° of arc
5	Standard:	3.01 cm. outline circle	3° 31'
	Comparisons:	3.01 cm. outline circle	3° 31'
		3.08 cm. outline circle	3° 36'
		3.18 cm. outline circle	3° 43'
		3.29 cm. outline circle	3° 51'
		3.36 cm. outline circle	3° 56'
6	Standard:	5.96 cm. outline circle	6° 58'
	Comparisons:	5.96 cm. outline circle	6° 58'
		6.20 cm. outline circle	7° 15'
		6.35 cm. outline circle	7° 26'
		6.60 cm. outline circle	7° 43'
		6.77 cm. outline circle	7° 55'
7	Standard:	3.01 cm. solid circle	3° 31'
	Comparisons:	3.01 cm. solid circle	3° 31'
		3.08 cm. solid circle	3° 36'
		3.18 cm. solid circle	3° 43'
		3.29 cm. solid circle	3° 51'
		3.36 cm. solid circle	3° 56'
8	Standard:	5.96 cm. solid circle	6° 58'
	Comparisons:	5.96 cm. solid circle	6° 58'
		6.20 cm. solid circle	7° 15'
		6.35 cm. solid circle	7° 26'
		6.60 cm. solid circle	7° 43'
		6.77 cm. solid circle	7° 55'
9	Standard:	3.04 cm. outline square	3° 33'
	Comparisons:	3.04 cm. outline square	3° 33'
		3.11 cm. outline square	3° 38'
		3.22 cm. outline square	3° 46'
		3.33 cm. outline square	3° 54'
		3.42 cm. outline square	4° 0'
10	Standard:	6.02 cm. outline square	7° 2'
	Comparisons:	6.02 cm. outline square	7° 2'
		6.22 cm. outline square	7° 16'
		6.45 cm. outline square	7° 33'
		6.63 cm. outline square	7° 45'
		6.85 cm. outline square	8° 1'

APPENDIX IV - cont.

Condition	Stimuli		° of arc
11	Standard:	3.04 cm. solid square	3° 33'
	Comparisons:	3.04 cm. solid square	3° 33'
		3.11 cm. solid square	3° 38'
		3.22 cm. solid square	3° 46'
		3.33 cm. solid square	3° 54'
		3.42 cm. solid square	4° 0'
12	Standard:	6.02 cm. solid square	7° 2'
	Comparisons:	6.02 cm. solid square	7° 2'
		6.22 cm. solid square	7° 16'
		6.45 cm. solid square	7° 33'
		6.63 cm. solid square	7° 45'
		6.85 cm. solid square	8° 1'
13	Standard:	3.02 cm. line	3° 32'
	Comparisons:	3.04 cm. solid square	3° 33'
		3.11 cm. solid square	3° 38'
		3.22 cm. solid square	3° 46'
		3.33 cm. solid square	3° 54'
		3.42 cm. solid square	4° 0'
14	Standard:	3.04 cm. solid square	3° 33'
	Comparisons:	3.05 cm. line	3° 34'
		3.10 cm. line	3° 37'
		3.22 cm. line	3° 46'
		3.30 cm. line	3° 52'
		3.40 cm. line	3° 59'
15	Standard:	3.02 cm. line	3° 32'
	Comparisons:	3.01 cm. solid circle	3° 31'
		3.08 cm. solid circle	3° 36'
		3.18 cm. solid circle	3° 43'
		3.29 cm. solid circle	3° 51'
		3.36 cm. solid circle	3° 56'
16	Standard:	3.01 cm. solid circle	3° 31'
	Comparisons:	3.05 cm. line	3° 34'
		3.10 cm. line	3° 37'
		3.22 cm. line	3° 46'
		3.30 cm. line	3° 52'
		3.40 cm. line	3° 59'

APPENDIX IV- cont.

