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THE EFFECT OF STIMULUS SIZE ON THE PERCEPTION OF CONTOURS

BY

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date

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Executive Officer

The City University of New York

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Since the discovery of the "on-off" receptive fields of vertebrate optic nerve fibers and of the interrelationships among elements of the compound eye of Limulus, much research has been devoted to the study of interactions among parts of the retina. The interaction found in the eye of Limulus is lateral inhibition which can yield patterns of response similar to the Mach bands reported by human observers (Ratliff and Hartline, 1959). Where adjoining areas of the visual field have different luminances, lateral inhibition can cause an accentuation of the contour between the two areas (Ratliff and Hartline, 1959).

The present study was intended to determine the area over which interaction is effective in the formation of contours. Some evidence on the extent of interaction is already available from brightness contrast and difference threshold experiments. Leibowitz, Mote, and Thurlow (1953) found that an inducing field separated from a test field by 10' of visual angle diminished the brightness of the test field by a considerable amount. When the separation was increased to 30', the inducing field had practically no effect. Diamond (1955) found that as he increased the size of an inducing field, the brightness of an adjacent test field decreased. The length of inducing field beyond which further increases had no effect on test-field brightness varied considerably with inducing field luminance and subject, with the range being 5' to 27'. Thomas (1968) found that increasing the size of inducing fields on both sides of either a light or a dark test line caused an alteration in the brightness of the line. The maximum effect occurred for inducing fields of 16' width ; an increase to 32' had no further effect.

Beitel (1936) found that the threshold for detecting a 10' square field on a dim background was increased by the presence of another 10' square when the separation between the two was 8.5' or less. When the separation was 17.2', the threshold of the one square was not affected by the presence of the other. Stecher (1968) found that the threshold for seeing a brightness difference between two rectangles increased when the two rectangles were separated from each other. Most of the increase occurred with separations up to 7'.

More directly related to the present experiment are observations on the contribution of stimulated areas to the appearance of Mach bands. Mach (cited in Ratliff, 1965) concluded that points within 16' of a dark Mach band contributed to the appearance of the band. Békésy (1960) estimated the half-width of his theoretical neural units to be 10' to 5'. This value would be the maximum extent on the retina over which stimulation on one point could exercise inhibitory effect.

The relationship between Mach bands and the contours seen at edges is still not clear. On the one hand, contours may be considered an extreme or limiting case of Mach bands, in which both the bright and dark bands become extremely narrow. This approach is supported by evidence that Mach bands are visible at the locus of a luminance step (Matthews, 1966) and by apparent brightness mappings of luminance step patterns done by Békésy (1968) and Heinemann (in press).

Further support for this approach stems from the recognition that, because of the spread function of the eye, even the most carefully focused luminance steps are imaged as gradients of illumination on the retina (Westheimer and Campbell, 1962; Krauskopf, 1962). Evidence against this approach comes from the more frequent report that Mach bands are <u>not</u> seen at the borders between fields of different luminance (Fiorentini and Radici, 1958, cited in Ratliff, 1965).

A technique which has been used for studying the processes occurring in fields with luminance gradients or abrupt luminance changes is to find the difference threshold for a small stimulus presented at various locations in the larger stimulus. Such experiments may reveal if the processes occurring with the Mach band- and contour- producing stimuli are similar, and they provide estimates of the extent of interaction among elements of the retina. Fiorentini, Jeanne, and Toraldo di Francia (1955, cited in Ratliff, 1965) found that the difference threshold for a small spot of light was elevated in the region of a bright Mach band, but not in the region of a dark Mach band. The threshold was not affected if the spot was presented at some distance from the luminance gradient on the bright side, the distance necessary for no effect varying between 4' for steeper gradients and 12' for flatter gradients. Fiorentini and Zoli (1966) found the difference threshold for a thin line stimulus presented at various locations in a field which contained a light-dark boundary. The threshold was highest at the boundary, and on either side of the boundary it dropped gradually until it reached a constant level at about 7' from the boundary. In a second experiment Fiorentini and Zoli (1967) used the same procedure as above, but the contrast at the light-dark boundary was subliminal or barely supraliminal. In this case they found that ΔI for the thin line was elevated just adjacent to the light-dark boundary on the dark side and *lowered* adjacent to the boundary on the light side. Once again these effects seem to extend out to 7' from the boundary.

The idea of measuring the area necessary for perceiving a sharp contour was suggested by Lamar, Hecht, Schlaer, and Hendley's concept (1947) of the "useful area" involved in making brightness discriminations. Lamar et al. obtained the luminance difference threshold in a spatial forced-choice situation for rectangular fields whose area ranged from 0.5 to 800.0 square minutes of visual angle. For each stimulus area, there were stimuli of three to five values of length-to-width ratio, or perimeter, for a total of 45 different stimuli. They found that the thresholds for the rectangles are not related to area in any simple way. Total flux at threshold ($\Delta I/I$ X area) is a monotonically increasing function of length of field when the width of the field is less than about 3'. When width exceeds 3', total flux increases as the field width increases. Lamar et al. interpret this last finding as indicating that the addition of area beyond a width of 3' does not serve to lower the threshold of the stimulus. Said another way, the addition to the stimulus of area which is farther than 1½' from the stimulus border does not lower the threshold for the stimulus. In other words, Lamar et al. seem to have found that a thin strip of area around the border of the test field determined the difference threshold. Their estimate of 1½' for the width of this useful strip seemed to unify all their data on difference thresholds for rectangular fields. This useful strip width is obviously much smaller than the estimates of interaction distance found in all the previously mentioned studies.

In the present study the luminance difference necessary for seeing a sharp contour between two fields has been measured while the area of the fields on either side of the contour was varied. This is a more direct test of the contribution of area than Lamar et al. achieved, since the length of the contour (corresponding to Lamar et al.'s perimeter) could be held constant while the stimulated area was increased on both sides of the contour. Since the Lamar et al. treatment suggests that the length of the border (perimeter, in their case) is an important variable, the length of the border to be detected has been varied in this experiment.

APPARATUS

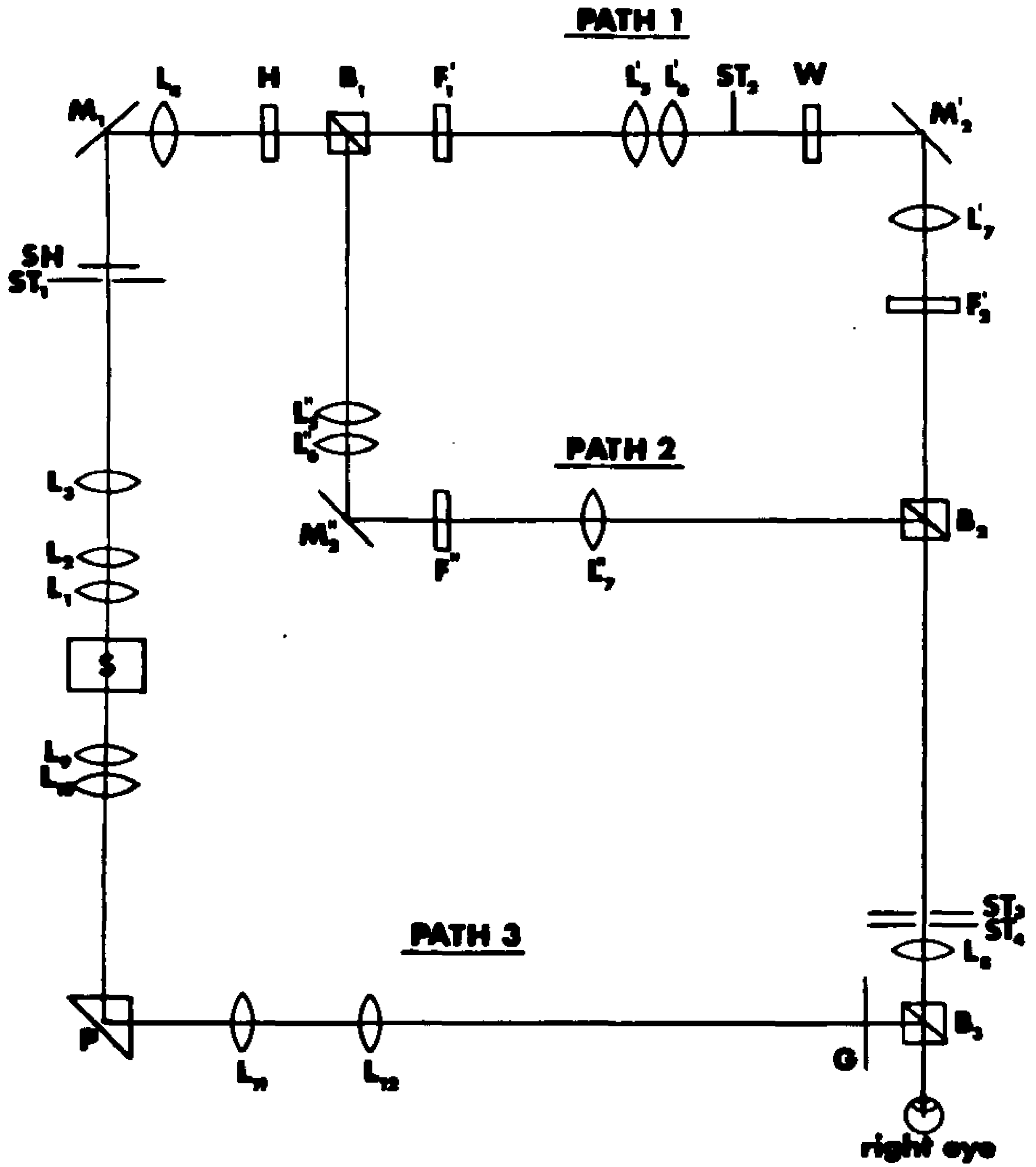
Figure 1 is a schematic diagram of the optical system, which presented stimuli to the subject's right eye. The light source (S) is a projection lamp with a horizontal ribbon filament (Westinghouse EDW T10 SR 6A). The source was run at a constant current of 15.5 amps supplied by an Electro H filtered DC power supply.

The lenses L_1 and L_2 collimate the light from the source. Lens L_3 forms an image of the filament in the plane of stop ST_1, which is a metal plate with a small circular aperture. An electro-magnetic shutter, SH, is positioned very close to ST_1, so that the shutter is effectively in the plane of the filament image. The light is then reflected by the first surface mirror M_1 and collimated by lens L_4. It passes through the heat absorbing glass H.

The light is then partly transmitted and partly reflected by the beam splitting cube B_1, to form paths 1 and 2 respectively. Path 2 provides light for the entire rectangular field that the subject views, while Path 1 provides light to the left half of the field only. In Path 1, lenses L'_5 and L'_6 form an image of the filament in the plane of the neutral density wedge W. The stop ST_2, consisting of a razor blade mounted vertically on a microscope stage, covers one half of the path at lens L'_6 and forms the edge seen by the subject at the center of the split field. Lens L'_7 forms an image of ST_2 in the plane of stops ST_3 and ST_4.

After passing through the wedge, the light is reflected by mirror M'_2. It is recombined with Path 2 as it passes through beam splitting cube B_2. Finally

FIG. 1. DIAGRAM OF THE OPTICAL SYSTEM.


PATH 1
M_1
L_4
H
B_1
F'_1
L'_5
L'_6
ST_2
W
M'_2
L'_7
F'_2
SH
ST_1
L''_5
L''_6
PATH 2
M''_2
F''
L''_7
B_2
L_3
L_2
L_1
S
L_9
L_{10}
ST_3
ST_4
L_8
PATH 3
P
L_{11}
L_{12}
G
B_3
right eye

it passes through stops ST_3 and ST_4, which control the width and length of the split field, and lens L_8. The light then passes through beam splitter B_3, and an image of the filament, as delimited by stop ST_1, is formed in the plane of the subject's pupil. The subject has a "Maxwellian view" of the rectangular opening provided by stops ST_3 and ST_4.

The lenses and mirrors of Paths 1 and 2 are identical, but Path 2 has no neutral density wedge and no stops. The intensity of the light in Path 2 was varied by the use of neutral density filters placed in filter holder F". The intensity of light in Path 1 was varied in the first set of measurements by the wedge used in conjunction with neutral density filters placed in filter holder F'_2. During the second set of measurements, made at the lower intensity level, the wedge was not used, and filters were placed in filter holder F'_1.

Path 3 provides an adapting field which is not in Maxwellian view. Light from the back surface of the ribbon filament is collimated by lenses L_9 and L_{10} and reflected by the right-angle prism P. It passes through lenses L_{11} and L_{12} and falls on the back (non-flashed) surface of the flashed opal glass G. The subject sees the evenly illuminated front surface of the glass reflected by beam splitting cube B_3.

Since both subjects were uncorrected myopes, the adapting field (G) and stops ST_3 and ST_4 were placed at the subjects' far point. During construction of the optical system, care was taken to assure that all parts of the stimulus were in good focus at the same time.

The stimulus presented to the subject was a rectangle split in half vertically, presented on a black background, which was in turn on a square adapting field (see Fig. 2). The black background was formed by placing black tape on the front surface of the diffusing glass in Path 3. The approximate dimensions of the black background were 9.5° of visual angle in length, 4.75° in width (see Table 1 for exact sizes of all stimuli). Each side of the square adapting field was approximately 12° of visual angle. The dimensions of the split field were determined by stops ST_3 and ST_4. ST_3 is the variable slit from a Bausch and Lomb High Intensity Grating Monochromator. It was used to determine the width of the field, which had the values 10', 12', 24', 60', and 142' of visual angle. ST_4 is a vernier caliper whose variable opening determined the length. The lengths used were 1.7', 2.8', 5.5', 8.5', 23', 66', and 424'.

