VISUAL ACUITY AS AFFECTED BY ADJACENT BORDERS IN A TARGET

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ABSTRACT

VISUAL ACUITY AS AFFECTED BY
ADJACENT BORDERS IN A TARGET

by J. Yves Lortie

This investigation examines the effect of adjacent borders upon detection of a fine line.

A review of the literature on contour processes indicates that borders near one another exert a mutually depressive influence. This influence was shown to extend to distances as far as four degrees on the retina. If in a set-up traditionally used for studying visual acuity two dark bars are introduced at different distances from a fine line to be detected, one would expect visual acuity to be impaired when the bars are close to the line. As the distance is increased, the depressing effect of the bars should progressively decrease. Moreover, such a depressive effect, if present, can be better understood by performing temporal manipulations of borders. Thus, varying the order of presentation of the bars and line should reveal significant interactions between contours. It should also throw some light on the relationship between contour processes and visual acuity.

It was the purpose of this author to examine those points, or more generally to analyze some of the implications of relating visual acuity and contour processes.

Two trained observers participated in the experiment. Six situations were investigated in which several spatial and temporal manipulations of borders were performed, such as length of bars and line, distance of bars from the line, order of presentation of bars and line, and shifting of bars.

The results indicate that visual acuity is affected by the presence of borders in the vicinity: (1) Distance between the bars turned out to be a significant factor. When these bars were near the line, more time was required for its detection than when they were far out. At an intermediary distance, however, they had a facilitatory effect upon visual acuity. (2) The length of bars, when near the line, counterbalanced the facilitatory effect of an increase in length of this one. (3) Removal of the bars at the same time as the line was projected had a strong depressive effect upon visual acuity. (4) A shifting of the bars away from the line also required more time for its detection. (5) A shifting of the bars toward the line was facilitatory in the case of one observer, and inhibitory in the case of the second one. (6) Equally, for one observer simultaneous presentation of the bars and line had a facilitatory influence upon visual acuity while the effect was inhibitory for the other.

The results were discussed in terms of contour formation. They suggest that any factor which impairs visual acuity does so by interfering with this neural process. Among the factors found to play a significant role are the presence of other contours in vicinity, their order of formation and their destruction.

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VISUAL ACUITY AS AFFECTED BY

ADJACENT BORDERS IN A TARGET

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INTRODUCTION

Visual acuity is a spatial discrimination involving a simultaneous comparison of different areas of a target. It is defined as the reciprocal of the minimum visual angle subtended by some relevant element of the target, measured in minutes of arc. In order for visual acuity to take place, there must be a detectable disparity or lack of uniformity in the different portions of the target; in other words, borders must exist in the target itself.

A recent review (Westheimer, 1965) indicates that many different data have been collected concerning visual acuity. Equally, various explanations have been offered; the most important of these have been critically reviewed by Senders (1948) and Falk (1956). The discussion has been brought up to date by Boynton (1962).

However, the detection of a fine line, a grating, or any other figure, implies the formation of contours (Bartley, 1941, p. 334). This neural mechanism[1] has not been given all the attention it deserved in psychophysical as well

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[1]Because he is dealing with three different types of phenomena: physical, neurophysiological, and perceptual, the author, following Bartley (1958 a, p. 130), differentiates between borders, contours, and edges. The abrupt changes in illumination of the target are called borders, the corresponding neural processes are named contour formation or contour processes and the perceptual end-results are the edges.

as in neurophysiological researches. For example, one of the major findings of the studies devoted to it is that borders or abrupt changes of luminance in a target, at certain distances one from the other, interact in the formation of their respective contours, thus changing the perceptual outcome (Fry & Bartley, 1935). Any condition affecting this process, as for example, the depressing influence of borders in near vicinity, should change visual acuity. Very few studies, however, have approached the problem in this way. It was the purpose of the present author to examine the evidence offered about this process, to study its relation to visual acuity, and to perform further manipulations of borders in order to observe their effects upon detection of a fine line.

In this chapter some of the studies on contour formation are reviewed and generalizations to which they led are examined. A review of these generalizations in relation to visual acuity follows. Finally, specific questions are formulated which it is the purpose of the author to study.

Contour Processes

Definition

When a target with abrupt borders is projected upon the retina, the information which reaches the cortex through the optic tract can be conceived of as being of two types:

(1) a longitudinal propagation of activity along the different channels of the pathway; (2) a lateral or cross-sectional type of activity which takes place in the retina and across the channels (Nelson, Bartley & Wise, 1963). This lateral type of discharge has been called contour formation (Bartley, 1941, p. 229) or contour processes (Bartley, 1958 a, p. 130). Thus, contours are neural processes underlying spatial discriminations in which edges are involved.

Contour processes have been posited in order to deal with these facts:

(1) the retinal image of a sharp border is blurred;

(2) brightness discrimination is affected by the distance between borders in a target, and by the timing of successive presentations of borders;

(3) the perceptual or phenomenological properties of a target differ depending on the degree of illumination used.

Blur of the Retinal Image

In proper conditions, abrupt borders in any portion of a target lead to the perception of steep, sharp edges. However, the corresponding image formed on the retina, besides being upside down, is more or less blurred, never as clear-cut as the borders themselves. In other words, the image on the retina is not an exact replicate of the physical object impinging on it. As the edge is seen as clear-cut, some neural mechanism, conceived in terms of enhancement and depression of lateral activity, is needed to resharpen what has become blurred.

The gradient-wise distribution of retinal illumination results mainly from diffraction effects and different aberrations of the refractive power of the eye. These two types of defects vary with the size of the pupil. Thus as the pupillary diameter decreases, diffraction effects become larger (Westheimer, 1963). With large pupils diffraction becomes negligible but, on the other hand, chromatic aberration comes in: it depends on different wavelengths being refracted by different amounts, and this creates indistinct color effects along the edges of the perceived image.

Another type of aberration found in optical systems is spherical aberration: the rays refracted through the outer portion of the lens are brought to a focus nearer that lens than those from the center. This normally would produce a blurred and distorted image. This factor, however, is negligible in the eye: it is compensated to a high degree by the peripheral flattening of the cornea (Bartley, 1960, p. 202; Westheimer, 1963), and also by the size of the pupillary aperature and the structure and curvature of the lens (Bartley, 1960, p. 202).

Other characteristics of the eye also affect the amount of blur of the retinal image: one of these is the accommodative power of the eye. Poor accommodation increases the amount of blur by bringing the image out of focus (Westheimer & Campbell, 1962). Moreover, it has been found that, during fixation, accommodation is constantly changing (Campbell & Westheimer, 1960; Arnulf & Dupuy, 1961).

Finally, physiological nystagmus would be assumed to decrease the steepness of the gradient: the rapid oscillations of fixation successively present adjacent areas of the target to the same retinal receptors and this should enhance the blur of the formed image. The author, though, did not find any direct evidence supporting this view.

Distance Between Borders in Brightness Discrimination

Suppose a small disk is surrounded by a larger ring and that the luminance of the disk is increased till the observer perceives a difference in brightness between the disk and its annular surround. It has been found (Blachowski, 1913) that the threshold for the detection of the disk decreases as the area of the surround is increased. Blackowski explained his results in terms of spatial summation. Fry & Bartley (1935), however, have demonstrated that the decrease in threshold detection when the area is enlarged is due to the fact that in these conditions the outer borders of the ring are farther away from the borders of the disk and they interfere less with the formation of the appropriate contour.

In their experiment they used a disk with a diameter of 3/8 inch and a large 6 inch ring surrounding it. Also a dark circular band, the diameter of which could be increased or decreased, was superimposed on the ring. By decreasing the diameter of the dark band, the distance between its inner border and the border of the disk was decreased, and the opposite was observed when the experimenter was increasing the diameter of the band. The area of the ring, however, remained constant. It was found that when the distance between the borders of the disk and the inner border of the band was 4 degrees or less the threshold of detection of the disk was higher; it increased in proportion as the distance between those borders was decreased. The authors concluded that already formed contours exert a depressive influence upon the formation of other contours in their immediate surround.

Other manipulations by the same authors allowed them to reach a second conclusion, that is: contours parallel to the activating contour are depressed while those perpendicular or at right angles to it tend to be facilitated. Thirdly, existing contours prevent activity from spreading in the visual system; a third contour interposed between two activating contours will block the activity between these two.

Timing of Successive Presentations of Borders

The work of Fry & Bartley, reviewed above, has indicated the effect of spatial distribution of events upon contour formation. Timing of events is a second important variable. Helson & Fehrer (1932) presented targets of different shapes tachistoscopically. With a very brief exposure, these were seen as "dim patches of light." As the exposure was lengthened, definite forms with sharp edges were recognized.

In an extensive experiment, Werner (1935) used many different targets and manipulated spatial as well as temporal variables. For example, in a part of the experiment he had a small illuminated disk alternate with an illuminated ring the inner border of which coincided with the outer border of the disk.

When the disk was briefly presented first and was followed after about 150 msec. by the ring, the disk was not seen. The outcome was the same, when the figures were dark and the ground illuminated. With a slower rate of succession, the disk was seen and then the ring. Werner concluded that with a fast rate of succession, contours do not have time to form and consequently the figure is not perceived as such. Too short a duration of presentation depresses or destroys the formation of contours and it affects the appreciation of the brightness that a surface would otherwise have.

Other shapes, where the space between two wide dark bars was occupied by several thin lines parallel or perpentidular to these bars yielded results sensibly similar to those of Fry & Bartley for the parallel lines: these were strongly affected by the previous presentation of the wide bars.

The lines perpendicular to the bars were depressed also, but to a lesser degree. Fry & Bartley had found that borders at right angles tended to facilitate contour formation. Fry & Bartley, however, were manipulating space or distance between borders, while Werner manipulated duration of presentation in that part of his experiment.