Condition	Stimuli		° of arc
17	Standard:	3.01 cm. solid circle	3° 31'
	Comparisons:	3.04 cm. solid square	3° 33'
		3.11 cm. solid square	3° 38'
		3.22 cm. solid square	3° 46'
		3.33 cm. solid square	3° 54'
		3.42 cm. solid square	4° 0'
18	Standard:	3.04 cm. solid square	3° 33'
	Comparisons:	3.01 cm. solid circle	3° 31'
		3.08 cm. solid circle	3° 36'
		3.18 cm. solid circle	3° 43'
		3.29 cm. solid circle	3° 51'
		3.36 cm. solid circle	3° 56'
19	Same as condition 17		
20	Same as condition 18		

APPENDIX V
MEANS AND STANDARD ERRORS BY OBSERVER AND CONDITION FOR EXPERIMENT I

Observer		Comparison 1	2	3	4	5
			Condition 1			
DH	M	-.86	.03	1.035	2.10	2.905
	SE	.118	.126	.135	.183	.204
JH	M	-.025	.36	1.15	3.605	4.14
	SE	.088	.117	.209	.277	.280
SS	M	-.067	.022	.12	.262	.342
	SE	.011	.034	.037	.028	.045
DW	M	.04	.27	1.625	2.61	3.09
	SE	.029	.069	.125	.179	.283
AC	M	.135	.415	1.90	3.19	(3.472)9
	SE	.057	.097	.265	.444	(.469)
Total	M	-.1554	.2194	1.166	2.3534	(2.7898)
	SE	.06	.047	.114	.200	(.223)
			Condition 2			
DH	M	-.645	1.115	2.45	(3.569)9	(3.697)6
	SE	.136	.176	.182	-	-
JH	M	.085	1.27	2.84	4.69	(4.552)7
	SE	.117	.260	.522	.054	-
SS	M	-.035	.085	.257	.324	.547
	SE	.024	.017	.025	.014	.043
DW	M	.01	.61	1.48	2.465	3.01
	SE	.033	.102	.050	.134	.115
AC	M	.065	.615	1.985	3.315	(3.255)6
	SE	.027	.160	.346	.398	-
Total	M	-.104	.739	1.802	(2.873)	(3.012)
	SE	.053	.092	.179	(.230463)	-

APPENDIX V - cont.
MEANS AND STANDARD ERRORS BY OBSERVER
AND CONDITION FOR EXPERIMENT I

Observer		Comparison 1	2	3	4	5
			Condition 3			
DH	M	-.52	.44	.605	1.81	2.715
	SE	.188	.140	.082	.230	.236
JH	M	.072	.73	1.15	3.31	4.19
	SE	.060	.171	.231	.208	.127
SS	M	-.121	.035	.12	.217	.319
	SE	.02	.053	.021	.055	.029
DW	M	-.06	.28	.845	1.95	2.725
	SE	.032	.057	.156	.266	.265
AC	M	.22	.91	1.73	2.925	(3.25)9
	SE	.042	.25	.340	.528	-
Total	M	.0818	.479	.89	2.0424	(2.6398)
	SE	.053	.079	.115	.200	.225
			Condition 4			
DH	M	-.535	.965	2.045	3.155	(3.148)8
	SE	.217	.20	.307	.146	-
JH	M	.735	2.185	3.625	(4.363)9	(4.166)7
	SE	.162	.326	.274	-	-
SS	M	-.11	.095	.215	.385	.595
	SE	.039	.036	.028	.038	.054
DW	M	.275	.61	1.585	2.46	3.075
	SE	.064	.089	.144	.116	.099
AC	M	.245	.715	1.43	2.82	(3.536)8
	SE	.042	.137	.318	.450	-
Total	M	.122	.914	1.75	(2.6366)	(2.903)
	SE	.082	.128	.188	(.209)	(.220)

APPENDIX V - cont.

Observer		Comparison 1	2	3	4	5
			Condition 5			
DH	M	-.345	-.05	.665	2.01	3.08
	SE	.063	.060	.170	.265	.195
JH	M	-.115	.17	.675	1.74	3.07
	SE	.047	.084	.098	.137	.152
SS	M	-.26	-.10	.04	.265	.372
	SE	.018	.025	.033	.058	.045
DW	M	-.04	.265	.975	1.72	3.00
	SE	.01	.025	.039	.098	.181
AC	M	.085	.31	1.715	3.43	(4.087)8
	SE	.021	.050	.233	.411	-
Total	M	-.135	.119	.814	1.833	(2.722)
	SE	.027	.033	.098	.175	(.206)
			Condition 6			
DH	M	.04	.85	2.005	(3.821)9	(4.07)5
	SE	.141	.152	.223	-	-
JH	M	-.09	.30	.915	2.689	2.835
	SE	.049	.111	.150	.121	.042
SS	M	-.235	-.105	-.008	.17	.349
	SE	.016	.027	.008	.028	.023
DW	M	-.02	.455	.80	1.735	2.515
	SE	.011	.046	.064	.067	.095
AC	M	.155	.71	1.55	(2.585)4	-
	SE	.035	.091	.261	-	-
Total	M	-.03	.442	1.052	(2.199)	(2.442)
	SE	.035	.063	.122	(.211)	-

APPENDIX V - cont.