The subject continually viewed the adapting field and black background. A trial was a 250 millisecond exposure of the rectangular field, with the duration controlled by a modified Gerbrands tachistoscope timer which activated the shutter. This exposure duration was chosen as a compromise value which would be larger than most published critical durations but short enough to control the likelihood of eye movements.

The luminance of the adapting field at beam splitting cube B_3 was measured with a Spectra Pritchard Photometer. The retinal illumination for the two Maxwellian fields was determined by the subject's matches of these fields to the adapting field and to each other. During these judgments the diameter of the entrance pupil for the adapting field was fixed at 2.5 mm by an artificial pupil. The

FIG. 2. STIMULUS CONFIGURATION

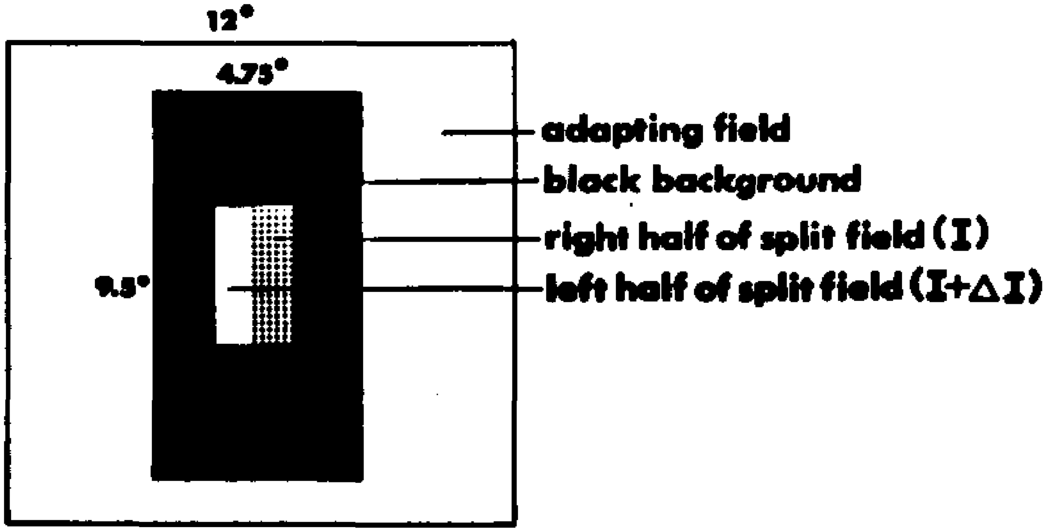

12°
4.75°
9.5°
adapting field
black background
right half of split field (I)
left half of split field (I+ΔI)

TABLE 1

EXACT SIZES OF ALL STIMULI IN DEGREES OF VISUAL ANGLE

	Subject MAS		Subject PK	
	Measurements		Measurements	
	1st set	2nd set	1st set	2nd set
Length-adapting field	12° 24'	11° 46'	11° 6'	11° 6'
Width-adapting field	12° 46'	12° 4'	11° 24'	11° 24'
Length-black background	10° 45'	8° 42'	9° 52'	8° 38'
Width-black background	5° 22'	4° 26'	4° 56'	4° 10'
Split field				
Lengths	1.7'	1.6'	1.7'	1.7'
	2.8'	2.6'	2.8'	2.8'
	5.5'	5.7'	5.5'	5.5'
	8.5'	8.3'	8.5'	8.5'
	23.0'	23.0'	23.0'	23.0'
	66.0'	66.0'	56.0'	56.0'
	444.0'	424.0'	408.0'	408.0'
Widths	10'	10'	10'	10'
	12'	12'	12'	12'
	24'	24'	24'	24'
	60'	60'	60'	60'
	142'	136'	148'	148'

diameter of the entrance pupil for the Maxwellian fields, determined by measuring the diameter of the filament image at the plane of the subject's pupil, was 1.3 mm.

During the experiment the subject's natural pupil was used. Unfortunately this leaves some uncertainty about the retinal illumination of the adapting field during the experiment. An estimate of pupil diameter taken from the curves of Reeves and Flamant in Le Grand (1959) gives an estimate of retinal illumination which is 0.5 log unit below the retinal illumination of the base field during the experiment. Since the base and adapting fields seemed to be of about the same brightness during the experiment, this estimate is probably in error.

To calibrate the wedge a piece of diffusing glass was placed in Path 1 after filter holder F'_2. The Spectra Pritchard Photometer measured changes in the luminance of the glass surface as the position of the wedge was changed.

The experiment was conducted in a dark, though not light-tight, room, and the subject's head position was fixed by a biting board.

PROCEDURE

Before each experimental session *S* adapted to darkness for ten minutes and then adapted to the black background and lighted adapting field for five minutes. *S* was instructed to fixate the lighted field during this period and during the 10-second intertrial intervals.

On the signal from *E*, *S* pressed a microswitch which initiated the exposure of the split field. *S* had to indicate whether or not he saw a clear contour between the two halves of the field. The ascending method of limits with the criterion of two consecutive "yes" responses was used to determine the thresholds.

The retinal illumination of the right half of the split field (I) was 234 trolands on the first set of measurements and 23 trolands (subject MAS) or 25 trolands (subject PK) on the second set. The luminance of the left half of the field was equal to the luminance of the right half of the field (I) plus the output of Path 1 (ΔI). This output was varied in 0.045 log unit steps by the wedge for the first set of measurements and in 0.10 log unit steps by filters for the second set of measurements. The maximum output of Path 1 was about 3200 trolands, although this output had slightly different values from one set of measurements to the other.

Three thresholds were obtained on a point (length–width combination) in one session, and each point was tested in four different sessions. For the first threshold on each point each day the step size used was twice as large as that given above, otherwise the step size was always as stated. If the three thresholds showed consecutive changes in one direction which totaled more than 0.3 log units, a fourth threshold was obtained.

A session lasted from one to two hours, during which 6 to 20 points were tested.

For the first set of measurements, at 234 trolands, thresholds were obtained for all the seven lengths and five widths given in the apparatus section, for a total of 35 points. For the second set of measurements, at the low luminance, thresholds were obtained for the five widths at only four lengths. These lengths are: 2.8', 8.5', 23', and 66'. Since considerable time elapsed between the first and second set of measurements (six months for PK, 12 months for MAS), two functions were obtained at approximately the same level as the first set (240 trolands for MAS, 263 trolands for PK) while the second set of measurements was being made. These functions were: (1) all five widths at a length of 8.5' and (2) all seven lengths at a width of 24'.

Ss were two women, one undergraduate and one graduate student.

RESULTS

The results for the set of measurements in which I is 234 trolands are presented in Table 2 and Figures 3, 4, 5, and 6. Figures 3 and 4 show ΔI plotted against width of the field, for the seven lengths of the field. Figures 5 and 6 show ΔI plotted against length of the field, for the five widths of the field.

For each point the four daily means of the thresholds were averaged. Circled points are length-width combinations for which sometimes no threshold was obtained. This occurred on trials when apparently the intensity required for the threshold exceeded the maximum intensity produced by the optical system. On *these trials the threshold was given a value of 0.05 log unit higher than the highest* intensity possible in Path 1 of the system, since this is the lowest value the threshold could possibly have had on that trial. This nominal value was averaged in the usual way with thresholds from the other trials of the day. The plotted points thus represent the lowest possible value of the threshold.

The threshold for seeing a contour decreases rapidly as the width of the field is increased. This change seems to slow when the width of the field is 24' and to stop when the width reaches 60', although these generalizations do not apply to the functions for all lengths. In general, the overall change shown in one function is from 0.80 to 1.10 log units, but the range for this change is 0.45 to 1.30 log units. *The size of the overall change may be related to the length of field for subject PK,*

TABLE 2

THRESHOLDS IN TROLANDS FOR FIRST SET OF MEASUREMENTS (I = 234 TROLANDS)

Subject MAS

field width	10'	12'	24'	60'	142'
field length					
1.7'	2950*	813	562	398	234
2.8'	1349	692	407	269	224
5.5'	617	331	98	85	56
8.5'	316	178	79	51	51
23.0'	209	117	41	34	34
66.0'	380	166	38	33	32
444.0'	282	174	39	24	28

Subject PK

field width	10'	12'	24'	60'	148'
field length					
1.7'	3630*	2340*	1550*	178	245
2.8'	3310*	1820*	562	178	178
5.5'	708	676	372	101	162
8.5'	562	309	141	55	51
23.0'	479	339	76	43	56
56.0'	109	126	78	46	45
408.0'	224	101	102	32	20

*lowest possible threshold - see text for explanation.

FIG. 3. THRESHOLD FOR SEEING A CONTOUR AS A FUNCTION OF WIDTH OF FIELD FOR SUBJECT MAS. I = 234 TROLANDS. CIRCLED POINTS INDICATE LOWEST POSSIBLE VALUE.

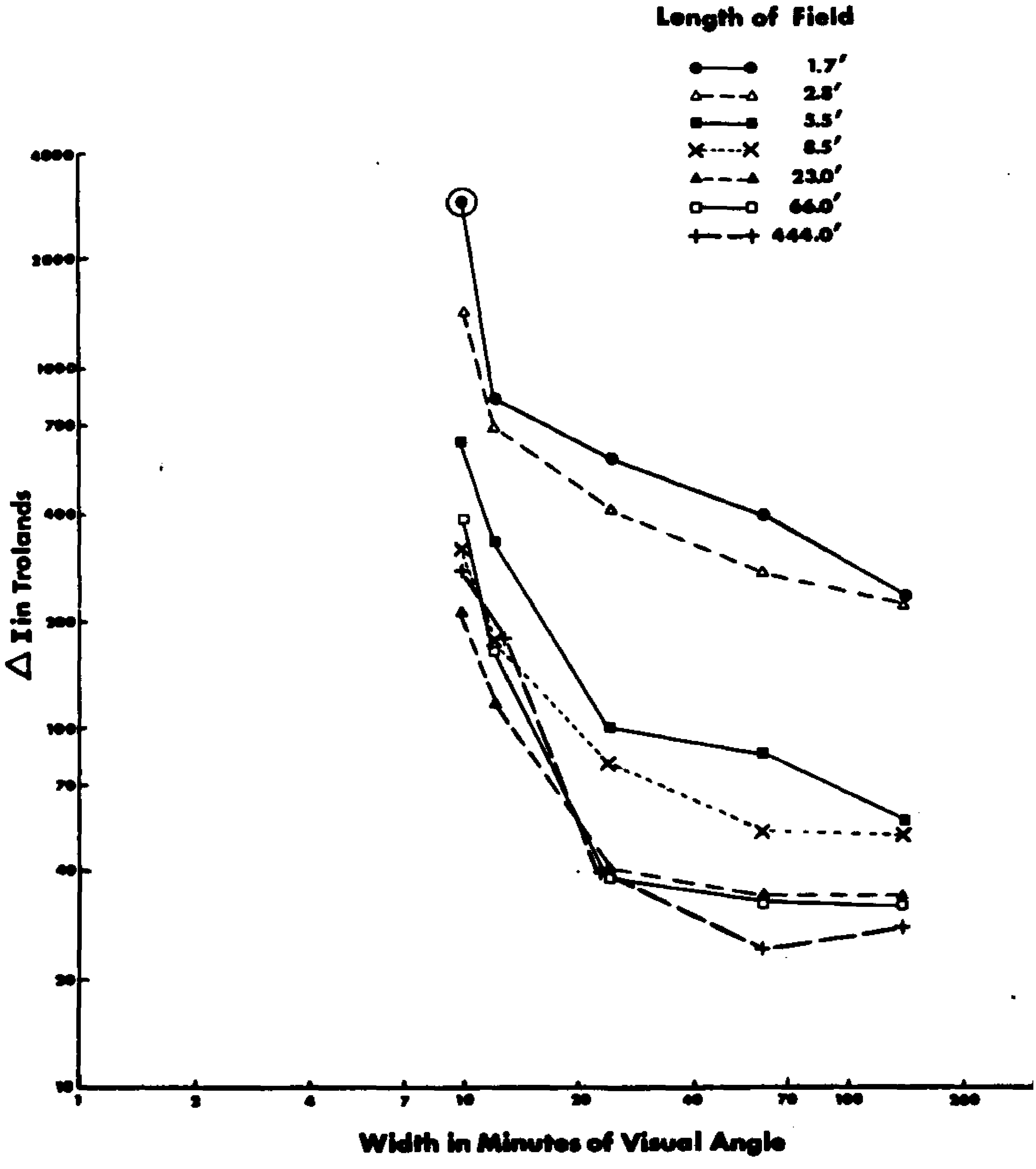

Length of Field
1.7′
2.8′
3.5′
8.5′
23.0′
66.0′
444.0′
Δ I in Trolands
4000
2000
1000
700
400
200
100
70
40
20
10
1
2
4
7
10
20
40
70
100
200
Width in Minutes of Visual Angle

FIG. 4. THRESHOLD FOR SEEING A CONTOUR AS A FUNCTION OF WIDTH OF FIELD FOR SUBJECT PK. I = 234 TROLANDS. CIRCLED POINTS INDICATE LOWEST POSSIBLE VALUE.