Role of Luminance Upon the Edge Properties of a Target

The intensity of illumination of the different portions of a target is another variable which has been shown to considerably alter the formation of contours. Suppose (Bartley, 1941, p. 6) a stimulus consisting of a small illuminated disk (spot of illumination) in a dark field. When the intensity is very low, the observer sees an indefinite spot of light, not well differentiated from the surround, which seems to wander about and may even disappear for brief moments. Phenomenologically the target is not seen as a disk, but as an indifferentiated spot. If the intensity of illumination is increased sufficiently, then the result is quite different: what emerges is a disk with sharp edges.

An experiment which demonstrates the role of illumination upon the edge properties of a disk has been performed by Bartley (1936). He used a target arrangement consisting of a disk surrounded by a ring the inner border of which coincided with the outer border of the disk. The disk portion of the target was alternately light or dark at each of several slow rates, while the ring portion was kept constant in illumination. Physically the duration of the light and dark phases of the disk was the same; however, the intensity of illumination of the ring determined the perceptual outlook: when the intensity of the ring was kept above the mean value of the two phases of the disk, the dark phase of the disk became predominant. When the intensity of the ring was reduced to a value below the mean, it was the light phase which precominated. The predominant phase possessed sharp edges and seemed to occupy most of the cycle, while the diminished phase had no definite edge but was seen as a mere shadow.

Contours in Relation ot Other Phenomena

Contour processes are involved not only in brightness discrimination, but also in many other phenomena: Bartley (1941) presents some evidence to the fact that contour formation has a decisive role in Fechner's paradox, in after-images and in visual acuity. Osgood (1953, p. 232) considers contour formation as being fundamental to all perceptual activity.

The relation between contour processes and visual acuity will be examined after the following section on neurophysiological researches.

Neurophysiological Studies on Contours

Although several psychophysical researches show the legitimacy and importance of contour processes, these have not been much investigated as such by neurophysiological techniques. This may be due to the complexity of the processes themselves: for example, it seems that in order to study them adequately large areas of the retina or many different channels of the optic tract would have to be covered simultaneously. In recent years microelectrode studies have tended to explore in a piecemeal fashion very restricted regions of the pathway, while macroelectrode techniques did not systematically investigate those processes.

However, there has been some interesting work on what can be considered as part-effects of contour formation, that is on inhibitory mechanisms. For example, Hartline and collaborators (Ratliff, 1961), working with the lateral eye of the horseshoe crab, Limulus, and using diffuse illumination as a stimulus, reached the conclusion that the detection and enhancement of edges is explainable in terms of lateral inhibitory interaction among retinal elements.

While Hartline and collaborators were working at the retinal level, Jung and co-workers (1961) investigated the visual cortex, recording neuronal discharges in the primary visual area of the cat. The stimulus used was diffuse illumination. For binocular stimuli, they proposed to classify the response patterns of the visual cortex into five neuronal types, named A to E, thus expanding the classification of the retinal elements which comprises on, off, and on-off neurons. As no physical borders were used, not much could be reported related to perception of edges. But, in 1958, Baumgartner, in the same laboratory, began to use what he calls "patterned light with white-black contrast," or targets with abrupt borders (a grid of light and dark bars). In one of their experiments, he and Hakas (Jung, 1961) exposed one of the light bars, subtending a visual angle of 5 degrees 41 minutes, and moved it by steps across the receptive fields of the cortical neurons. As expected, the response of these neurons was different from what is observed when there is no borders (diffuse illumination). When the illumination is on, a maximum of discharges is observed in the cortical B neurons if their receptive field is stimulated by the portion of the light bar at the margin of the dark bar (at the border). When the receptive field of these same neurons is presented with the dark ground, there is a minimum of discharges at light-on and also a reversal of their responses to onset the termination of illumination, that is when the illumination is on, the discharge of the B neurons is inhibited; it is activated when the illumination is off. The D neurons behave in the opposite way; they are activated when the illumination is on, and depressed when it is off, if their receptive fields are presented with the dark part of the target. When the light part is used, the off-response of these D neurons is maximal. To explain this reciprocal activation and inhibition of these two types of antagonistic cortical neurons and also the increased frequency of discharges at the border between the light and dark bars, they utilized the reciprocal and lateral inhibition schema of Jung, that is there is a reciprocal inhibition of antagonistic neurons (B and D) in the same receptive field, and a lateral inhibition of synergic neurons in the surrounding regions.

Another interesting finding of Baumgartner is that the neuronal discharges corresponding to the borders between light and dark bars vary with the width of the bars, a fact in agreement with psychophysical observations to be reviewed later.

From what has been done till now, one can easily conclude that physiological studies are still far from providing the information necessary to clarify the mechanism of contour formation. The conclusions reached by Hartline when applied to the human or even the vertebrate retina at a lower level (the cat, for example) are very limited, at least for the reason that the compound eye of the Limulus is structurally and functionally very different from the vertebrate eye. Hartline and co-workers agree that in the vertebrate retina interaction would be more complex and would comprise excitatory as well as inhibitory influences (Ratliff, 1961, p. 200). Also it is to be recalled that Hartline was recording neural impulses in one active nerve fiber at a time, thus reaching conclusions very limited in scope.

Baumgartner worked with a vertebrate organ, the cat eye, and also used borders in his target. Second, he took care of comparing his physiological findings (neuronal discharges in cats) with corresponding visual perceptions in man, thus coming closer to bringing the elements which would allow a thorough understanding of the process of contour formation. However, here also one finds serious limitations: for example, his conclusions are valid only when eye movements are excluded. Optokinetic nystagmus seems to be an important factor in the blurring of the retinal image as it was mentioned previously. Besides, here again the work done was very analytical, in a piecemeal fashion, the authors recording from one receptive field at a time, while contour formation seems to work over very large areas of the retina, as the psychophysical studies of Bartley have shown. In short, much more researches are needed before one can translate into clear physiological terms the processes of contour formation. Therefore, it is not the purpose of this author to work out such a mechanism. Attempts have been made elsewhere (Osgood, 1953, p. 229; Milner, 1958), but it is the author's opinion that they are premature. For the time being, more work should be performed on the psychophysical as well as on the physiological levels: physiological researches will offer direct evidence on contour processes, while psychophysical ones will bring in new facts and data which eventually one should be able to explain if he wants the processes to be of more than very restricted validity.

Contours Processes and Visual Acuity

While in studies involving brightness discrimination one was working with extended areas, in visual acuity the area becomes minimal, at least along one dimension, and borders are much nearer one another. This effect of borders upon one another should, therefore, become more prominent.

Manipulations of Borders in Visual Acuity

The distance between borders, in a visual acuity target, can be looked upon in several different ways: for example, in a target made up of a single line there is the distance between the two longitudinal and parallel borders of the line, the distance between the borders at the two extremities of the line, and also the distance between the line and the borders formed by the frame of the whole target. When the target consists of two parallel lines, there is, besides the factors just mentioned, the interspace between the two lines. In a grating, there are several interspaces. With a Landolt ring, the relation between borders is more complex, while with letters the complexity of the relations is very variable.

All of these shapes, and others, have been used in studying visual acuity. For example, disks (Ogle, 1961) as well as fine wires or lines (Fry & Cobb, 1935; Hecht & Mintz, 1939) have been used for studying the minimum visible. For the minimum separable the following configurations have been utilized: pairs of parallel bars (Fry & Cobb, 1935; Wilcox, 1932), Landolt ring (Shlaer, 1937), grating (Shlaer, 1937; Graham & Cook, 1937), two points (Oliva & Aguilar, 1957), and vernier adjustments (Baker, 1949; Leibowitz, 1955).

Among these, a very few are relevant to the problem with which the present author is concerned, those where borders in simple relation to one another are implied.

Single line. The minimum width for a single dark line to be visible was shown by Hecht & Mintz (1939) to be nearly 0.5 second at the highest illumination they used (30 millilamberts) and with binocular vision. The target was made up of a circular ground, an opal glass illuminated from behind and measuring 2 feet in diameter. The lines were made up of wires varying in thickness. The subject, in a chair on rollers, moved toward the target till he could ascertain the position of the line in the target. Hecht & Mintz explained its detection by the fact that the illumination on one row of cones is just perceptibly less than on the rows on either side of it. So, even if the retinal image of a fine line is fuzzy, it is not perceived as such but it is seen as a clear line because it would stimulate one row of cones less than the others adjacent to it. They maintained that no central mechanism of contour formation is necessary to convert the gradual distribution of illumination on the retina into a sharp line at the perceptual level.

Their explanation runs into serious difficulties. These have been covered by Senders (1948), and Falk (1956). Let's mention only that according to Hecht & Mintz visual acuity would depend only on intensity of illumination. As will be seen, other factors are also implied, for example the length of the line.

In the previous experiment, Hecht & Mintz always used wires of the same length. In another experiment, Hecht, Ross & Mueller (1947) varied the length of the fine wires. Again they found 0.43 sec. as the minimum width of a line to be seen against a bright sky. They found, however, that in order to get this result, the minimum length had to subtend an angle of about one degree at the eye. Below that value the threshold raised rapidly.

The facilitating effect of length of line was confirmed by Ogilvie & Taylor later on (1959).