Observer		Comparison 1	2	3	4	5
			Condition 7			
DH	M	-.915	-.145	.51	1.70	3.17
	SE	.075	.043	.103	.085	.137
JH	M	-.335	-.03	.795	1.98	3.715
	SE	.112	.068	.142	.284	.212
SS	M	-.26	-.091	.065	.225	.479
	SE	.042	.022	.022	.03	.056
DW	M	-.005	.245	.935	1.845	2.725
	SE	.014	.022	.096	.122	.099
AC	M	.03	.41	1.075	3.125	3.88
	SE	.03	.073	.135	.416	.405
Total	M	-.297	.078	.676	1.775	2.794
	SE	.056	.037	.069	.166	.199
			Condition 8			
DH	M	-.025	.67	1.625	(3.808)9	(3.812)4
	SE	.101	.122	.239	-	-
JH	M	-.105	.435	1.095	2.855	(3.1)7
	SE	.027	.072	.106	.097	-
SS	M	-.19	-.065	-.025	.104	.257
	SE	.018	.011	.008	.019	.022
DW	M	.06	.59	1.035	1.92	2.725
	SE	.035	.053	.055	.084	.090
AC	M	.04	.42	1.135	(2.619)8	-
	SE	.022	.057	.162	-	-
Total	M	-.044	.41	.973	(2.261)	(2.474)
	SE	.026	.048	.1	.194	-

APPENDIX V - cont.

Observer		Comparison 1	2	3	4	5
			Condition 9			
DH	M	-.84	.03	1.15	2.565	3.43
	SE	.146	.055	.114	.153	.164
JH	M	-.165	-.135	.735	2.705	3.965
	SE	.110	.067	.291	.304	.128
SS	M	-.378	-.085	.062	.269	.479
	SE	.028	.013	.013	.045	.055
DW	M	-.01	.635	1.265	2.61	3.555
	SE	.022	.072	.166	.213	.211
AC	M	.10	.45	1.985	4.055	(3.687)4
	SE	.020	.057	.293	.407	-
Total	M	-.349	.179	1.039	2.441	(3.023)
	SE	.062	.050	.124	.206	(.228)
			Condition 10			
DH	M	-.245	1.565	(2.679)7	(2.95)6	(2.984)3
	SE	.064	.209	-	-	-
JH	M	-.12	2.39	(3.043)7	(2.90)2	-
	SE	.068	.282	-	-	-
SS	M	-.265	.072	.187	.339	.612
	SE	.036	.013	.021	.006	.031
DW	M	-.10	.456	1.067	1.95	2.622
	SE	.019	.063	.086	.104	.084
AC	M	.015	.435	(2.187)8	(2.733)3	-
	SE	.026	.055	-	-	-
Total	M	-.149	.984	(1.833)	(2.174)	(2.071)
	SE	.024	.144	-	-	-

APPENDIX V - cont.

Observer		Comparison 1	2	3	4	5
			Condition 11			
DH	M	.845	-.210	1.445	2.99	3.725
	SE	.128	.093	.108	.17	.160
JH	M	-.57	.04	.595	2.56	3.495
	SE	.102	.167	.311	.296	.309
SS	M	-.406	-.125	-.011	.169	.350
	SE	.035	.019	.018	.033	.032
DW	M	.023	.445	1.24	2.26	3.445
	SE	.018	.043	.118	.123	.185
AC	M	.05	.59	1.905	3.355	(3.36)7
	SE	.015	.109	.332	.494	-
Total	M	-.359	.148	1.035	2.267	(2.875)
	SE	.058	.057	.133	.198	.226
			Condition 12			
DH	M	-.315	.79	(1.767)7	(3.07)5	(3.41)2
	SE	.094	.175	-	-	-
JH	M	-.15	.61	(2.822)8	(2.397)4	(2.235)2
	SE	.089	.274	-	-	-
SS	M	-.213	-.033	.14	.22	.492
	SE	.025	.012	.011	.018	.029
DW	M	-.085	.31	.985	1.73	2.725
	SE	.019	.051	.086	.129	.10
AC	M	.035	.22	(1.949)9	(2.512)4	-
	SE	.027	.043	-	-	-
Total	M	-.146	.379	(1.533)	(1.986)	(2.215)
	SE	.032	.076	(.160)	-	-

APPENDIX V - cont.