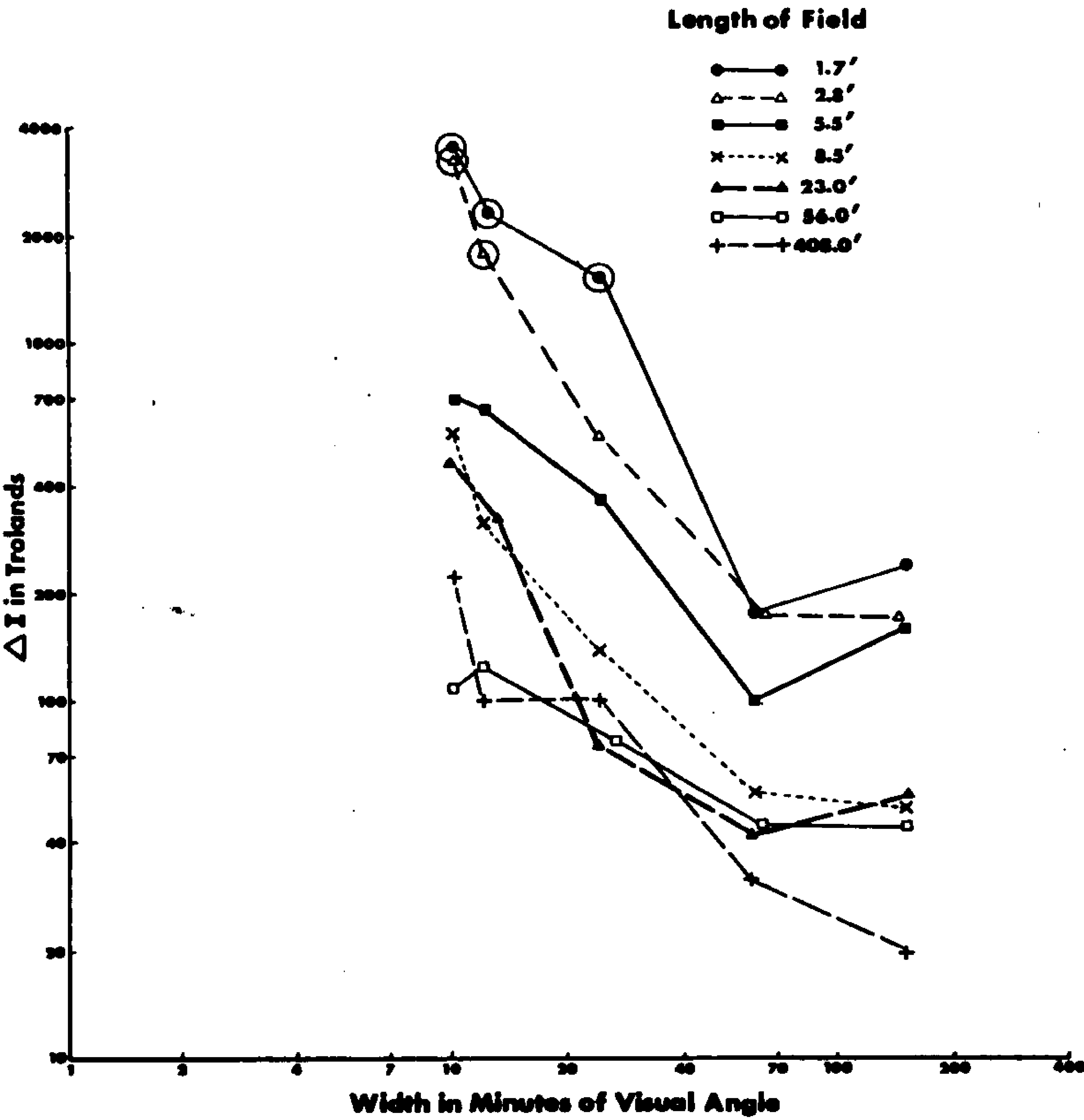
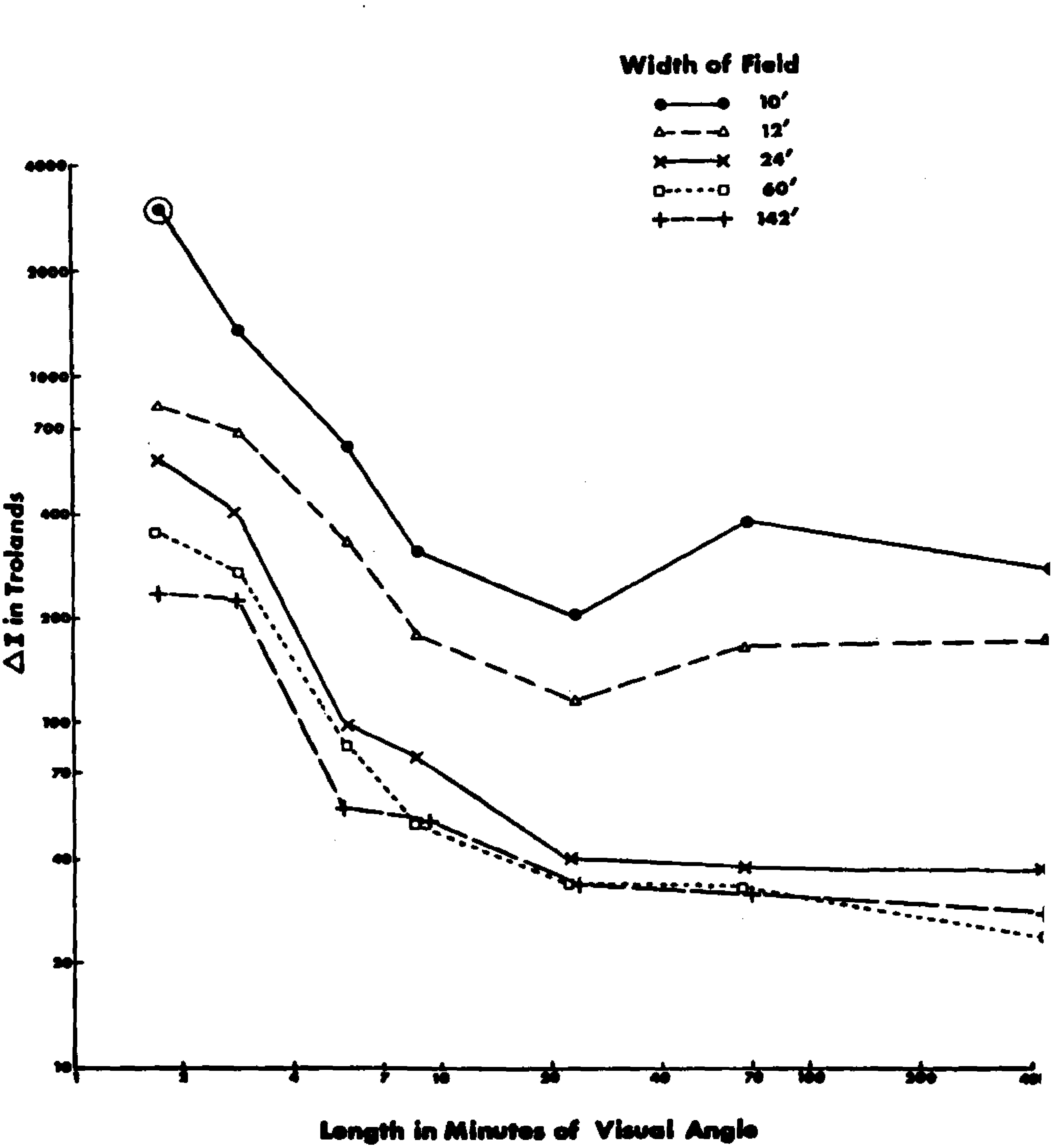
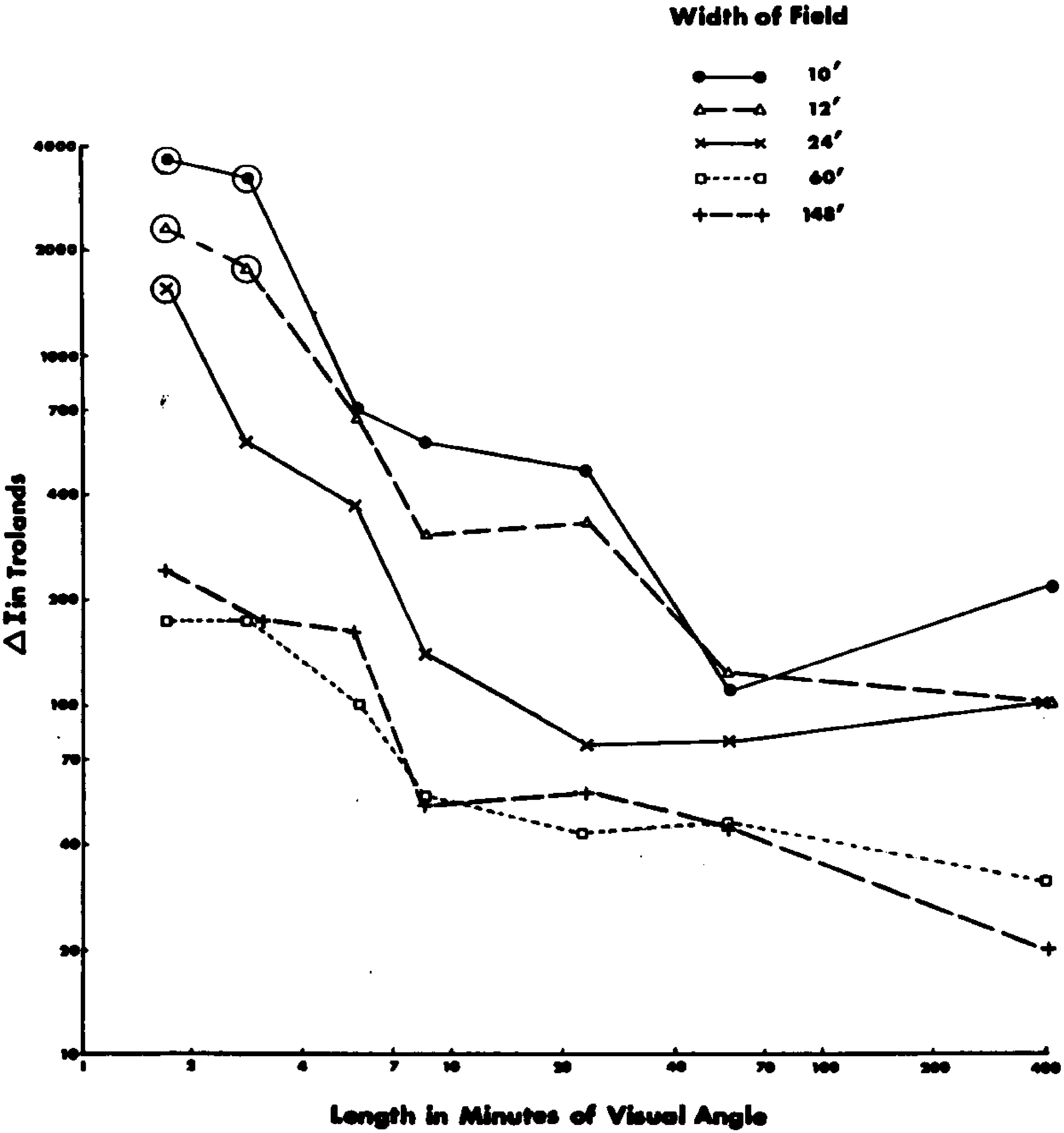

Length of Field
1.7′
2.8′
5.5′
8.5′
23.0′
56.0′
408.0′
Δ I in Trolands
4000
2000
1000
700
400
200
100
70
40
20
10
Width in Minutes of Visual Angle
1
2
4
7
10
20
40
70
100
200

FIG. 5. THRESHOLD FOR SEEING A CONTOUR AS A FUNCTION OF LENGTH OF FIELD FOR SUBJECT MAS. I = 234 TROLANDS. CIRCLED POINTS INDICATE LOWEST POSSIBLE VALUE.



Width of Field
10′
12′
24′
60′
142′
ΔI in Trolands
4000
2000
1000
700
400
200
100
70
40
20
10
1
2
4
7
10
20
40
70
100
200
Length in Minutes of Visual Angle

FIG. 6. THRESHOLD FOR SEEING A CONTOUR AS A FUNCTION OF LENGTH OF FIELD FOR SUBJECT PK. I = 234 TROLANDS. CIRCLED POINTS INDICATE LOWEST POSSIBLE VALUE.


Width of Field
10′
12′
24′
60′
148′
ΔI in Trolands
4000
2000
1000
700
400
200
100
70
40
20
10
1
2
4
7
10
20
40
70
100
200
400
Length in Minutes of Visual Angle

there being a greater change with shorter fields. This relationship does not exist for subject MAS.

The threshold decreases as the length of the field is increased. Most of this change seems to occur from the length of 2.8' to the length of 8.5'. Most of the functions relating threshold to length of field become flat for lengths of 23' and greater. There also seems to be little change between 1.7' and 2.8'. The overall change shown in one function is generally from 0.9 to 1.3 log units, with size of the change related to width of field for PK, but not MAS.