The effect of the width of a light bar on visual acuity has been investigated by Fry & Cobb (1935). Using bars 50 minutes long they determined the threshold values for a number of different widths, beginning with a bar whose width was 3 minutes 12 seconds and then using bars of lesser width till they obtained one in which width and intensity were reciprocal. They were able to demonstrate that the retinal distribution of illumination is Gaussian in character; therefore, it is the intensity at the center of the retinal image of the bars which determines visual acuity. With a very narrow bar the intensity at the center may be subthreshold. Increasing the width of the bar increases the intensity at the center, so that the line may then become visible. However, one reaches a point where this relationship of width and intensity does not hold any longer; for example, any bar wider than 4 minutes 2 seconds, in the conditions of the experiment, did not reduce the threshold of detectability. It is to be noted that in this direct method of estimating the blur of the retinal image, nystagmus or the rapid oscillatory movements of the eye as well as diffraction and the chromatic and spherical aberrations were taken into account.

That the retinal gradient of illumunation is Gaussian or approximately so has been confirmed by Westheimer and Campbell (1962). In their experiment they used a streak light filament. They estimated the spread of the corresponding retinal illumination by determining the distribution of intensity in the aerial image formed by reflection of the filament at the fundus and subsequent reverse passage through the eye.

Parallel lines. When one is using two parallel bars visual acuity has been shown to depend not only on the interspace between these bars but to a certain point on the width of the bars themselves. For example, Fry & Cobb (1935) in the same series of experiments as described above, used two pairs of light bars measuring 33 minutes 20 seconds in length. One set of bars were 16 minutes 40 seconds in width while the second set, the narrow bars, were 2 minutes 48 seconds. Their results indicated that with an increase in the luminosity of the bars from 0 to 3 foot-candles visual acuity, in the case of the wide bars, always increased, rapidly at first and then more slowly. In the case of the narrow bars, visual acuity improved markedly till the luminosity reached slightly more than one foot-candle, and then it deteriorated. To explain their findings the authors utilized the principle established by Fry & Bartley, namely that borders near one another interfere in contour formation. With narrow bars, parallel borders are near one another, the contour processes corresponding to each one of these borders interfere and depress each other thus elevating the threshold for detection of the interspace. With wider bars, the borders are farther apart and their influence is much less marked.

The importance of bar width in determining visual acuity was further studied by Kravkov (1938). Wilcox (1932), studying the effect of illumination upon visual acuity, had found that with dark bars on a light ground detection of the interspace between the two bars increased with an increase in retinal illumination, but that with light bars on a dark ground, visual acuity first improved and then deteriorated. Furthermore, he observed that dark bars tended to be subjectively widened at low intensity, and that this apparent enlargement was decreasing with an increase in intensity, the bars subjectively appearing to shrink. Kravkov showed that the conclusions of Wilcox are valid for narrow bars only, not for wide bars. He explained this phenomenon of shrinking, called negative irradiation by Wilcox, in terms of the findings of Fry & Bartley on the depressing influence of borders parallel to one another on contour formation. In brief, with narrow bars two factors are at work, one photic intensity, favoring visual acuity, the other, borders near one another, impoverishing it by creating a shifting in contour processes toward one another. With an increase in photic intensity, the increased steepness of the blur gradient would overcome the depressing effect of the other factor and an improved visual acuity would result. With broad bars, photic intensity becomes the main factor and no shifting is observed.

The Present Problem

The studies reviewed above, especially those by Kravkov, Fry & Cobb, indicate that borders near one another affect each other in determining visual acuity. Moreover, the work of Fry & Bartley on brightness detection had shown that this depressing influence may extend to distances as far as 4 degrees on the retina. If a whole target subtends a visual angle of only a degree or so, which is very often the case in experimental set-ups where visual acuity is investigated, then the borders formed by the frame of the target should exert some influence on the perception of the line or lines. For example, the background field in Wilcox's study subtended an angle of 1 degree 10 minutes in width and 20 minutes in height. According to the generalizations of Fry & Bartley, these borders of the field which are parallel to the two lines should affect their detection. Second, those borders perpendicular to the lines should exert a facilitatory influence. As the lines are relatively short, 20 minutes in length, this influence should be serious. But these variables have not been dealt with in Wilcox's study.

The same problem is encountered in any set-up wherein relatively small background fields are used.

It seems then that systematically examining the effects of bars presented at varying distances from a fine line would be justified: besides throwing new light on the processes investigated, such a study would allow one to test the validity of using a background field of restricted dimensions and at the same time ignoring its effects when theorizing about visual acuity.

In fact, one would expect visual acuity to be impaired if these borders are in close vicinity of the line. As the distance is increased, the depressing effect of the bars should progressively decrease. As simple as this may seem, the present author does not know of any study trying to investigate it. One study came close, though: Flom and coworkers (Flom, Weymouth & Kahneman, 1963) examined the effect of four dark bars placed tangential to a Landolt ring and at varying distances from it, upon detection of the position of the gap in the ring. The maximum interaction was found at approximately five times the gap width. However, in that study the relation between borders is very complex; it is far from being the ideal situation for unraveling the functioning of contour processes.

Another aspect of the problem refers to temporal manipulations of borders. As contour processes take time to complete themselves, it appears that varying the order of presentation of different portions of the target would be essential for one to better understand the relationship between contour formation and visual acuity. For example, the bar borders: the bars borders may be presented before the line to be detected, or simultaneously with it, or they may be removed at the exact moment the line is projected, etc.: all these manipulations should reveal significant interactions between borders. To the author's knowledge, such manipulations have not been tried. Traditionally all the elements of a target have been presented at the same time. In a typical experiment the target is presented for unlimited time and the observer indicates if he can detect or not the relevant portion (Hecht & Mintz, 1939). Or, while the observer is looking at the target, the distance between bars or lines may be varied by the experimenter till these are viewed as separate (Wilcox, 1932). In other experiments, the observer has a limited time for looking at the target, but again all the relevant portions of the target are presented together for a certain duration (Niven & Brown, 1944).

Rare are the exceptions to that procedure: for example, Granit & Harper (1930) used the c f f method, but their purpose was to study the relation between spatial summation and visual acuity. Equally, Bartley and collaborators (Bartley, Nelson & Soules, 1963) utilized intermittent illumination; this was done, however, in order to investigate the effect of brightness enhancement upon visual acuity. Thus, in these two types of studies temporal manipulations of different portions of a target were effected but they were not of the kind suggested above.

Third, another generalization of Fry & Bartley should lead to interesting studies in visual acuity. They have shown that already formed contours prevent activity from spreading in the whole retina. Therefore, in specific conditions to be determined, already formed contours should improve visual acuity. As far as the present author knows, this generalization has not been investigated.

The purpose of the present study was to examine those factors, or more generally to analyze some of the implications of relating visual acuity and contour processes. If distance and timing of borders can be shown to affect visual acuity, a new type of evidence will be brought forth for the processes involved. In order to determine whether this is so, the effects of diverse spatial and temporal manipulations of borders were analyzed:

(1) manipulations of length of borders and distance between them;

(2) temporal manipulations of different portions of the target.

Within this general framework, six specific questions were studied:

(1) Would a decrease in the distance between two dark bars retard the detection of a fine line appearing in the interspace between those bars?

(2) Similarly, would a dark foreperiod followed by a simultaneous presentation of the bars and line, hinder visual acuity?

(3) To what extent would a lighted foreperiod without any border in the target and followed by a simultaneous projection of the bars and line, affect the detection of this same line?

(4) Would a foreperiod with two bars which vanish when the line appears, create much interference upon seeing the line?

(5) Would an instantaneous shifting of the positions occupied by the bars while the line is projected, increase the duration required for detecting the line? If so, would the effect be different when the shifting is toward the line than when it is away from it?

(6) Finally, would longer bars cancel out the facilitatory influence of an increase in the length of the line upon visual acuity?

The general plan of this research involved testing two trained observers for visual acuity under three different levels of photic intensity, in situations wherein spatial and temporal manipulations of targets were performed.

METHOD

Subjects

Two subjects were used throughout the whole experiment: J.V., a graduate student in Education (male, 33 years old) and the author himself (male, 35 years old).

J.Y.L. had his vision corrected for myopia. As for J.V., he declared, at the beginning of the experiment that he had normal vision. However, a few months after the second part of the experiment was completed, that is in April 1965, he had his eyes examined and a slight degree of hypermetropia (+1.50 diopter) was found. The implications of this refraction defect are discussed in the proper section of this report.

J.V. had been trained thoroughly in May 1964: he then spent more than fifty hours as experimenter or subject in a first attempt at studying contour formation. The data collected at that time had to be rejected when the whole procedure was modified later on. However, the experience acquired by both J.V. and J.Y.L. led to more reliable data in the second attempt. As Wilcox (1932) mentions, visual acuity for fine lines varies with practice.

J.V. though well practiced, was not aware of the hypotheses to be tested and he knew vaguely about the process of contour formation.

Nelson, Bartley and De Hardt (1960) have shown that data obtained from well-trained subjects are alike in pattern and that they are close to the mean found with more naive subjects. In order to check that point, the author, at first, expected to have two naive subjects besides the two trained ones. It was not possible, at this period of the year, to find students who would spend a month or so in the laboratory. Only one subject was found (D.V., male 33 years old, a relative of J.V.). He was trained during two days and then data were collected. However, he repeatedly failed the test targets (to be described later) and his data had to be rejected entirely.

Apparatus and Material

The apparatus was the Gerbrands Tachistoscope, with two illuminated G backs and the associated Dual Timer. Because the illumination of the G backs was not uniform except for a very small area, the apparatus was slightly modified in the following ways the two neon bulbs, in each G back, instead of being about one inch behind the milk glass, as in the original set-up, have been moved approximately six inches away from the glass; a wooden frame, painted white inside, completed the arrangement. As a result the illumination became uniform to an acceptable degree over the entire area allowed by the tachistoscope ($7\frac{1}{4}$" x $7\frac{3}{4}$").