Observer		Comparison 1	2	3	4	5
			Condition 13			
DH	M	.145	.860	1.66	2.625	3.30
	SE	.140	.170	.272	.240	.132
JH	M	-.620	-.04	.36	1.08	2.20
	SE	.101	.162	.106	.208	.341
SS	M	-.195	-.051	.077	.205	.334
	SE	.032	.026	.034	.035	.006
DW	M	-.08	.325	1.12	1.92	3.01
	SE	.033	.061	.179	.235	.179
AC	M	.365	.81	2.57	3.525	(3.558)6
	SE	.123	.178	.328	.340	-
Total	M	-.077	.381	1.157	1.871	(2.480)
	SE	.061	.081	.159	.193	(.204)
			Condition 14			
DH	M	-.81	-.20	.955	1.645	2.34
	SE	.137	.212	.261	.216	.173
JH	M	-.125	.275	.90	2.125	2.997
	SE	.157	.207	.291	.410	.318
SS	M	-.266	-.116	.01	.131	.212
	SE	.034	.019	.021	.022	.017
DW	M	.065	.25	1.20	1.895	2.69
	SE	.078	.042	.088	.166	.119
AC	M	.11	.39	1.62	2.94	3.575
	SE	.045	.126	.254	.379	.407
Total	M	-.225	.1198	.937	1.747	2.363
	SE	.065	.071	.118	.177	.196

APPENDIX V - cont.

Observer		Comparison 1	2	3	4	5
			Condition 15			
DH	M	-1.615	-1.53	-.865	-.11	.51
	SE	.073	.095	.171	.187	.249
JH	M	-2.01	-1.56	-1.045	-.91	-.165
	SE	.056	.126	.154	.149	.147
SS	M	-.285	-.24	0	.07	.287
	SE	.064	.055	.051	.031	.042
DW	M	-1.315	-.785	-.215	.055	.30
	SE	.207	.197	.046	.053	.094
AC	M	.185	.56	.945	2.805	3.76
	SE	.051	.162	.129	.385	.405
Total	M	-1.008	-.74	-.236	.382	.938
	SE	.127	.129	.114	.201	.226
			Condition 16			
DH	M	.245	.955	2.035	2.545	3.165
	SE	.243	.229	.314	.226	.166
JH	M	1.585	2.435	3.185	3.965	4.565
	SE	.264	.368	.26	.187	.063
SS	M	-.146	-.033	.022	.205	.335
	SE	.067	.048	.032	.041	.05
DW	M	1.69	1.66	2.86	4.145	(4.335)7
	SE	.254	.178	.291	.235	-
AC	M	.36	.525	1.60	3.35	3.68
	SE	.073	.162	.364	.390	.361
Total	M	.747	1.1084	1.940	2.842	(3.216)
	SE	.137	.156	.199	.230	.234

APPENDIX V - cont.

Observer		Comparison 1	2	3	4	5
			Condition 17			
DH	M	.20	1.05	1.73	2.83	3.43
	SE	.264	.238	.376	.186	.297
JH	M	3.055	3.755	4.24	(4.175)8	(4.175)6
	SE	.305	.298	.074	-	-
SS	M	.19	.435	.505	.815	.985
	SE	.038	.061	.074	.108	.08
DW	M	3.565	(4.285)8	(4.34)4	(4.55)1	-
	SE	.247	-	-	-	-
AC	M	3.21	(4.067)9	-	-	-
	SE	.371	-	-	-	-
Total	M	2.044	(2.7184)	(2.704)	(3.093)	(2.865)
	SE	.246	-	-	-	-
			Condition 18			
DH	M	-1.62	-.88	-.27	.52	1.085
	SE	.284	.366	.299	.409	.394
JH	M	-2.275	-1.615	-1.205	-.72	-.24
	SE	.090	.120	.153	.07	.091
SS	M	-1.77	-1.31	-1.125	-.663	-.495
	SE	.153	.160	.089	.071	.065
DW	M	(-3.15)1	(-3.15)5	-2.77	-1.50	-.995
	SE	-	-	.205	.122	.195
AC	M	-1.33	-.825	-.495	-.045	.305
	SE	.201	.110	.094	.062	.070
Total	M	(2.029)	(-1.556)	-1.173	-.690	-.068
	SE	-	-	.148	.129	.134