Results for the second set of measurements are shown in Table 3 and Figures 7 and 8. Δ I is plotted against width for the four lengths that were used at the lower retinal illumination. In general these curves seem to have the same shape as the functions for the higher illumination. They tend to flatten out between the 24' and 60' widths. The size of the total drop in threshold from narrowest to widest stimulus seems to be about the same as that obtained for the high illumination data, except that the shortest stimuli (2.8') show a larger drop in the low illumination measurements.

The two functions which were obtained at the higher intensity during the second set of measurements are plotted in Figures 9 and 10, along with comparable functions from the first set of measurements. The measurements, though made many months apart, are remarkably similar. Subject PK seems to show a slight rise in threshold in her Δ I-width function, but this rise is not present in the Δ I-length function.

TABLE 3

THRESHOLDS IN TROLANDS FOR SECOND SET OF MEASUREMENTS

Subject MAS

I = 23 trolands

field width	10'	12'	24'	60'	136'
field length					
2.6'	673*	170*	41	39	26
8.5'	52	25	10	6	5
23.0'	23	15	5	5	4
66.0'	22	15	5	3	3

I = 240 trolands

field length					
1.6'			525		
2.6'			436*		
5.5'			132		
8.5'	331*	186	76	37	52
23.0'			42		
66.0'			36		
424.0'			41		

Subject PK

field width	10'	12'	24'	60'	148'

I = 25 trolands

field length					
2.8'	1072*	1350*	96	47	35
8.5'	74	43	19	10	10
23.0'	87	43	16	8	7
56.0'	115	115	11	7	7

I = 263 trolands

field length					
1.7'			631		
2.8'			1072*		
5.5'			191		
8.5'	813*	372*	129	83	85
23.0'			89		
56.0'			89		
408.0'			162		

*lowest possible value - see text for explanation.

FIG. 7. THRESHOLD AS A FUNCTION OF WIDTH OF FIELD FOR LOW ILLUMINATION MEASUREMENTS FOR SUBJECT MAS. I = 234 TROLANDS. CIRCLED POINTS INDICATE LOWEST POSSIBLE VALUE.

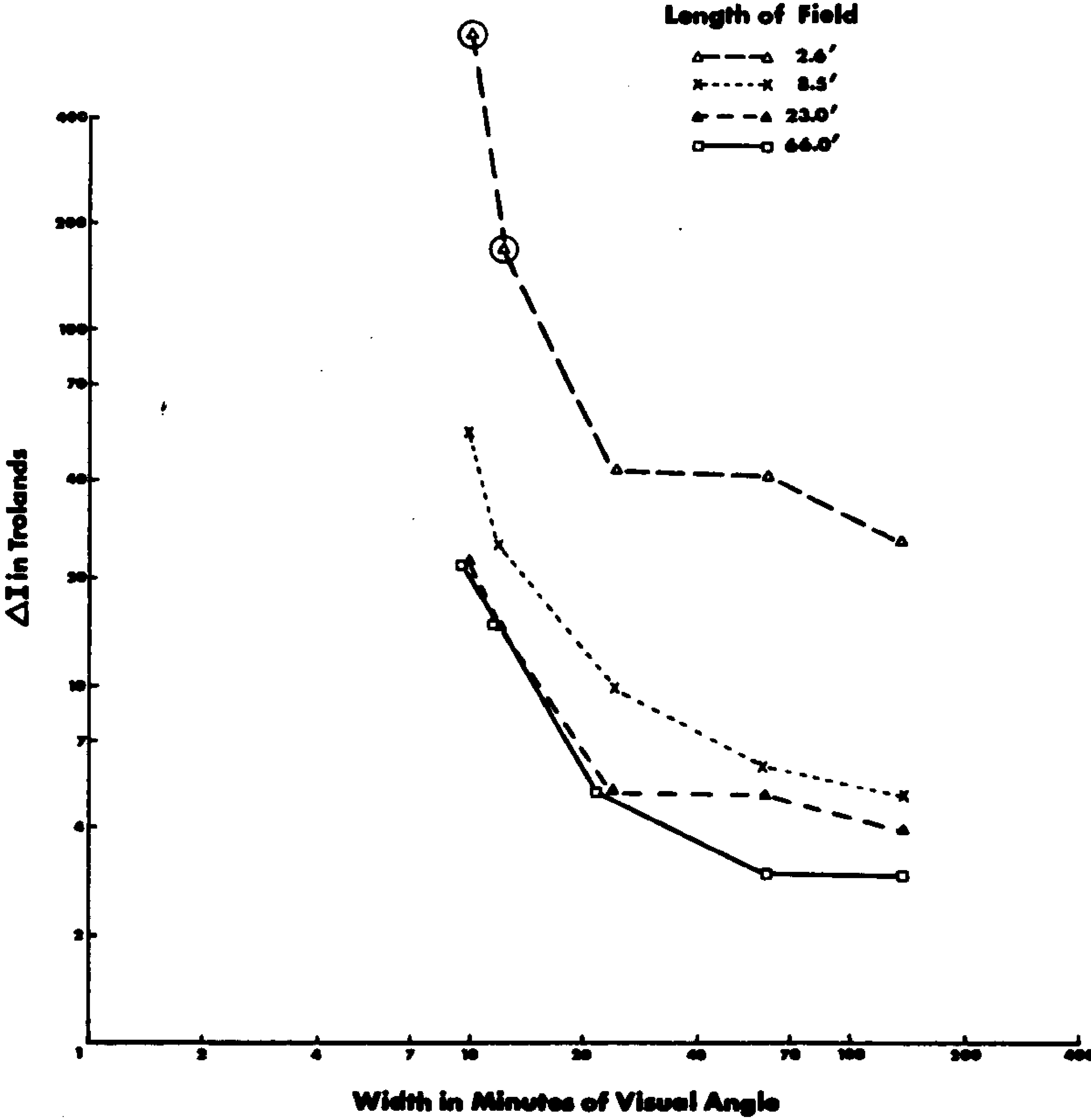

Length of Field
2.6′
8.5′
23.0′
66.0′
ΔI in Trolands
400
200
100
70
40
20
10
7
4
2
1
2
4
7
10
20
40
70
100
200
400
Width in Minutes of Visual Angle

FIG. 8. THRESHOLD AS A FUNCTION OF WIDTH OF FIELD FOR LOW ILLUMINATION MEASUREMENTS FOR SUBJECT PK. I = 234 TROLANDS. CIRCLED POINTS INDICATE LOWEST POSSIBLE VALUE.

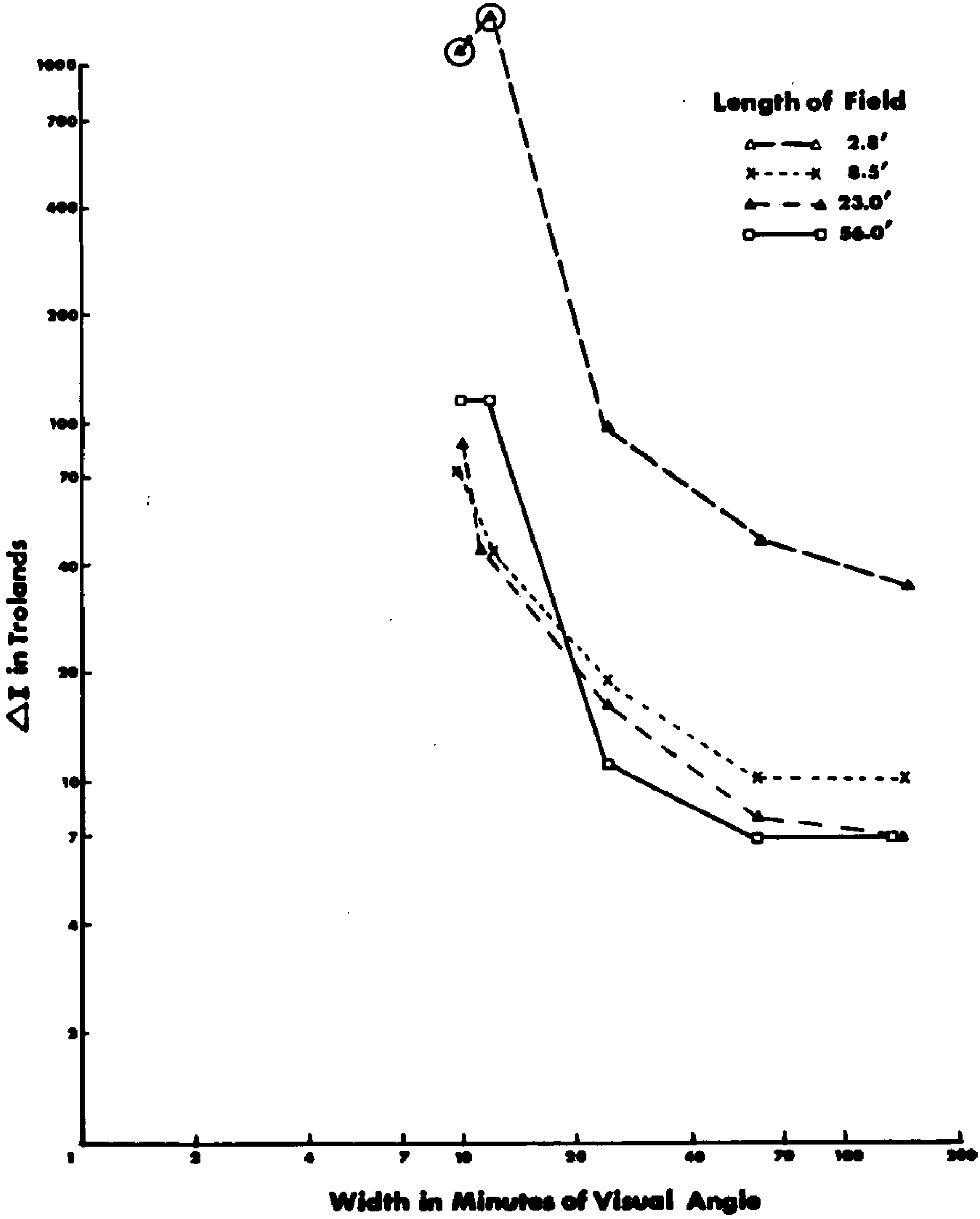

Length of Field
2.8′
8.5′
23.0′
56.0′
ΔI in Trolands
1000
700
400
200
100
70
40
20
10
7
4
2
1
2
4
7
10
20
40
70
100
200
Width in Minutes of Visual Angle

FIG. 9. THRESHOLDS OBTAINED IN THE FIRST AND SECOND SET OF HIGH ILLUMINATION MEASUREMENTS FOR A FIELD LENGTH OF 8.5'. CIRCLED POINTS INDICATE LOWEST POSSIBLE VALUE.