Second, the small rubber head-set on the Tachistoscope was replaced by a 14" x 20" wooden black board with three sides protruding 5" in order to block any photic radiation coming from other sources than the one to look at. An adjustable chin-head rest (American Optical Company) was used which was much more reliable and comfortable than the original set-up besides allowing one to wear glasses. When properly installed, the observer has his right eye 24" from the source and viewed the different targets through a 7/8" peephole located 1½" from his eye[1]: this set-up allowed an angle of vision of 33 degrees. A piece of black paper protruding 1" was put to the left of the peephole in order to impede any illumination from reaching the left eye. With the right eye closed, only with full illumination on was it possible for the observer's left eye to detect a certain amount of brightness, and it was so low it was assumed not to interfere with the behavior of the right eye during the experiment proper.

The illumination was varied by means of Cinemoid Grey Filters (No. 60) introduced immediately behind the peephole.

Calibration of the Dual Timer was accomplished with a K M 1 Short Timer (which could measure from 0.005 msec. to 10 sec. with an accuracy of 2%). Afterwards, the main source

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[1]No artificial pupil was used for fear that it would not be in line with the natural one. As the purpose of the author was not to measure the highest visual acuity attainable, in which condition the pupil size would become important, but to study the effects of borders upon contour formation in visual acuity, the pupil diameter becomes a less important variable.

of error resulted from trying to duplicate the different settings: a very slight variation in the successive settings for a specific value yielded results which differed by several milliseconds.

The material consisted of $8\frac{1}{2}$" x 13" transparent (Celluloid) cardboards introduced in the G backs. These cardboards supported the fine line to be detected and the dark bars assumed to exert an influence upon its detection. Thirteen targets were prepared for the fore period and twelve for the exposure period. Two more targets, used in exposure period, were test targets. The first five targets were identical as for the size of the bars and of the line, the only factor varied being the distance separating the bars from the line. In target 1 F (fore period), the two bars, which measured $\frac{1}{4}$" x $\frac{1}{2}$" (36' x 1° 12') each, were separated 6" (14° 14') on the horizontal plane, and occupied the middle of the target on the vertical plane. At the center, two small red disks of approximately 1/20" in diameter and separated by 5/16" served as fixation points. Target 1E (exposure) was identical as for the dark bars, but a fine line made up of copper wire $\frac{1}{2}$" (1° 12') long and .006" (52") thick occupied the center of the target and was parallel to the bars. (This line was cleaned and treated with $HgCl_2$ in order to become "gray" and have the least reflection possible, even though the illumination was coming from behind.) These two targets are outlined in Figure 1. With this arrangement, the only

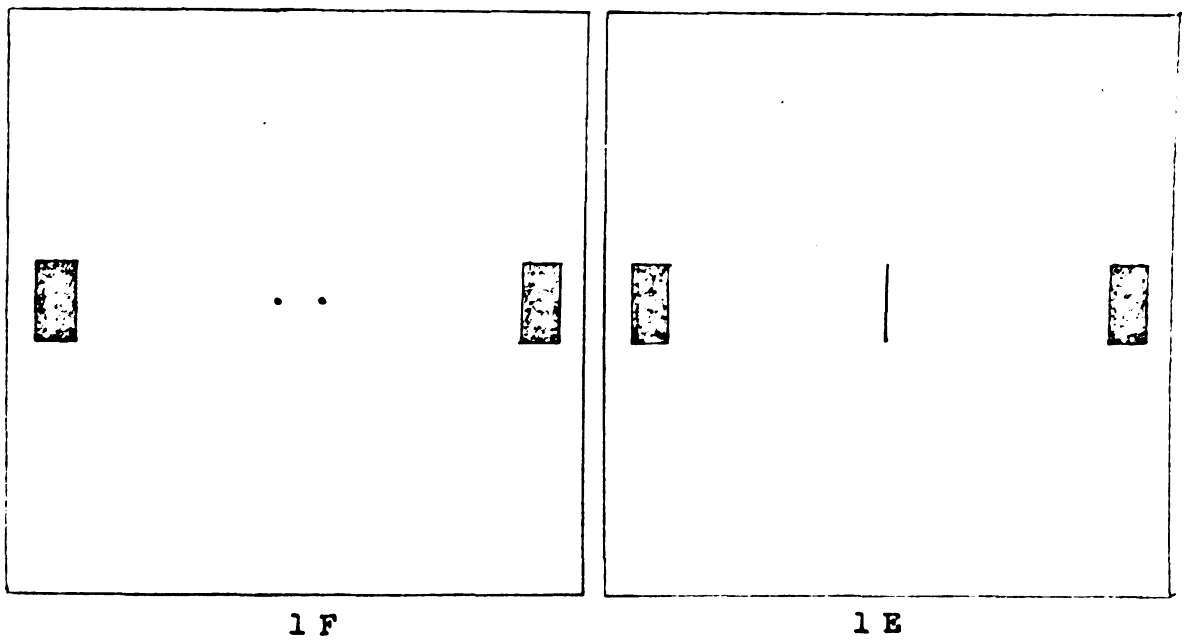

Fig. 1. Targets 1 F and 1 E used in fore and exposure periods respectively. In fore period two dark bars, which measured ½" x ¼" (1° 12' x 36'), were 6" (14° 14') apart. Two small "red" fixation points helped maintain proper fixation. In exposure period target 1 F vanished, being almost instantaneously replaced by target 1 E in such a way that everything seemed unchanged except for the fine line appearing in the middle of the space previously occupied by the two fixation points. (Not drawn to scale).

change observed when one was switching from the fore period to the exposure period was the vanishing of the red disks and the appearance of the line in the middle of the space separating those two disks. The dark bars for both periods had to coincide in order to avoid any perceived movement. Accordingly, great care was exercised during the preparation of the targets: measurements of the bars and of the length of the wire were taken by means of a rule graduated in 64^{th} of an inch, and a template and magnifying lens were used to facilitate the work. The thickness of the wire was measured with a Cenco Ratchet Micrometer.

In targets 2 F and 2 E the distance between the bars was 2" (4^{o} 46'). One inch (2^{o} 23'), ½" (1^{o} 12') and 5/64" (11') separated the bars in targets 3 (F and E), 4 (F and E), and 5 (F and E) respectively. In target 5 F the dark bars occupied the place where the red disks would normally be, in which case the bars themselves served as fixation points.

In the next group of targets the distance between the bars was maintained at 5/64" (11'), but this time the length of the bars was varied. In targets 6 F and 6 E the bars were 4" long (9^{o} 31'); in targets 7 F and 7 E they were 2" long (4^{o} 46'), while in targets 8 F and 8 E they were only ¼" long (36'). The length of the line in the exposure targets (6 E, 7 E, and 8 E) coincided with that of the bars.

In the third group of targets the same lengths were utilized as in the second group, except that this time the distance between the bars was kept at 6" (14° 14'). Thus, targets 9 F and 9 E contained bars measuring 4" in length (9° 31'), but these were 6" (14° 14') one from the other. Targets 10 F and 10 E were 2" long (4° 46'), while targets 11 F and 11 E were ¼" long (36').

Target 12 F was a black cardboard with two small fixation points: two small holes were made in the cardboard and a piece of "red "filter was put behind these fixation points.

Target 13 F was transparent and contained only the two fixation disks.

Target 14 E had no bars, but only the fine line in the middle. This line was ½" long.

Two more targets were test targets. One was a piece of transparent celluloid without any line nor bars on it. The other was identical to target 5 E, except that it had no line but only the two bars.

In all the targets the area was kept constant in order to rule out any explanation of the results in terms of spatial summation.

Preparation of Subjects

General preparation. Because the two observers served as experimenters also, it was essential that J.V. as well as the author be familiar with the psychophysical method used. As said before, J.V. participated in a first attempt made in May 1964. At that time the author explained to him the nature and shortcoming of the method to be used and readings were assigned to him on the topic.

As a subject he was asked to use as consistent a criterion as possible and he was warned that test targets, where the line is absent, might be used during the experiment. The author as a subject also was aware that test trials would be used once in a while when he would be the observer.

No formal written instructions were given the observer, but he was cautioned again and again to look at the pair of fixation points, and to indicate in the test period whether or not a line was visible in the direction of the fixation points.

It is always to be recognized that attention may vary somewhat and that this may be a factor in the production of variability in the results. In the absence of any marked variability in the results, it is also possible to account, in part, for the results as the target is varied, by saying that attention is different for each target condition. This is another way of saying that the central nervous system organization is varied by the targets and that not all of the systematic differences often attributed solely to retinal patterns of stimulation and/or to neuroretinal activity, is rightly so attributed.

Immediate preparation. At the beginning of each session the subject dark adapted for 30 minutes; for the first 15 or 20 minutes he wore dark adaptor goggles (Picker

Panoramic Goggle) and then went in the dark room for the remaining 10 or 15 minutes.

Procedure

The experiment took place in a 16' x 12' dark room. However, two 7.5 watt "red" bulbs were used by the experimenter to manipulate the targets, operate the timer, and collect data. The observer sat comfortably in front of the apparatus and observed the targets. Before each presentation a signal was given to him. Between trials, he was informed not to look directly at the target, especially when the illumination was high.

Experimental situations. The experiment comprised two parts. In Part One, which took place in July and August 1964, six situations were investigated under three levels of photic intensity (see Figure 2 for an illustration of these situations):

(1) The distance between the two dark bars and the line was decreased. The first five sets of targets were used so that the distance of the bars respective to one another was varied in five steps from 14° 14' to 11'.

(2) The fore period was dark with only two small fixation points visible, and the line and bars appeared together in exposure period. Target 12 F as well as targets 1 E and 5 E were utilized.