APPENDIX V - concluded

Observer		Comparison 1	2	3	4	5
			Condition 19			
DH	M	-.04	.525	1.80	2.785	2.95
	SE	.117	.191	.203	.192	.150
JH	M	2.95	3.645	4.005	4.195	(4.339)9
	SE	.234	.171	.096	.095	-
SS	M	-.225	-.015	.127	.267	.47
	SE	.050	.048	.043	.058	.067
DW	M	1.71	2.955	3.855	(4.425)7	(4.65)2
	SE	.188	.175	.189	-	-
AC	M	.575	2.06	2.885	(3.789)9	-
	SE	.147	.265	.339	-	-
Total	M	.994	1.834	2.534	(3.092)	(3.102)
	SE	.183	.214	.223	-	-
			Condition 20			
DH	M	-1.96	-1.205	-.555	.28	.865
	SE	.095	.134	.206	.226	.200
JH	M	-2.08	-1.58	-1.16	-.45	-.125
	SE	.165	.096	.048	.090	.119
SS	M	-.655	-.49	-.275	-.04	.052
	SE	.135	.110	.085	.054	.043
DW	M	-2.57	-1.525	-.82	-.32	.12
	SE	.151	.194	.184	.060	.041
AC	M	-.41	.03	.42	1.545	2.615
	SE	.094	.121	.119	.284	.376
Total	M	-1.54	-.954	-.478	.202	.705
	SE	.133	.107	.098	.126	.168

APPENDIX VI

MEANS AND SUMS OF SQUARES BY OBSERVER AND CONDITION FOR EXPERIMENT II*

Condition		Observer DH	JH	SS	DW	AC
1	M	.48	.483	.518	.525	.433
	SS	3.730	2.3657	2.6867	2.7609	1.8849
2	M	.414	.519	.525	.517	.477
	SS	2.8676	2.7083	2.7587	2.6761	2.2809
3	M	.507	.535	.545	.535	.488
	SS	3.1627	2.8753	2.9739	2.8643	2.3870
4	M	.535	.50	.504	.515	.474
	SS	3.8875	2.5120	2.5408	2.6555	2.2526
5	M	.387	.4800	.498	.52	.484
	SS	2.2037	2.3212	2.4828	2.7066	2.3484
6	M	.17	.5110	.524	.527	.475
	SS	1.3850	2.6233	2.4784	2.7803	2.2637
7	M	.227	.506	.512	.522	.497
	SS	1.3699	2.5652	2.6266	2.7268	2.4997
8	M	.339	.4740	.496	.518	.491
	SS	1.6989	2.2610	2.4656	2.6854	2.4239
9	M	.698	.4740	.503	.491	.461
	SS	5.519	2.3182	2.5309	2.4147	2.1393
10	M	.898	.5130	.498	.507	.472
	SS	8.6486	2.8997	2.4878	2.5727	2.2338
11	M	.6210	.482	.521	.544	.467
	SS	5.1221	2.3634	2.7163	2.9600	2.1915
12	M	.132	.487	.502	.528	.529
	SS	1.0364	2.3793	2.5206	2.7906	2.8025
13	M	.352	.50	.521	.532	.459
	SS	2.7662	2.5212	2.7169	2.8328	2.1117
14	M	.214	.512	.537	.54	.509
	SS	.8798	2.6382	2.8849	2.9178	2.5947

*These data are based on raw scores from which .5 has been subtracted.

APPENDIX VI - concluded

Condition		DH	JH	SS	DW	AC
15	M	.823	.493	.467	.487	.414
	SS	7.3369	2.4935	2.1849	2.3761	1.7400
16	M	.733	.439	.442	.480	.422
	SS	8.4889	2.1203	1.9578	2.315	1.7850

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