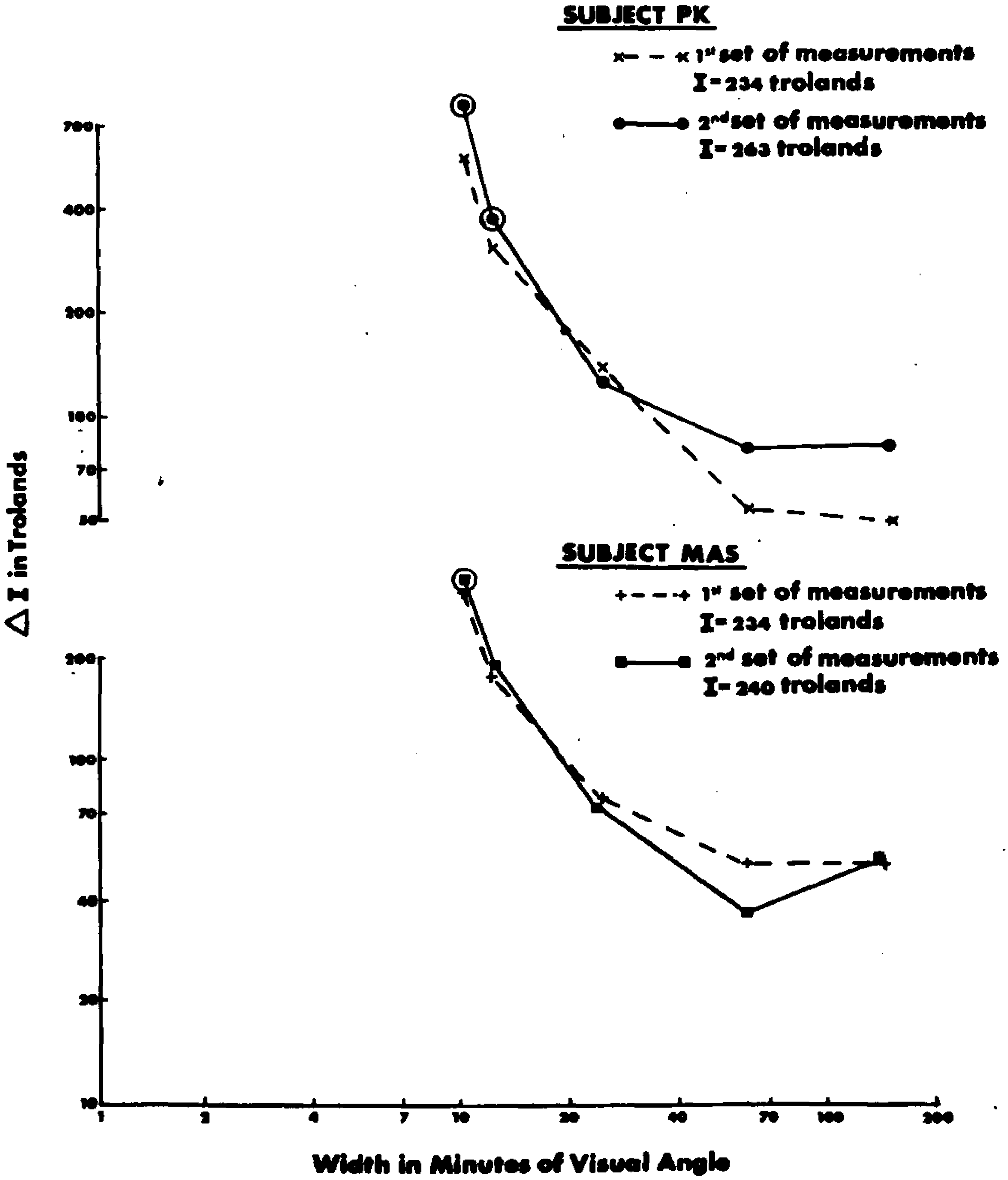
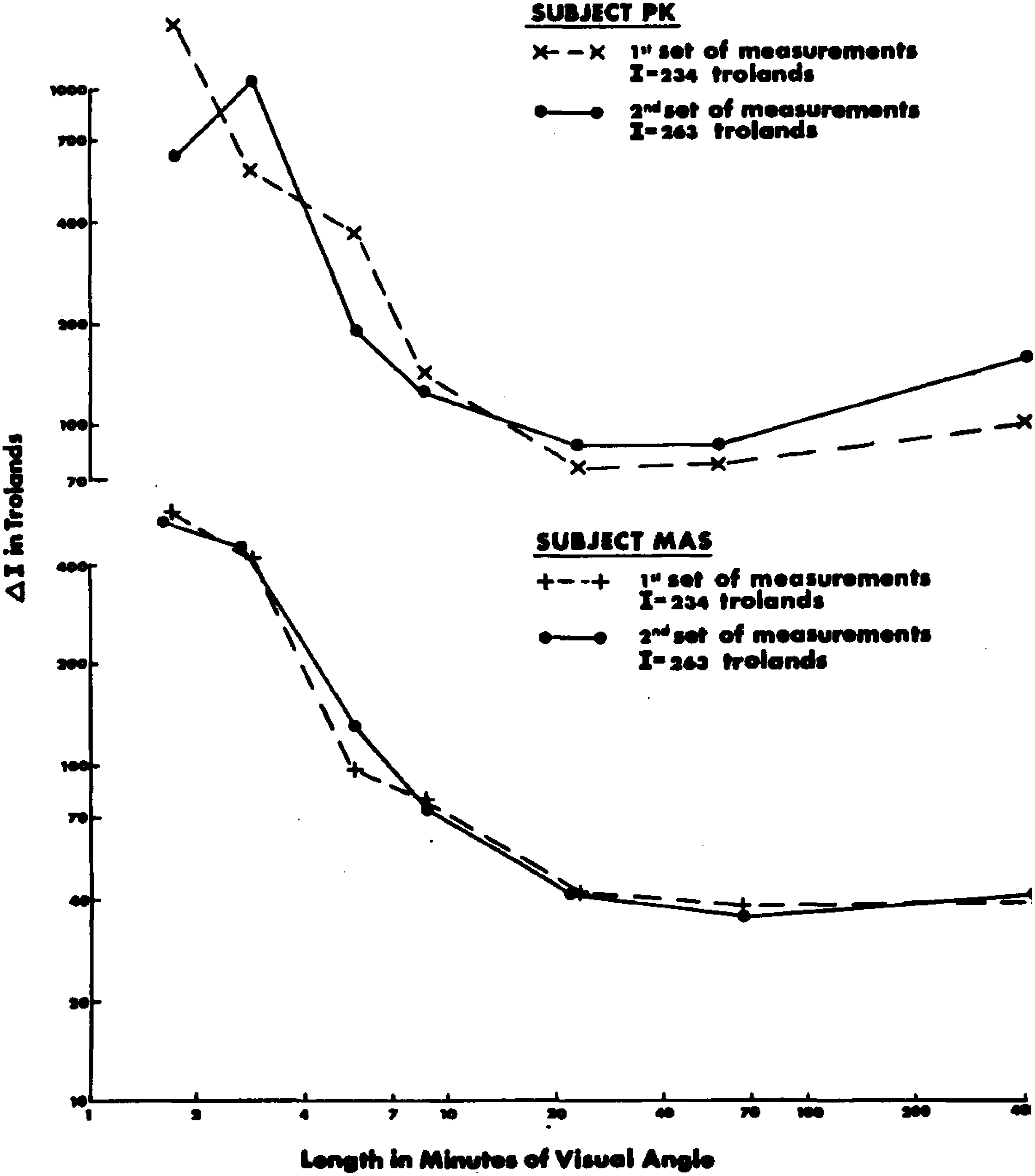

SUBJECT PK
1st set of measurements
I= 234 trolands
2nd set of measurements
I= 263 trolands
700
400
200
100
70
50
SUBJECT MAS
1st set of measurements
I= 234 trolands
2nd set of measurements
I= 240 trolands
200
100
70
40
20
10
1
2
4
7
10
20
40
70
100
200
Δ I in Trolands
Width in Minutes of Visual Angle

FIG. 10. THRESHOLDS OBTAINED IN THE FIRST AND SECOND SET OF HIGH ILLUMINATION MEASUREMENTS FOR A FIELD WIDTH OF 24'. CIRCLED POINTS INDICATE LOWEST POSSIBLE VALUE.


SUBJECT PK
×- -× 1st set of measurements I=234 trolands
●—● 2nd set of measurements I=263 trolands
SUBJECT MAS
+- -+ 1st set of measurements I=234 trolands
●—● 2nd set of measurements I=263 trolands
ΔI in Trolands
1000
700
400
200
100
70
400
200
100
70
40
20
10
1
2
4
7
10
20
40
70
100
200
40
Length in Minutes of Visual Angle

Figures 11 and 12 show $\Delta I/I$ as a function of width for the four lengths that were tested at both illumination levels. For MAS, $\Delta I/I$ seems to be higher for the low intensity measurements. This difference occurs at all but the longest length (66'). For PK this difference is greater, and it occurs at all lengths. If PK's high intensity curves were all raised by 0.2 log unit, which is the amount of rise shown between her two high intensity functions in Figure 9, then many of the $\Delta I/I$ differences would disappear. This adjustment of the curves would be legitimate if one assumed that the subject's criterion for seeing a sharp contour had become higher in the months between the first and second set of measurements. However, since PK's length functions (Fig. 10) do not show a rise in threshold from the first to the second set of measurements, the adjustment of other high intensity curves is probably not justifiable.

FIG. 11. $\Delta I/I$ AS A FUNCTION OF WIDTH OF FIELD FOR LOW AND HIGH ILLUMINATION MEASUREMENTS. SUBJECT MAS.

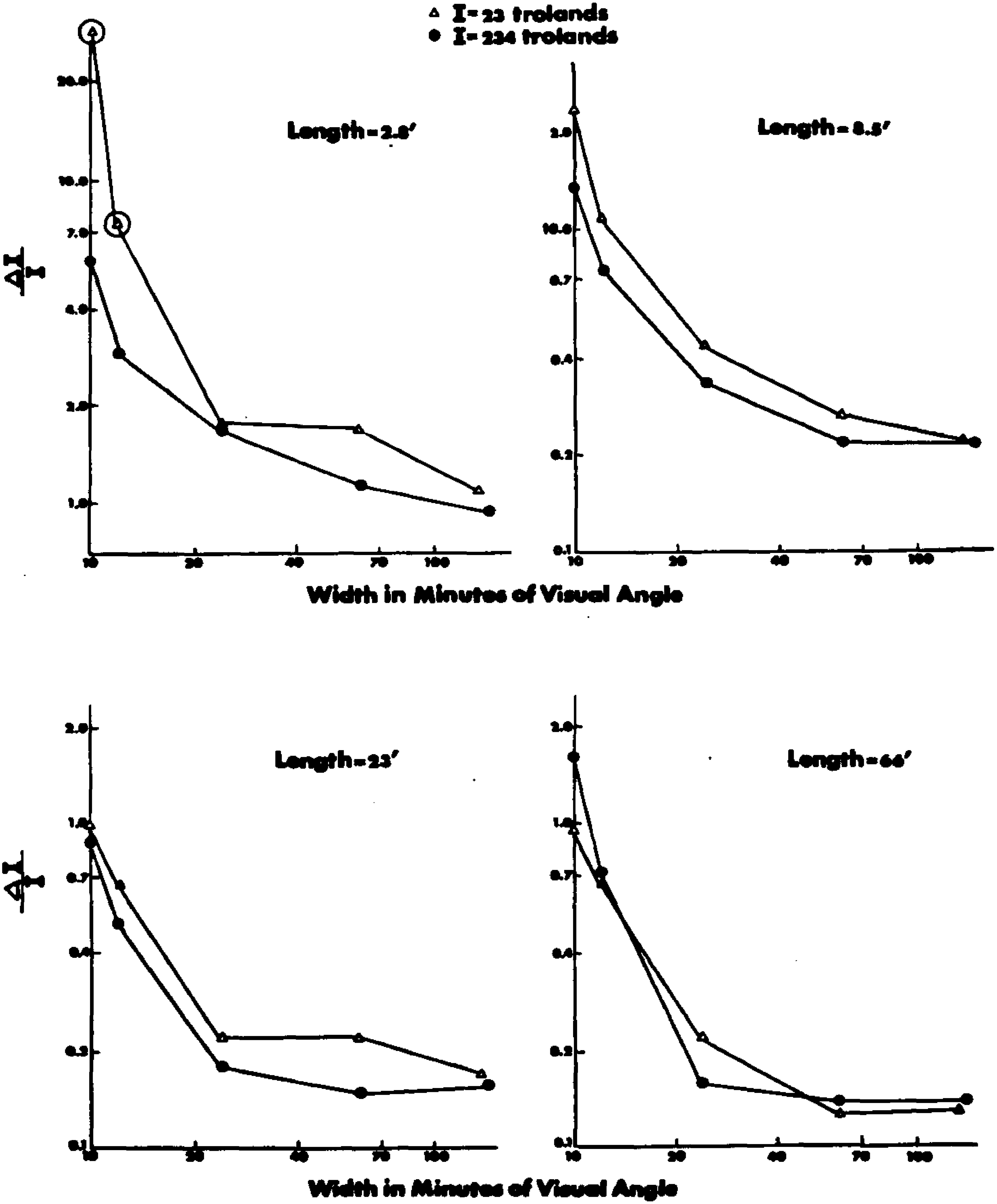
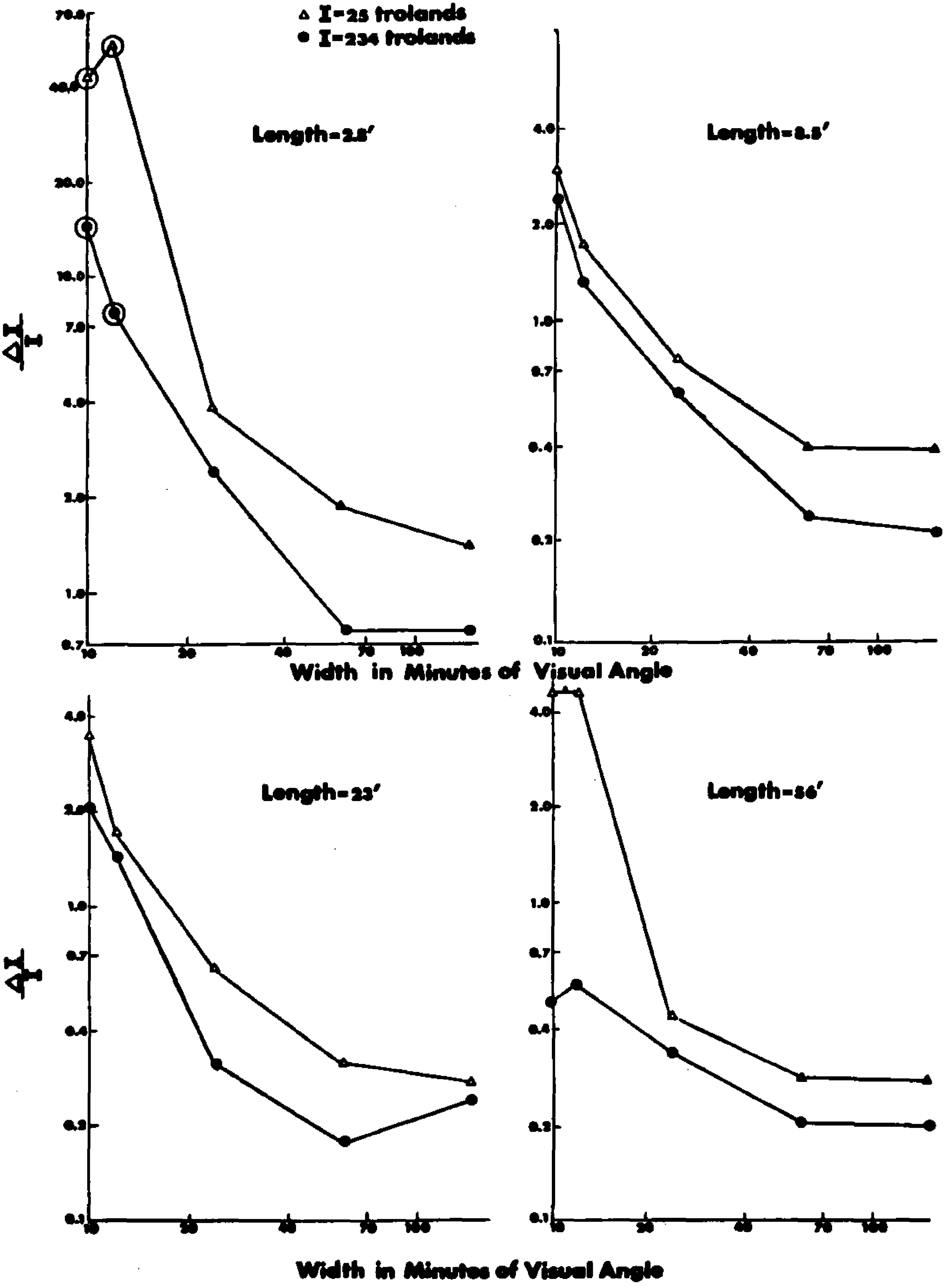

△ I = 23 trolands
● I = 234 trolands
Length = 2.8′
Length = 8.5′
Length = 23′
Length = 66′
ΔI/I
ΔI/I
20.0
10.0
7.0
4.0
2.0
1.0
2.0
10.0
0.7
0.4
0.2
0.1
2.0
1.0
0.7
0.4
0.2
0.1
2.0
1.0
0.7
0.4
0.2
0.1
10
20
40
70
100
Width in Minutes of Visual Angle
Width in Minutes of Visual Angle

FIG. 12. $\Delta I/I$ AS A FUNCTION OF WIDTH OF FIELD FOR LOW AND HIGH ILLUMINATION MEASUREMENTS. SUBJECT PK.