(3) The fore period was lighted but the target did not contain the vertical bars. During the exposure period the

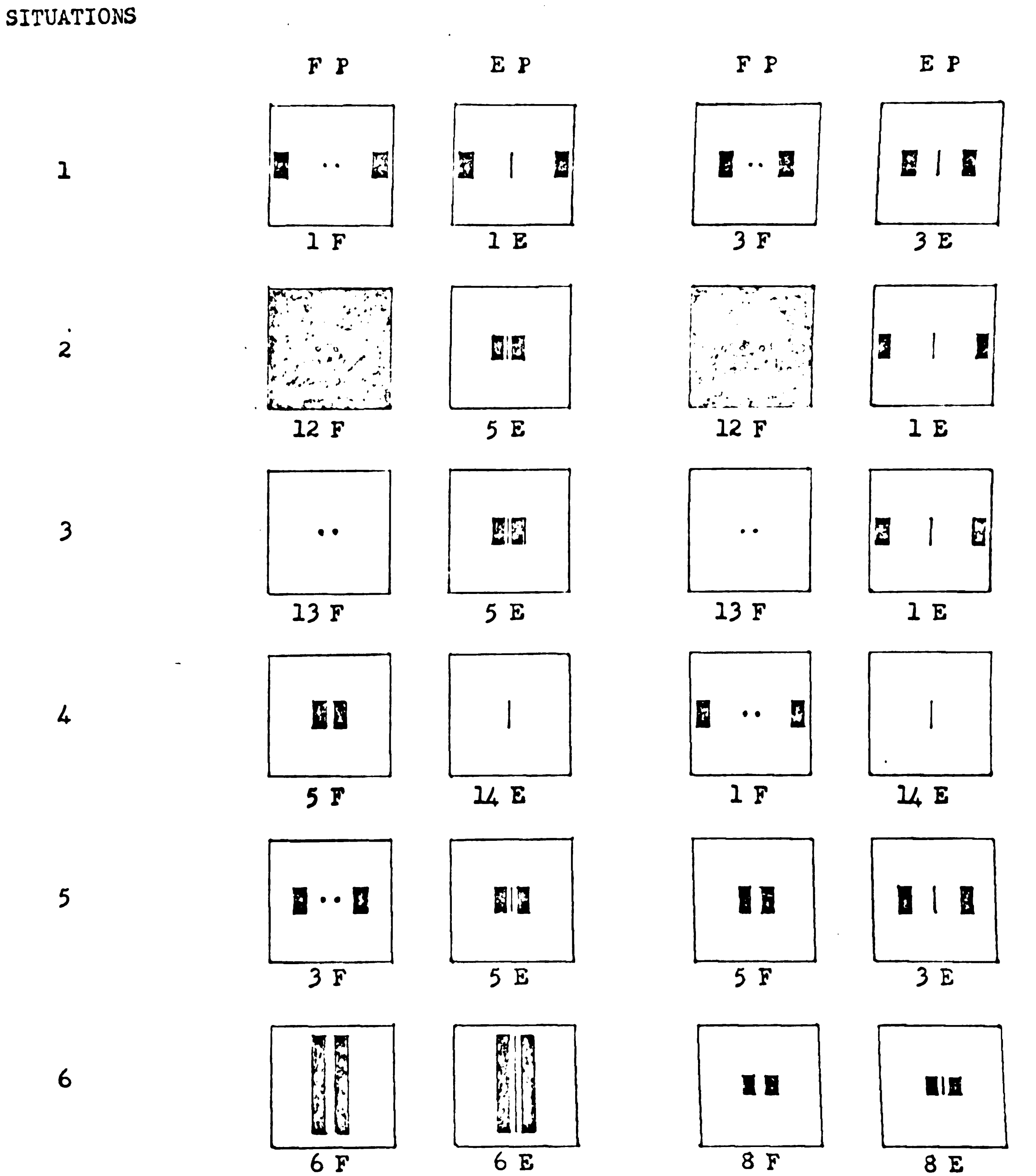

Fig. 2. The six experimental situations examined under three different levels of photic intensity. Not all the conditions investigated in the first and sixth situations are included. FP is for fore period, EP for exposure period. 1 F, 1 E, etc, correspond to the different targets described previously in the text. (Not drawn to scale).

two bars and the line appeared simultaneously. Target 13 F was used in fore period. The exposure period was identical with the one in the second situation.

(4) The two vertical bars were present in fore period, but they vanished and the line appeared alone in exposure period. Targets 1 F and 5 F as well as target 14 E were used.

(5) The two bars did not occupy the same position in fore and exposure periods. In one of the conditions targets 3 F and 5 E were used so that a shifting of borders toward the center resulted. In the other condition the use of targets 5 F and 3 E created a shifting of borders toward the periphery.

(6) The length of the line and of the two bars was increased. Targets 6 F and 6 E through targets 11 F and 11 E were utilized. The length was varied from 9° 31' to 36' in three steps. Two distances between the bars (14° 14', and 11') were used.

Part Two was performed as a check on the reliability of data in those situations where the two observers disagreed. The situations re-examined were: Situations 2, 3 and 5. This part took place approximately six months after the first one, that is in February 1965.

The psychophysical method used was the method of limits. At first it was decided that the descending as well as the ascending orders would be used. After a few days of experimentation it was found that the threshold as determined by the descending order was consistently higher than it was with the ascending order if the illumination was low and the task difficult. Then the author checked the literature and found that often the ascending order is used exclusively. For example, Wilcox used this order only, arguing that it has "great reliability and consistency" (Wilcox, 1936). Furthermore, there are other arguments which can be used against the descending order; for example, because of habituation one can say he saw the line when in fact he did not see it, but in the ascending order when he sees the line for the first time, he is much less influenced by what he has seen before. Thirdly, the problem of seeing the after-image is much less critical with the ascending order.

A minor change in this method was effected: a doubtful answer was considered as a "no" answer.

Ten threshold determinations were effected in every case and the threshold of resolution was computed by averaging all the ten readings.

Order of presentation of targets: in Part One, situations 1, 2, 3, 4, and 5, were tested all together during a same session at three predetermined levels of illumination. The purpose, here, was to avoid day-to-day variations affecting the seeing of the different targets in different ways. As the order of investigation of each situation might affect the performance of the subject, the order of these situations 1, 2, 3, 4, and 5, was determined at random, before each session, by means of a table of random numbers. Also, for any situation, the order of presentation of each target size was predetermined in the same manner. For each target two stimulus threshold determinations was taken in a row and written down. In some instances where J.V. acted as subject, three or four determinations were taken in a row. Also on the first two sessions one or two trials were effected before recording the threshold values. When all the situations were covered at the lowest level of illumination, the experimenter passed to the next level under a different predetermined order of presentation. The test targets, without any line appearing in the exposure period, were used approximately once every two sessions. A session lasted 3 or 4 hours and it always took place in the afternoon.

The last situation (Situation 6) was tested alone at a different session because testing it with all the others would have required too much time (approximately 5 hours). In these circumstances one situation had to be discarded. Situation 6 was chosen because it used targets different from those utilized in the other situations. As a result, the data obtained for that situation are not directly comparable with the others.

In Part Two of the experiment the same procedure was followed, except that only three situations were examined.

As a result a session required about half the time needed by one in the First Part.

The length of the sessions in Part One is somewhat unusual. But it is to be remembered that the subject was instructed to ask for a temporary halt any time he felt he needed one. For this reason the time spent on the task was sensibly less than the one indicated above. Moreover, a comparison of the results in Part One and Part Two, this one being much shorter, does not seem to indicate any detrimental effect due to fatigue.

RESULTS

For any condition and unless otherwise specified, the results are the averages of ten threshold determinations of which no more than two were taken on the same day.

In general the data were stable and consistent. Table 1 presents in raw form typical data from J.Y.L. and J.V. on threshold duration for low photic intensity. At medium and high intensities, the stability of data is even better.

Table 1. Raw Data on Threshold Duration Obtained in Some of the Situations--for the Two Observers--Photic Intensity .053 c/ft^2.

Situation	Condition	Observer	Readings in milliseconds	Means
2, Dark fore period	Distance: 14°14'	J.Y.L.	55,65,45,35,45 35,55,55,55,55	50
		J.V.	75,95,65,55,55 25,45,45,35,45	54
1, Distance varied	Distance: 4°46'	J.Y.L.	45,45,35,35,55 45,85,85,55,45	53
		J.V.	35,35,55,25,15 45,25,35,35,35	34

In some conditions J.V.'s data were less stable and the task seemed more difficult for him. As this does not show in the data chosen at random and presented in Table 1 above, the two conditions found, upon inspection, to be less stable than the others are reported in Table 2.

Table 2. Raw Data Found to Be Less Stable, Photic Intensity .053 c/ft^2. Observer J.V.

Situation	Condition	Readings in milliseconds	Means
2, Dark fore period	Distance: 11'	205,155,365,265,95 65,245,305,175,85	196
5, Shifting of borders	Distance in fore: 2° 23'	285,175,245,225,85 85,145,125,85,65	152

First situation. <u>Effect on visual acuity of a decrease in the distance between borders</u>.--Figure 3 illustrates the effect of a decrease in the distance between the two dark bars upon detection of the line. The results of J.Y.L. are shown in Figure 3A. First, it can be seen that for any distance examined, the time required for seeing the line decreased as the illumination was increased from .053 c/ft.^{2} to 10.97 c/ft.^{2}. Second, the effect of the distance between the bars upon the threshold of detectability is clearly apparent at all the three levels of intensity used. A Kendall coefficient of concordance (W= .83) is significant at $P < .02$, which means that for this observer the target (distance) that required more time under low illumination also tended to require more time at medium and high photic intensity.