△ I=25 trolands
● I=234 trolands
Length=2.8'
Length=8.5'
Length=23'
Length=56'
ΔI/I
ΔI/I
70.0
40.0
20.0
10.0
7.0
4.0
2.0
1.0
0.7
4.0
2.0
1.0
0.7
0.4
0.2
0.1
10
20
40
70
100
Width in Minutes of Visual Angle
Width in Minutes of Visual Angle

DISCUSSION

The data obtained indicate that the distance over which stimulated points can have an effect in the formation of contours is between 10' and 30' of visual angle. This finding is not unreasonable in view of other studies of spatial interaction, but it is much larger than the useful strip width of 1 - 1½' reported by Lamar, Hecht, Schlaer, and Hendley.

The present data cannot be unified by the "useful flux" concept borrowed from Lamar et al.'s treatment of difference threshold data. In this treatment a strip within the perimeter of the target is thought to determine, or be the locus of the determination of the difference threshold. The total area of this strip (width of strip times perimeter of the target) is multiplied by the threshold for that target size and shape to give a "useful flux." When log useful flux is plotted as a function of log perimeter, all of Lamar et al.'s data points fall quite neatly on a line with a slope of 2/3.

This same analysis was applied to the data for subject MAS. A useful strip width of 12' was chosen by Lamar's procedures. By the same procedures, a "useful length" of 8.5' was chosen, reflecting the finding that for subject MAS, increases in length beyond 8.5' do not have much effect on the threshold for seeing a contour. The useful area for a stimulus is, then, the product of the length and width of the stimulus. If either dimension exceeds the "useful size" for that dimension, then the "useful size" is substituted for the actual size in the multiplication. Useful flux is determined by multiplying useful area for a stimulus by the threshold for seeing a contour in that stimulus. Useful flux is plotted as function of length, which corresponds to Lamar's perimeter, in Figure 13.

The points do not fall on the same line, although the functions for all widths are similar. The function for the 10' width is higher on the ordinate than all other functions. The points for the 12' width are higher than those for the remaining three widths in four out of seven cases. Because the 10' points are all higher than the 12' points, the simple useful flux notion cannot unify the data. To make these two functions lie at the same level, one would have to use a width less than 5' for the 10' points or a width greater than 6' for the 12' points. Neither of these procedures is consistent with the useful flux treatment.

Several mathematical models have been formulated to describe the effects of lateral inhibition in the visual system. (These are reviewed by Ratliff in Mach Bands). One of the simplest to use, which still incorporates the essential features of many of the other models is the neural unit proposed by Békésy (1960). This unit has been used by other authors, with varying degrees of success, to describe the psychological effect of luminance variations in one dimension (Thomas, 1966; Hood and Whiteside, 1968). In order to apply this unit to the present experiment, the model must be extended to deal with luminance variations in two dimensions.

Békésy's neural unit describes the neural effects of stimulating a point on the retina or other receptor surface (see Figure 14). At the point of stimulation

FIG. 13. USEFUL FLUX AS A FUNCTION OF LENGTH OF FIELD. SUBJECT MAS.

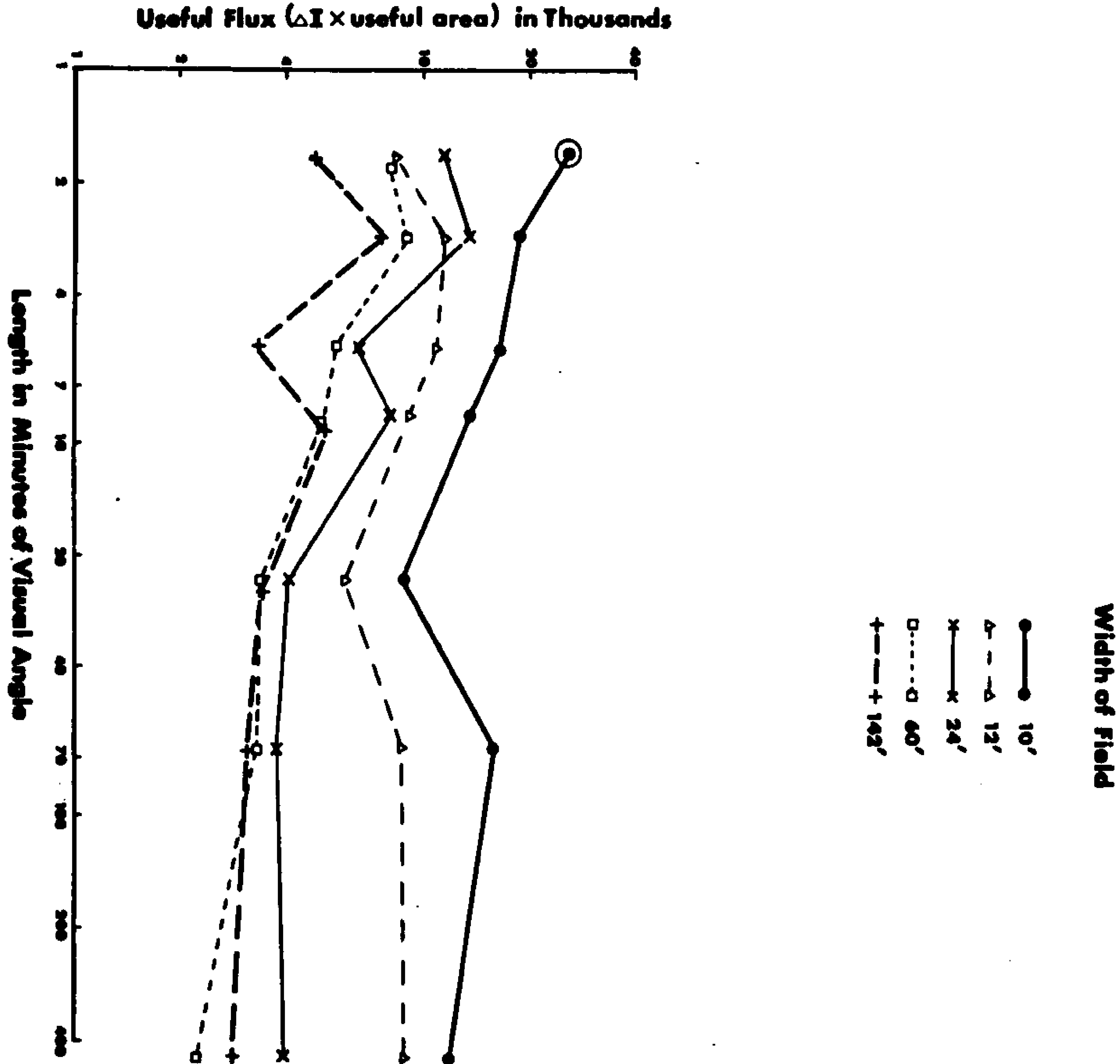
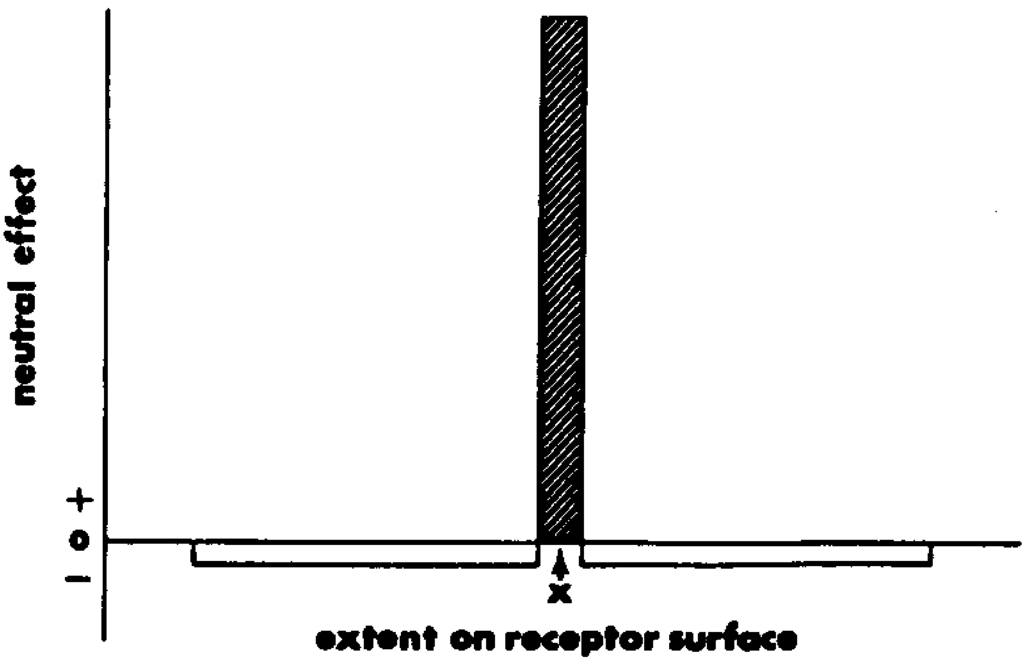
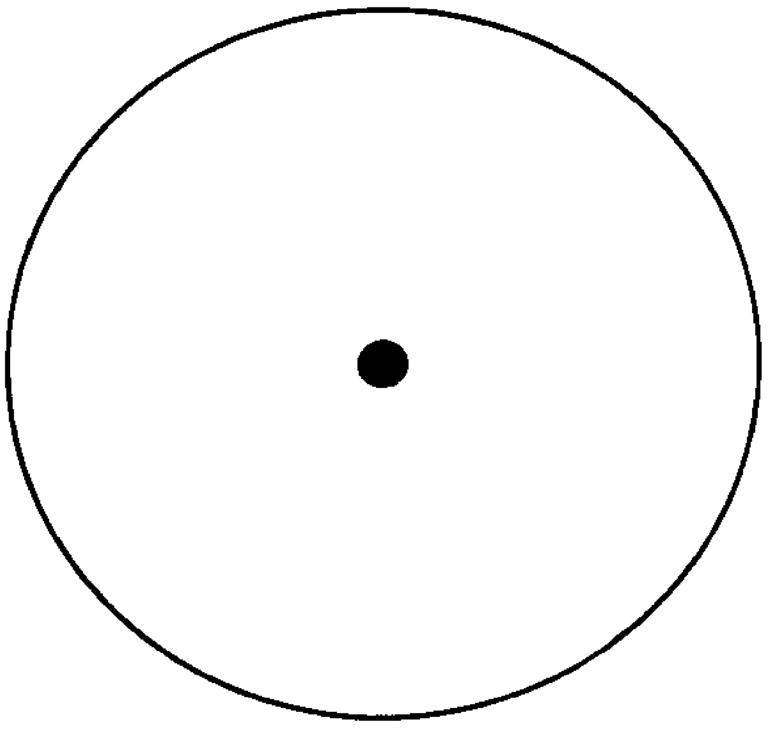

Useful Flux (ΔI × useful area) in Thousands
Length in Minutes of Visual Angle
Width of Field
10′
12′
24′
60′
142′

FIG. 14. GRAPHICAL REPRESENTATIONS OF NEURAL UNIT. A: ONE-DIMENSIONAL MODEL. B: TWO-DIMENSIONAL SPREAD OF NEURAL EFFECT. CROSS-HATCHED AREA IS EXCITATORY REGION.