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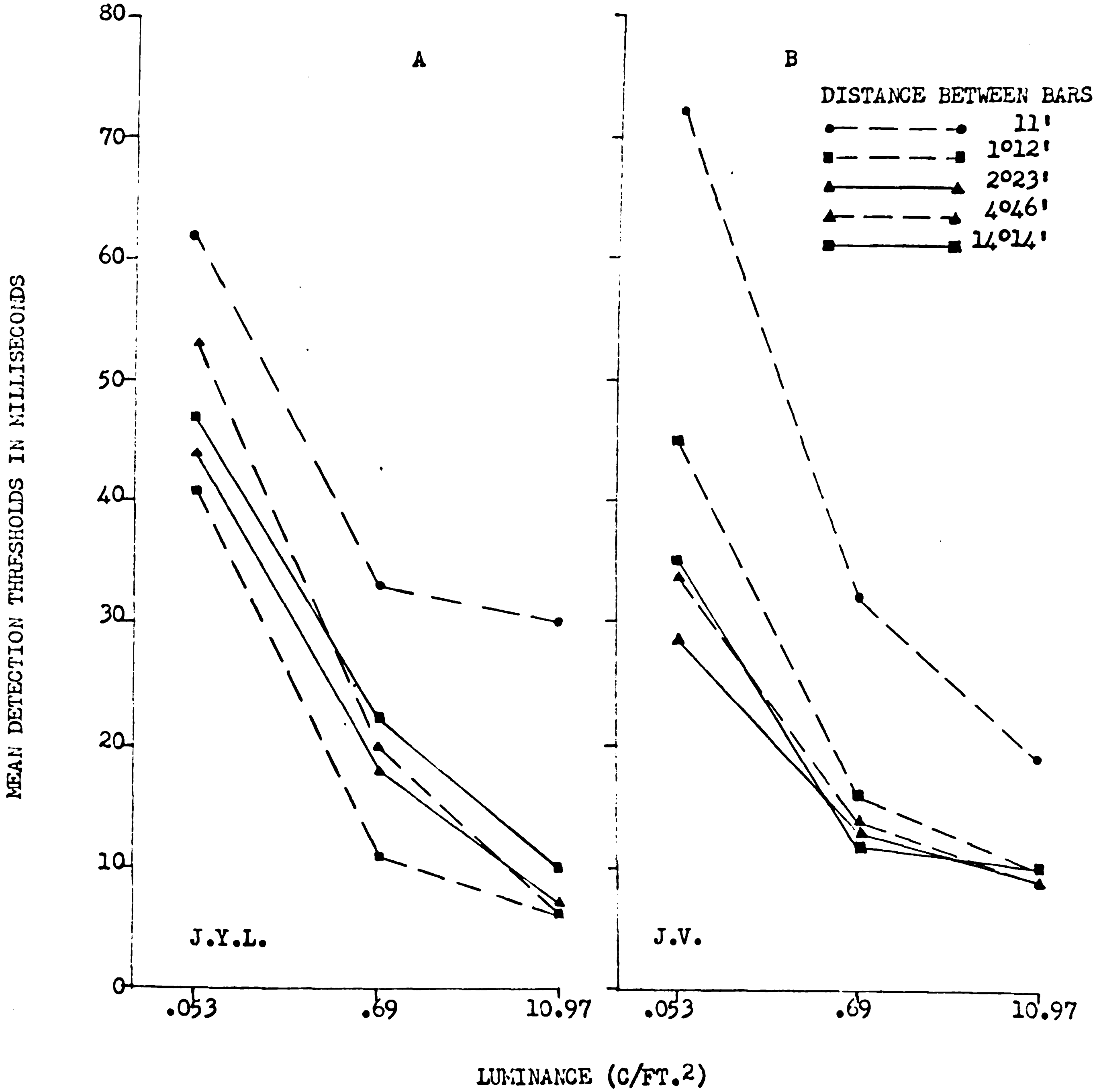


Fig. 3. Visual acuity as dependent upon the distance of adjacent borders. The distance between the inner borders of the two vertical bars was varied in five steps from 14° 14' of visual angle to 11'. In part A, J.Y.L. was the observer, and J.V. in part.B.

However, the duration required for detectability of the line did not necessarily increase proportionately with a decrease in distance from 14° 14' to 11'. If one takes the curve obtained for the condition where the distance between the bars subtended 14° 14' as the criterion for comparing all the other curves it can be seen that the fine line was perceived more rapidly at 1° 12' and 2° 23' than at 14° 14', the condition where the bars were almost coincident with the frame and as such were assumed not to exert any influence on the detectability of the line. This effect is maintained at all three levels of photic intensity, thus showing some facilitatory influence of the bars upon visual acuity.

When the bars were very close together (11'), however, it took much more time to detect the line, as can be seen by inspecting the upper curve of Figure 3A, which indicates some inhibitory effects of the bars upon visibility of the line. Also, it can be seen that while the effects noticed for all the other distances examined tended to diminish when the photic intensity was increased to 10.97 c/ft.^{2}, the inhibitory effect created by the bars when they were close to one another tended to be comparatively larger at the same intensity.

Results of J.V. are shown in Figure 3B. It can be seen that data for this observer are very similar in trend to those of J.Y.L. A Kendall W test (W= .79) was significant at $p < .05$.

As compared to the standard condition, the inhibitory influence of the bars when they were close together is even more apparent here. Yet, the facilitatory influence noticed above is much less evident in Figure 3B. For example, at 1^{o} 12' duration is increased as compared to the standard condition, thus indicating that some inhibitory influence began to appear when the bars were slightly more than 1^{o} apart. At a greater distance (2^{o} 23') and with the lowest illumination used there is a slight indication of the facilitatory effect noticed before.

The curve corresponding to a distance of 4^{o} 46' is almost identical with the criterion, thus showing some support to the assumption that at a distance of 4^{o} the influence of borders upon one another is no longer effective.

For this observer also, while the effects of borders at 1^{o} 12', 2^{o} 23', and 4^{o} 46' seemed to be less marked when the illumination was increased (the curves are very close together at 10.97 c/ft.^{2}), the inhibitory effect of borders at 11' was maintained even at the highest illumination used.

Situation 2. Effects of a darkened fore period.--Besides distances between borders, other manipulations were effected. For example, in one of the situations the fore period was dark, with only two small fixation points visible and the line and bars appeared together in exposure period.

Figure 4A presents the results obtained by J.Y.L. while those of J.V. are shown in Figure 5A.

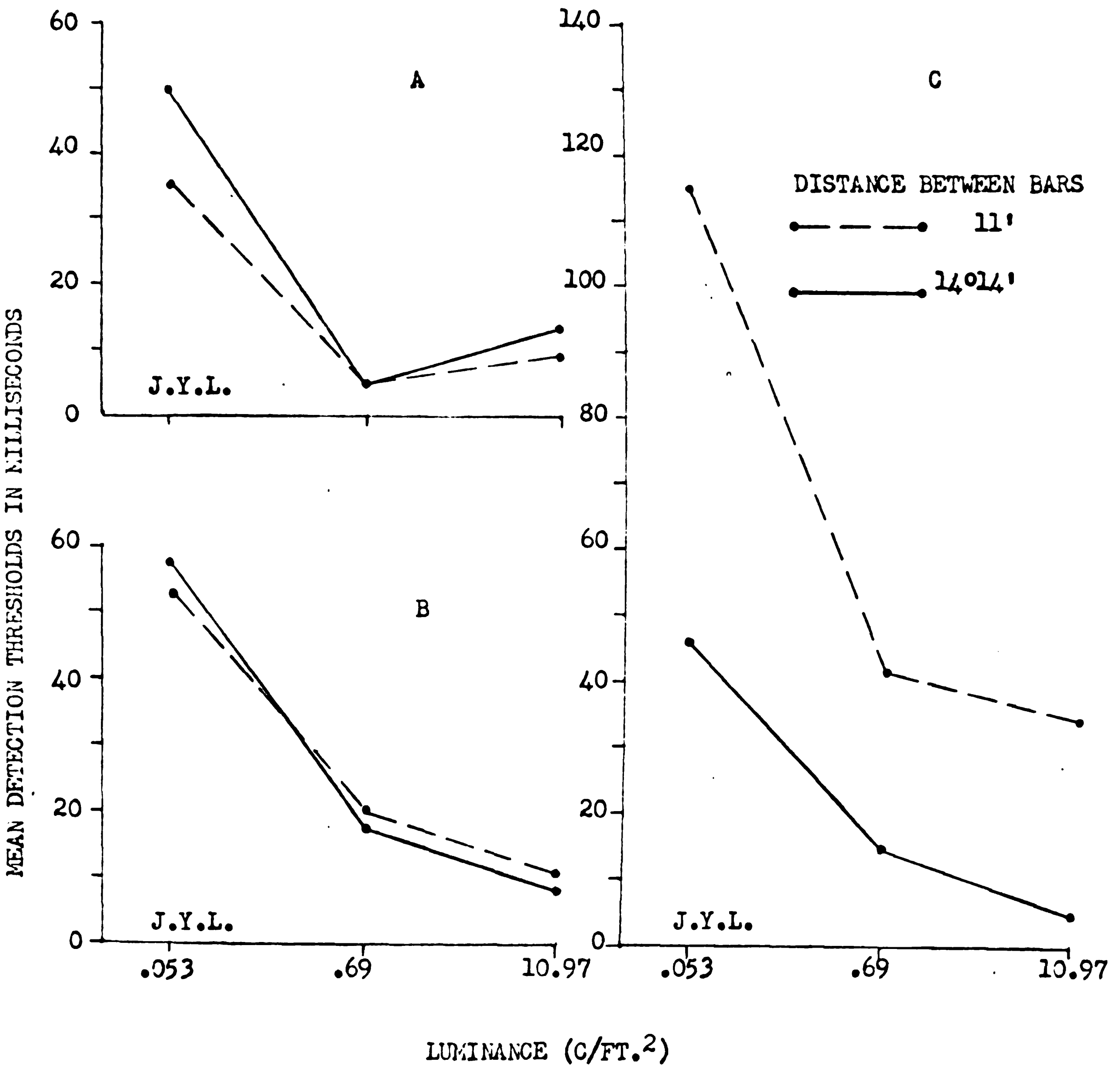


Fig. 4. Effects of diverse manipulations of adjacent borders upon detection of the line. Data for J.Y.L. In part A the fore period was unilluminated; in part B it was lighted but contained no vertical bars, while in part C the bars vanished in exposure period.

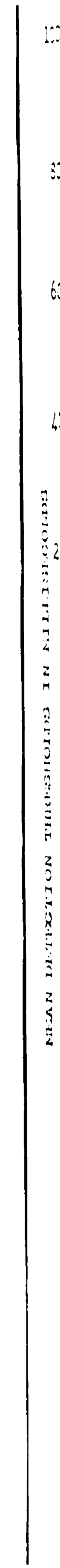
By examining Figure 4A one can see that at low illumination it took less time for the observer to detect the line when the bars were close together (11') than when they were far apart (14^{o} 14'), suggesting that in some conditions borders near one another exert a facilitatory influence upon visual acuity. At medium intensity no difference was observed between the two curves, thus indicating that the distance between the bars did not interfere with visual acuity, while at high intensity there seemed to be a tendency for both curves to raise again, this tendency being slight for the curve representing a distance of 11' but more accentuated in the case of the wide distance.

Data for J.V. show a very different pattern depending on the distance of bars (Figure 5A). Thus, if at medium intensity the time required for detection of the line was about the same be the bars close to one another or far apart, one cannot conclude the same thing when low or high illumination were used. At low intensity much more time was required for detecting the line when the bars were near one another. This is the opposite of what was found with J.Y.L. as the observer. At high intensity the trend is the same as the one observed in J.Y.L.'s data, except that the tendency is much more pronounced here; thus, it became much harder for J.V. to detect the line when the bars were far apart. It seems as though in the present situation, borders in near the vicinity of the line improved visual acuity by substantially decreasing the glow affect produced under some conditions when the bars are far apart. This will be further discussed in the proper section.

Because the data of the two observers did not agree, another session took place six months later (February, 1965) in order to check their reliability. In Figure 6A it can be seen that the first observer was fairly consistent over a period of six months. The same tendency is observed. Only for the lowest intensity is there any increase in duration noticed, specially in the condition where the bars were close together.

Equally, the second observer (J.V.) was consistent over the same period. By inspecting Figure 6C one can notice that the trend remains the same, except that the difference between the two curves representing wide and short distances respectively were less marked at low intensity than on the first occasion.

Situation 3. Effects of a lighted fore period without any borders.--In the present situation the fore period was lighted but the target did not contain the vertical bars. During the exposure period the two bars and the line appeared simultaneously. In one condition, the bars were 14° 14' apart, and in the other they were close together (11'), as in the previous situation. The curves obtained can be seen in Figures 4B for J.Y.L. and 5B for J.V. In Figure 4B one can again notice the tendency for visual acuity to require less time with an increase in illumination. However, it does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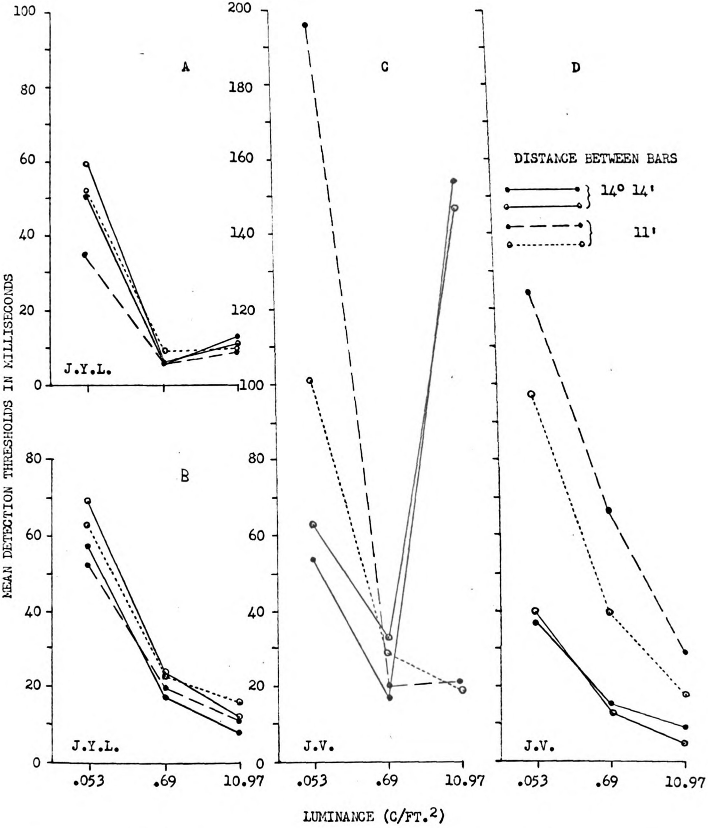

Fig. 6. Comparisons of sets of data collected at a six month interval. Portions A and C represent, for J.Y.L. and J.V. respectively, the situation where the fore period was dark, and portions B and D stand for the one where the fore period was illuminated but contained no bars. The solid lines represent the condition where the bars were far apart, and the broken ones where they were close together. The closed circles represent data gathered in July 1964, and the open circles data for the same conditions collected six months later.

not seem that the presence or absence of borders near the line differently affected visual acuity when these borders were presented at the same time as the line. A Sign Test for paired replicates was not significant at p= .05.

If one looks at Figure 5B, he can observe a clear difference between the curve representing data when bars were close together and the one for a distance of 14° 14': thus, it took J.V. much more time to see the line when the bars were close to it than when far apart. This is not in agreement with results for J.Y.L.

Because the two observers did not agree when tested on the conditions depicted here, a retest was effected six months later. The results obtained on the second occasion appear in Figures 6B and 6D. Both observers were consistent over that period, the only difference worth noting being for J.V. a certain improvement in detecting the line when the bars were close to it, and for J.Y.L. a slight but consistent increase in time for the three levels of photic intensity, as one can see by comparing the curves drawn with open circles with those drawn with closed circles.

Situation 4. <u>Effects of disappearing borders upon detection of the line</u>.--Another situation was one in which the vertical bars, which were present in fore period, vanished and the line appeared alone in exposure period. The results for J.Y.L. are shown in Figure 4C, and those for J.V. in Figure 5C. Here the two observers show a very similar pattern of data. For the two of them there was an improvement in visual acuity when the intensity was increased from .053 c/ft.^{2} to 10.97 c/ft.^{2}. For the two observers also, detection of the line required more time when the borders of the bars were near one another, thus suggesting a strong inhibitory influence in such a condition.

Situation 5. Effects of a shift in the position of the bars in fore and exposure periods.--In the present situation, the dark bars occupied a predetermined position in fore period and a different one in exposure period. As the switching from fore to exposure was almost instantaneous, there was a shifting of borders from one position to another. In one of the two conditions examined the bars were set at 2° 23' from one another in fore period and at 11' in exposure period. In the other, the reverse was done. The results obtained with these manipulations are shown in Figure 7. In portion A the curve represented by closed triangles has been obtained when the borders were 2° 23' apart in pre-exposure and 11' in exposure periods. The closed circles represent the curve obtained when the borders were 11' apart in pre-exposure and 2° 23' in exposure. A comparison of those two curves indicates that when borders were shifting away from the line, this one required much more time to be detected than when they were shifting toward it. A replication of Situation 5 six months later gave the two curves represented by open circles and open