A



B

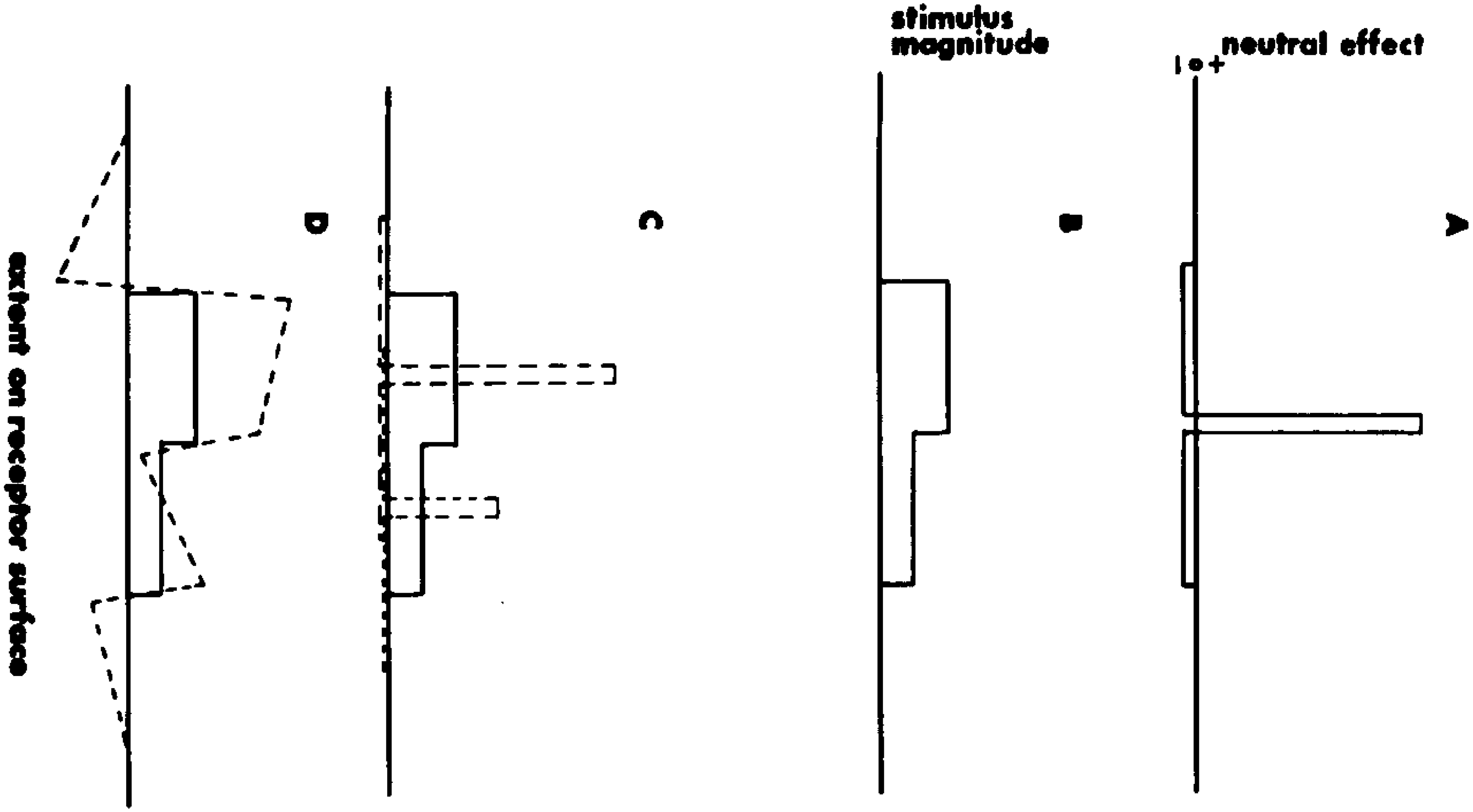


and for some small distance around it, the effect is excitation proportional to the stimulus magnitude. For a larger concentric area the effect is inhibition, but of a smaller amplitude than the excitatory effect. Following Békésy (1960), the inhibitory effects are assumed to spread out from the center of the unit without decrement, and the total excitatory effect (amplitude X area) is assumed to be 1.6 times the total inhibitory effect. It was arbitrarily decided that the half-width of the inhibitory region would be eight times as great as the width of the excitatory region, satisfying Békésy's requirement that the excitatory region be considerably smaller than the inhibitory.

Figure 14a is a graphical representation of the spread of neural effects in one dimension resulting from stimulation at point X. This diagram is typical of the models discussed by Békésy (1960) and Thomas (1966). Figure 14b illustrates the extent of neural effects on a two-dimensional receptor surface, without showing the magnitude of these effects. In order to maintain the ratio of 1.6 between total excitatory effect and total inhibitory effect, it is necessary to assume a very large excitatory effect. This effect would be represented in the graph by a third dimension for the height of the excitatory and inhibitory regions. In the model used in this analysis of the data, the height of the excitatory region (magnitude of excitatory effect) was calculated to be 371 times the height of the inhibitory region (magnitude of inhibitory effect).

The result of applying the neural unit to successive points on the stimulus pattern is called by Békésy the sensation magnitude. The process of finding sensation magnitude is illustrated for the one-dimensional model in Figure 15. Figure 15a is

FIG. 15. APPLICATION OF NEURAL UNIT TO STIMULUS PATTERN TO FIND SENSATION MAGNITUDE. A: NEURAL UNIT. B: STIMULUS PATTERN. C: APPLICATION OF NEURAL UNIT TO STIMULUS PATTERN. D: SENSATION MAGNITUDE (DASHED LINE) AND STIMULUS MAGNITUDE (SOLID LINE).


stimulus magnitude
neutral effect
- 0 +
A
B
C
D
extent on receptor surface

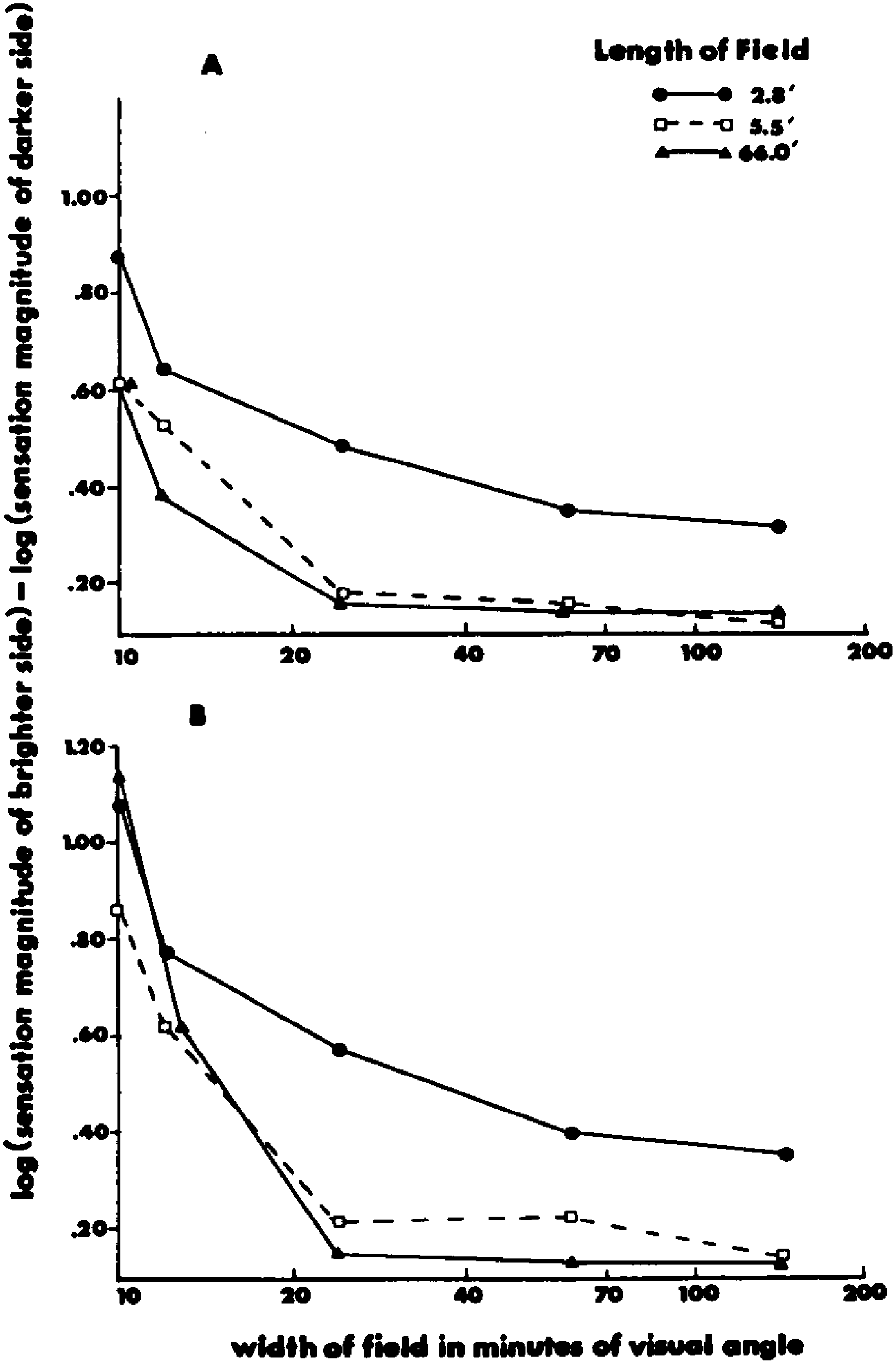
the neural unit previously described and seen in Figure 14a. Figure 15b is the spatial distribution of stimulus magnitude for a stimulus similar to the split field used in the present experiment. Figure 15c illustrates the successive application of the neural unit to points on the stimulus pattern separated by a distance equal to the diameter of the excitatory region. (Applying the neural unit at smaller intervals would simply produce a smoother distribution of sensation magnitude). Note that *neural effect is multiplied by stimulus magnitude.* Figure 15d illustrates sensation magnitude (dashed line) predicted for this stimulus pattern. Sensation magnitude at any point equals the sum of the products of neural effect and stimulus magnitude, which products are obtained for all placements of the neural unit.

The problem encountered in applying the Békésy model to the present data is in deciding what aspect of the "sensation magnitude" corresponds to the subject's response of seeing a contour. The most obvious choice is the difference between the sensation magnitudes on either side of the border between the two fields. Unfortunately this difference shows no variation for a great range of field lengths and widths. (A similar result was obtained by Nachmias, (1968) using a similar weighting function on square-wave patterns with 2, 4, and 8 bars.) Since the threshold data do change with changes in length and width, this interpretation of the model is not a useful description of contour mechanisms.

One aspect of the sensation magnitude which varies with the length and width is the ratio of the sensation magnitudes on either side of the border between the fields. As the size of the fields increases, the sensation magnitude decreases in areas of the field which are sufficiently near to the new addition, due to inhibition from this new area. Since the decrease in sensation magnitude is generally the same on both sides of the border, the difference between the two elements on either side of the border stays the same, but the ratio of their sensation magnitudes increases. This suggests that a logarithmic transform of the sensation magnitudes might produce variations in the difference between elements on the two sides of the border which correspond to the threshold variations found.

To test this possibility, the sensation magnitudes corresponding to the stimulus configuration at the threshold for seeing a contour was computed for all field widths at three field lengths. In making these computations the neural unit was assigned the following dimensions: (1) diameter of excitatory region - 1½', (2) extent of inhibitory effect - 12' on a side beyond the excitatory region. The latter dimension is taken from the "useful width" determination discussed above, and the excitatory dimension is one-eighth of the inhibitory dimension. Sensation magnitude was found by applying the neural unit to the stimulus pattern at points 1½' apart. The sensation magnitudes were transformed to logarithms, and the difference was then found between log sensation magnitude for the element on the brighter side of the border and log sensation magnitude for the element on the dimmer side of the border (for long stimuli, the difference was found for the center elements in the configuration). These differences are plotted as a function of width in Figure 16a for subject MAS. If the model is to prove useful in its present form, then all points on this graph should have the same log difference. Clearly they do not. The difference between the logs of the sensation magnitudes changes as a function of both length and width of field. In particular, the thresholds

FIG. 16. DIFFERENCE BETWEEN LOGARITHMS OF SENSATION MAGNITUDES ON EITHER SIDE OF LIGHT-DARK BORDER. STIMULUS MAGNITUDES ARE TAKEN FROM SUBJECT MAS'S THRESHOLD DATA.
A: DIFFERENCES OBTAINED WHEN INHIBITION IS ASSUMED TO SPREAD FOR 12' OF VISUAL ANGLE. B: DIFFERENCES OBTAINED WHEN INHIBITION IS ASSUMED TO SPREAD FOR 6'.


A
Length of Field
2.8′
5.5′
66.0′
1.00
.80
.60
.40
.20
10
20
40
70
100
200
B
1.20
1.00
.80
.60
.40
.20
10
20
40
70
100
200
log (sensation magnitude of brighter side) – log (sensation magnitude of darker side)
width of field in minutes of visual angle

for fields which are very small in either dimension seem to be too high to be accounted for by this model.

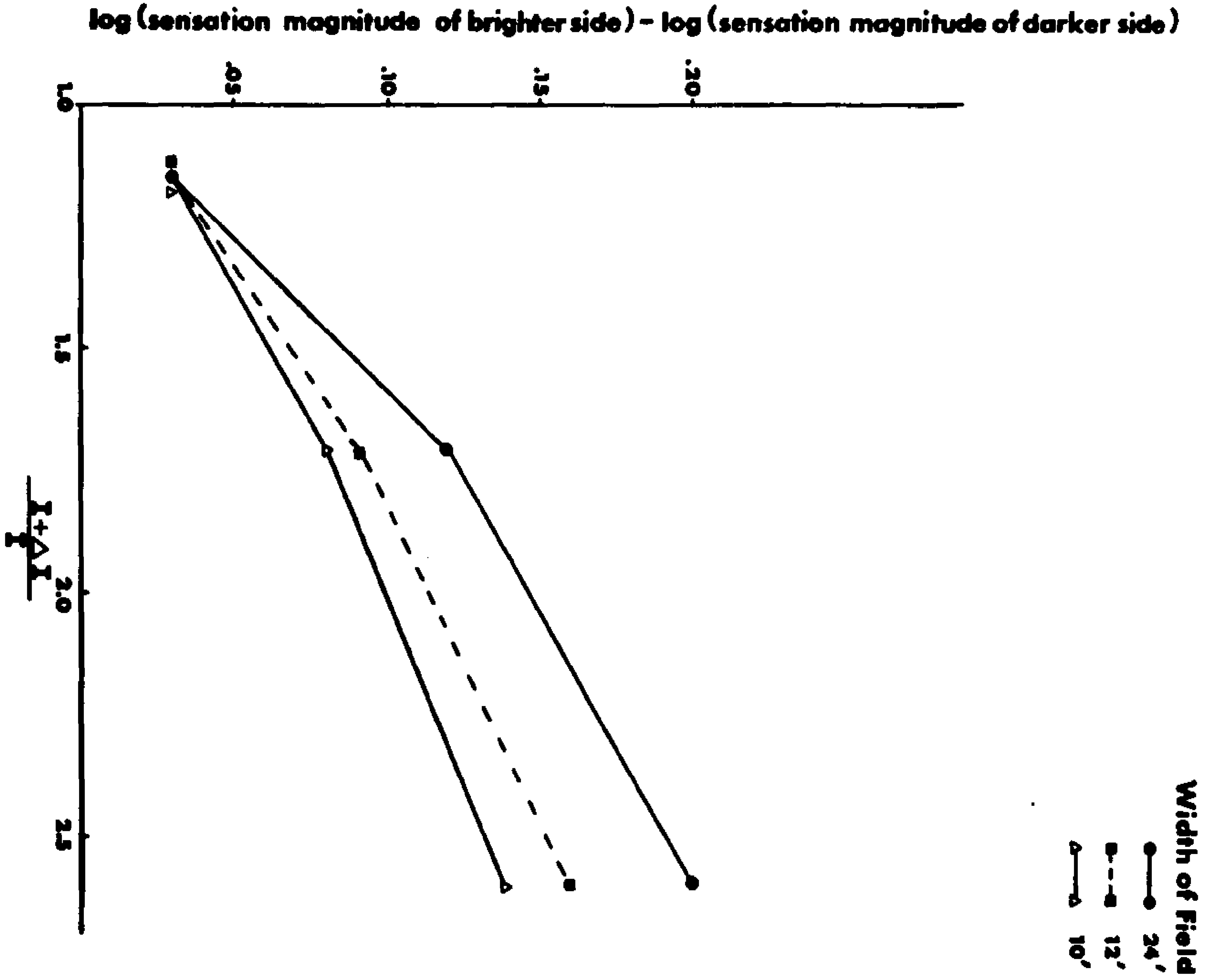
Changing the dimensions of the neural unit does not improve the model in this respect. Figure 16b shows the results obtained with a neural unit whose inhibitory region is one-half as wide as the unit used for Figure 16a. In this case inhibitory effects are assumed to spread for 6' rather than 12'. This narrower unit tends to spread the points farther rather than bring them closer. Larger units also do not unify the data. It can be shown that the difference between the logs of the two sensation magnitudes for a small field (length 2.8', width 5') reaches a minimum of about 0.83, as the width of the inhibitory unit becomes very large. For the same wide inhibitory units, the value of the difference between the logs of the two sensation magnitudes for larger stimuli is much smaller (e.g. difference = .06 for 12' wide, 66' long field).

Using a value other than 1.6 for the ratio between total excitatory effect and total inhibitory effect also does not improve the model's utility. The ratio between these values determines the sensation magnitudes corresponding to plateaus or gradients of illumination. If this ratio is 1.0, then there is no sensation magnitude corresponding to plateaus or gradients; in effect, sensation magnitude corresponds to the negative of the second derivative of the stimulus distribution. In regions of homogeneous stimulation, the excitatory and inhibitory influences cancel each other perfectly. When the ratio between the two effects is greater than 1.0, the sensation magnitude of plateaus or gradients is directly proportional to stimulus magnitude. Sensation magnitude at all points becomes larger as the ratio of excitatory effects to inhibitory effects increases. However, changing the value of this ratio does not change the relationships between the sensation magnitudes of the two border elements.

In the preceding treatment the neural unit was applied to a step pattern of illumination without consideration of the known blurring of the retinal image by the dioptric apparatus of the eye (Westheimer and Campbell, 1962; Krauskopf, 1962). Even when this blurring is taken into account, however, the model does not fit the obtained data. Figure 17 shows the predicted differences between the logs of the two sensation magnitudes for three values of $(I + \Delta I)/I$ and three stimulus lengths. The three $(I + \Delta I)/I$ values are 1.15, 1.70, and 2.60, which are MAS's threshold values for the 10', 12', and 24' widths, respectively, for a stimulus length of 66'. In correcting the stimulus magnitude for blurring, Krauskopf's (1962) data on the line spread function for a 3mm. pupil diameter were used. A one-dimensional neural unit with a central excitatory region of 1' and with inhibition spreading for 8' on a side was applied to the corrected stimulus magnitude.

If this revised treatment accounts for the data, then the three predicted points which represent the actual threshold for subject MAS should lie at the same value on the ordinate. These three points are: $(I + \Delta I)/I$ of 1.15 for the 24' width, $(I + \Delta I)/I$ of 1.70 for the 12' width, and $(I + \Delta I)/I$ of 2.60 for the 10' width. Their values on the ordinate are .03, .09, and .14 respectively. It is clear that even with a correction for the blurring of the stimulus, the model does not successfully predict the contour perception thresholds.

FIG. 17. PREDICTED DIFFERENCES BETWEEN LOGARITHMS OF SENSATION MAGNITUDES ON EITHER SIDE OF LIGHT-DARK BORDER WHEN STIMULUS MAGNITUDE IS CORRECTED FOR BLURRING BY OPTICAL MEDIA OF EYE.



log (sensation magnitude of brighter side) - log (sensation magnitude of darker side)
.05
.10
.15
.20
1.0
1.5
2.0
2.5
$\frac{I+\Delta I}{I}$
Width of Field
● 24'
■ 12'
△ 10'

The present data fail to be described by the useful flux and neural unit models because the thresholds for the small stimuli are higher than either model predicts. For example, in Figure 13, the useful flux function for the 5' width is higher than that for the other widths, indicating that the product of area and threshold is "too high." Since the useful area for these narrow stimuli cannot be decreased without lowering all the other functions in the figure, the model requires that the thresholds for these stimuli be lower than they are. The previous discussion of Békésy's neural unit has shown that, for the thresholds obtained in this experiment, the difference between logs of the sensation magnitudes on either side of the border is larger for the small fields, regardless of the width of inhibitory unit used.

One possible explanation, which is a horrible spectre in all psychophysical experiments, is that the subject used different cues in making his judgment depending on the length and width of the stimulus. This situation was encountered during the running of a pilot study on difference thresholds with the split field stimulus. For very small fields, the subject frequently noticed a difference in the shapes of the two fields before she noticed a brightness difference. While such an obvious discrepancy between actual and desired criterion did not arise in the present experiment, subjects did observe that the appearance of the sharp contour in the small fields was different in some respects from its appearance in the large fields.

Barring the possibility that the subject's criterion varied systematically with stimulus size, one can look to recent psychological and physiological experiments for alternative explanations. Evidence has been accumulating (e.g. Blakemore and Campbell, 1969; Graham and Nachmias, 1971) that the visual system contains neural units which are selectively sensitive to a small band of spatial frequencies. These units might involve opposed excitatory and inhibitory influences, but their receptive fields would be of different sizes. In that case, the assumption of a single size receptive field, which is basic to the above application of the Békésy model, would be vastly oversimplified, especially since the stimuli in this experiment would have complex Fourier transforms.

Recent physiological work on cats and monkeys (Hubel & Wiesel, 1962, 1968) has revealed cells in the striate cortex which are sensitive to edges and lines of particular orientations and size. These cells seem to be higher-order contour detectors which receive input from simpler opponent-process cells. This physiological evidence strongly suggests that contour perception involves some further processing of the stimulus beyond that provided by lateral inhibition.

REFERENCES

Beitel, R. J. Inhibition of threshold excitation in the human eye. Journal of General Psychology, 1936, 14, 31-61.

Békésy, G. von. Neural inhibitory units of the eye and skin. Quantitative description of contrast phenomena. Journal of the Optical Society of America, 1960, 50, 1060-1070.

Békésy, G. von. Brightness distribution across the Mach bands measured with flicker photometry, and the linearity of sensory nervous interaction. Journal of the Optical Society of America, 1968, 58, 1-8.

Blakemore, C. and Campbell, F. W. On the existence of neurones in the human visual system selectively sensitive to the orientation and size of retinal images. Journal of Physiology, 1969, 203, 237-260.

Diamond, A. L. Foveal simultaneous brightness contrast as a function of inducing field area. Journal of Experimental Psychology, 1955, 50, 144-152.

Fiorentini, A., Jeanne, M., and Toraldo di Francia, G. Measurements of differential threshold in the presence of spatial illumination gradient. Atti della Fondazione Giorgio Ronchi, 1955, 10, 371-379, cited in Ratliff, F. Mach bands: Quantitative studies on neural networks in retina. San Francisco: Holden-Day, Inc., 1965.

Fiorentini, A. and Radici, T. Brightness, width, and position of Mach bands as a function of the rate of variation of the luminance gradient. Atti della Fondazione Giorgio Ronchi, 1958, 13, 145-155, cited in Ratliff, F., Mach bands: Quantitative studies on neural networks in the retina. San Francisco: Holden-Day, Inc., 1965.

Fiorentini, A. and Zoli, M. T. Detection of a target superimposed to a step pattern of illumination. Atti della Fondazione Giorgio Ronchi, 1966, 21, 338-356.

Fiorentini, A. and Zoli, M.T. Detection of a target superimposed to a step pattern of illumination. II. Effects of a just-perceptible illumination step. Atti della Fondazione Giorgio Ronchi, 1967, 22, 207-217.

Graham, N. and Nachmias, J. Detection of grating patterns containing two spatial frequencies: A comparison of single-channel and multiple-channels models. *Vision Research*, 1971, *11*, 251-259.

Heinemann, E. G. Simultaneous brightness induction. In *Handbook of sensory physiology*, Vol. VII/4. *Visual Psychophysics*. Hurvich, L. and Jameson, D. (Eds.), Springer-Verlag, (in press).

Hood, D. C. and Whiteside, J. A. Brightness of ramp stimuli as a function of plateau and gradient widths. *Journal of the Optical Society of America*, 1968, *58*, 1310-1311.

Hubel, D. H. and Wiesel, T. N. Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. *Journal of Physiology*, 1962, *160*, 106-154.

Hubel, D. H. and Wiesel, T. N. Receptive fields and functional architecture of monkey striate cortex. *Journal of Physiology*, 1968, *195*, 215-243.

Krauskopf, J. Light distribution in human retinal images. *Journal of the Optical* Society of America, 1962, 52, 1046-1050.

Lamar, E. S., Hecht, S., Shlaer, S., and Hendley, C. D. Size, shape, and contrast in detection of targets by daylight vision. I. Data and analytical description. *Journal of the Optical Society of America*, 1947, *37*, 531-545.

Le Grand, Y. *Light, colour, and vision*. Translated by R. W. G. Hunt, J. W. T. Walsh, and F. R. W. Hunt. London: Chapman and Hall, Ltd., 1957.

Leibowitz, H. The use and calibration of the "Maxwellian view" in visual experimentation. *American Journal of Psychology*, 1954, *67*, 530-532.

Leibowitz, H., Mote, F. A., and Thurlow, W. R. Simultaneous contrast as a function of separation between test and inducing fields. *Journal of Experimental Psychology*, 1953, *46*, 453-456.

Matthews, M. L. Appearance of Mach bands for short durations and for sharply focused contours. *Journal of the Optical Society of America*, 1966, *56*, 1401-1402.

Nachmias, J. Visual resolution of two-bar patterns and square wave gratings. *Journal of the Optical Society of America*, 1968, *58*, 9-13.

Ratliff, F. *Mach bands: Quantitative studies on neural networks in the retina*. San Francisco: Holden-Day, Inc., 1965.

Ratliff, F., and Hartline, H. K. The response of *Limulus* optic nerve fibers to patterns of illumination on the receptor mosaic. *Journal of General Physiology*, 1959, *42*, 1241-1255.

Stecher, S. Luminance difference threshold and simultaneous contrast. *American Journal of Psychology*, 1968, *81*, 27-35.

Thomas, J. P. Brightness variations in stimuli with ramp-like contours. *Journal of the Optical Society of America*, 1966, *56*, 238-242.

Thomas, J. P. Linearity of spatial integrations involving inhibitory interactions. *Vision Research*, 1968, *8*, 49-60.

Westheimer, G. and Campbell, F. W. Light distribution in the image formed by the living human eye. *Journal of the Optical Society of America*, 1962, *52*, 1040-1045.