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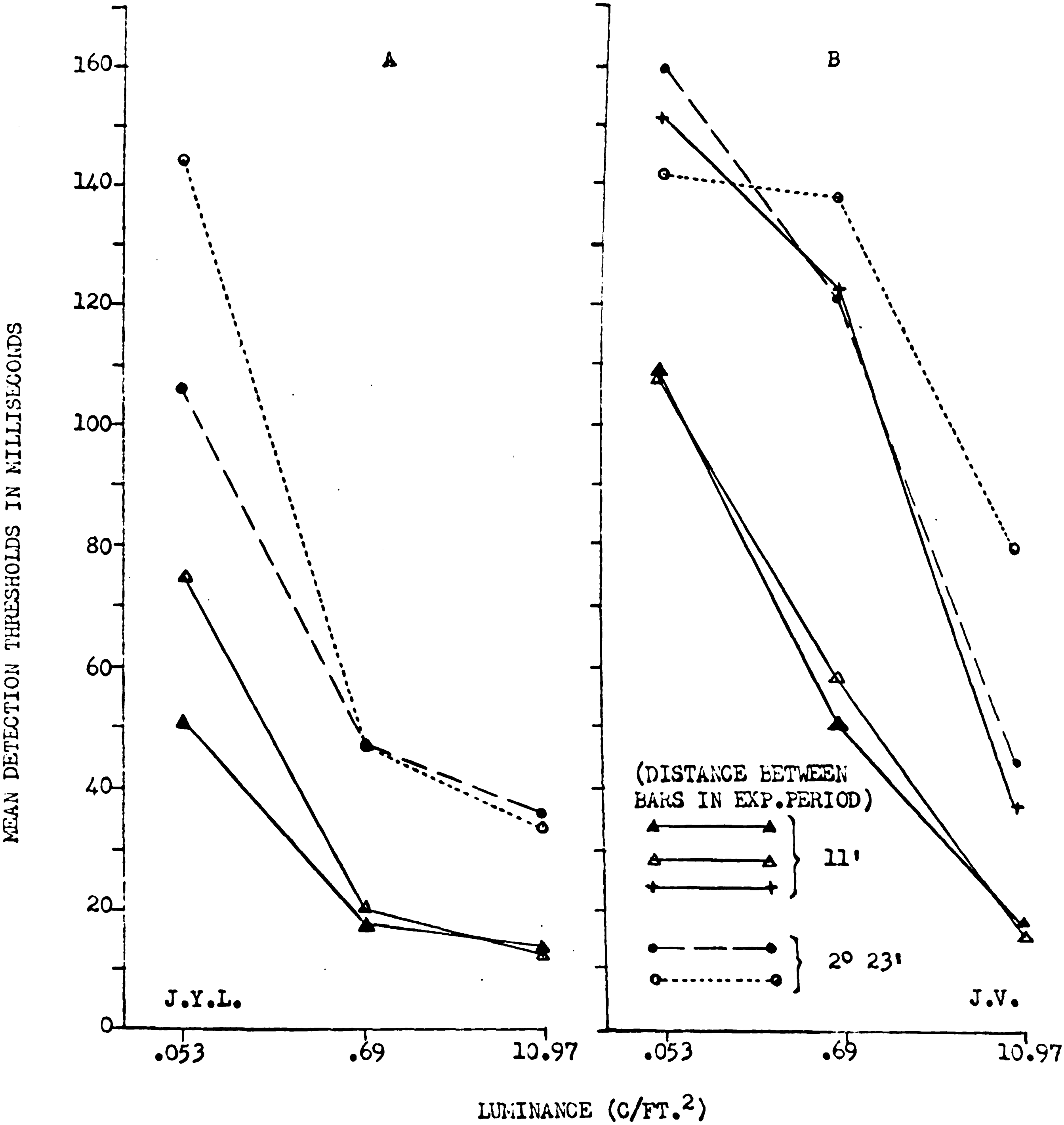

Fig. 7. Visual acuity as affected by a shifting of position of adjacent borders in fore and exposure periods. Portion A represents data for J.Y.L. and portion B data for J.V. The solid lines represent a shifting of bars toward the line, while the broken lines represent a shifting away from the line. The open triangles and circles are for the retest, made six months later, of the conditions represented by closed triangles and circles. The crosses display data showing poor stability (see text for explanation).

triangles. Again the stability of the results is well maintained, the tendency is the same, the only difference being a higher threshold for the two conditions where photic intensity was .053 c/ft.^{2}. For medium and high intensities there is an overlapping of curves obtained over the period of six months.

Data for the second observer are illustrated in part B of Figure 7. The results yielded by the condition where the shifting was toward the line (identified by crosses) and the condition where it was away from it (identified by closed circles) were about the same. At that time (July 1964) an inspection of the data indicated a noticeable tendency toward a decrease in duration as the experiment went on (Table 2, p. 40). To check that point the A. took several more data for this situation as well as for some others. While the tendency remained the same for the other situations, it definitively changed in the condition where shifting was toward the line. The curve identified by closed triangles shows other results based on eight threshold determinations for low and medium photic intensities, and six determinations for the high level of intensity. A valid explanation of this marked decrease in duration is not easy: the targets have been carefully inspected and there was nothing wrong with them. One possibility is that the observer did not fixate properly at first; he may have been distracted by the apparent movement of the two bars and may have learned, after several trials, to look only at the fixation points, not the bars. To check that assumption, J.Y.L. tried, later on, to bear his attention on the bars and he found out that apparent movement became more objectionable and that visual acuity was much impoverished.

A replication of the whole situation conducted six months later showed essentially the same trend for the condition where the bars were set at 2° 23' in exposure period (curves with closed and open circles). When the bars were close together in exposure period the data were almost identical with those obtained as a check and based on eight determinations (curves represented by open and closed triangles in part B of Figure 7). With this taken into consideration it can be seen that the two observers agreed in their tendency to require more time for seeing the line when the borders of the bars shifted away from it.

Finally, an overall inspection of Figure 7 shows that whatever process was acting at the time, there was a marked decrease in duration required for detection of the line as photic intensity was increased.

Situation 6. The effect of length of the line and bars upon visual acuity.--In the present situation three different lengths of bars and line were used. Portions A and B of Figure 8 present the results for the first observer (J.Y.L.) and portions C and D present those for J.V.

In part A the distance was kept at 14° 14'. The length of the line here became a significant factor in visual acuity,

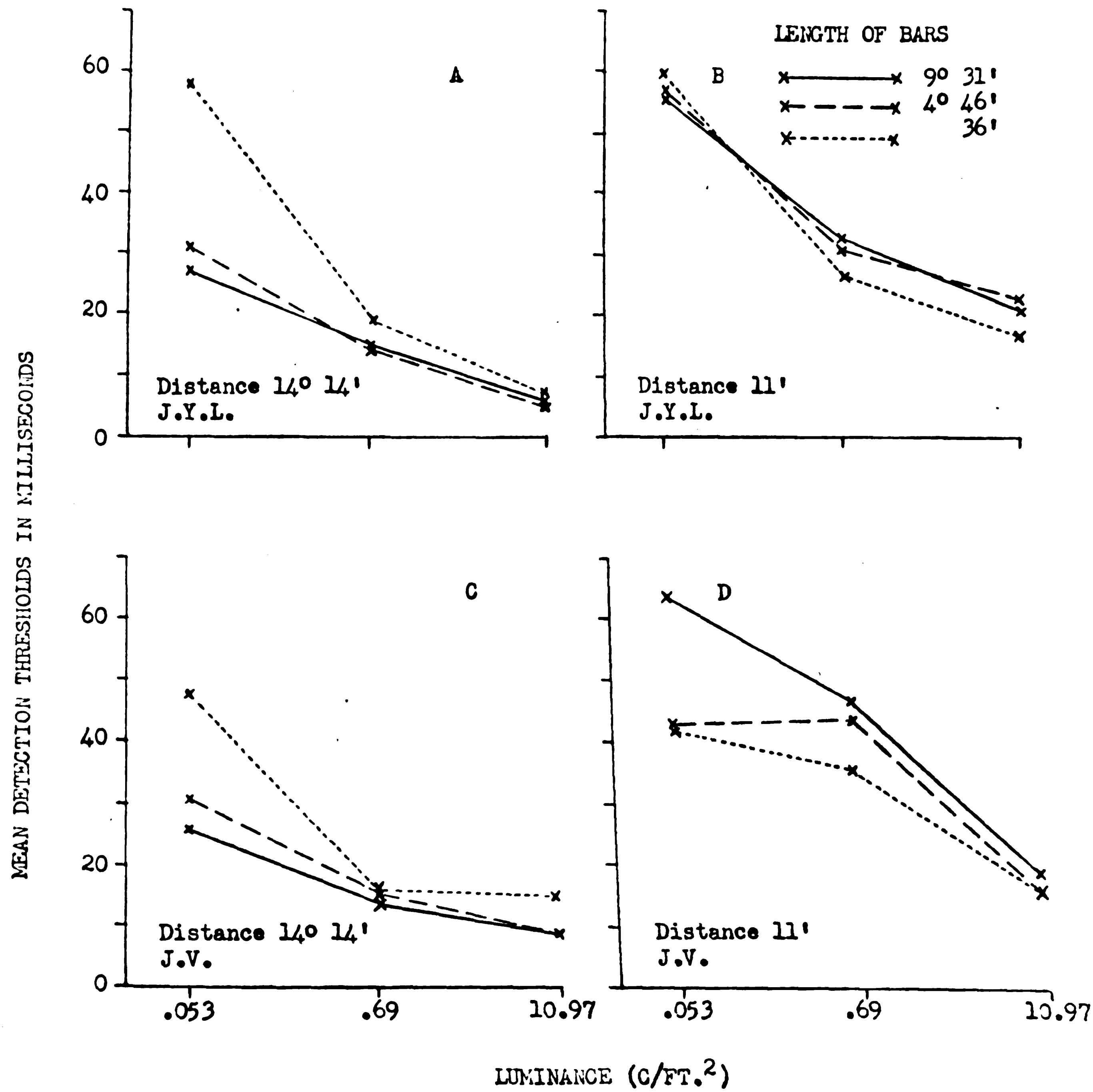

Fig. 8. The relation between bars length and visual acuity for two different distances of the bars. In parts A and C the two vertical bars are kept at a distance of 14° 14', while in portions B and D they are at 11' of visual angle. Data for J.Y.L. are displayed in parts A and B and those of J.V. in parts C and D.

especially at low intensity where the required duration decreased with an increase in length from 36' to 9° 31'. This is in agreement with results of Hecht, Ross & Mueller (1947), and Ogilvie & Taylor (1959). It can be seen that when the length does not subtend at least 1° the threshold of detection raises sharply with a decrease in illumination, as Hecht and collaborators have found.

In part B, the same bars and line were used, but the distance between the bars was kept at 11'. A comparison of the three lengths used does not show any differential effect due to the length of the line and bars. It seems as though there was a slight reduction in required duration when the line and bars were very short, but this is about all. The six conditions (three lengths at two different distances) have been submitted to the Kendall coefficient of concordance (W) and this one has been found to be significant at $p < .05$. So, the rank of each condition tended to remain the same over the three levels of photic intensity used.

Figure 9A, B, C, is a different illustration of the phenomenon. Here, instead of comparing the effects of a difference in length upon detection of the line, the A. compared the effects of distance. Hence, part A of Figure 9 represents the influence of borders of long bars (9° 31') upon visual acuity first when these bars were near one another (11'), and second, when they were far apart (14° 14'). Part B illustrates the same phenomenon for bars of medium

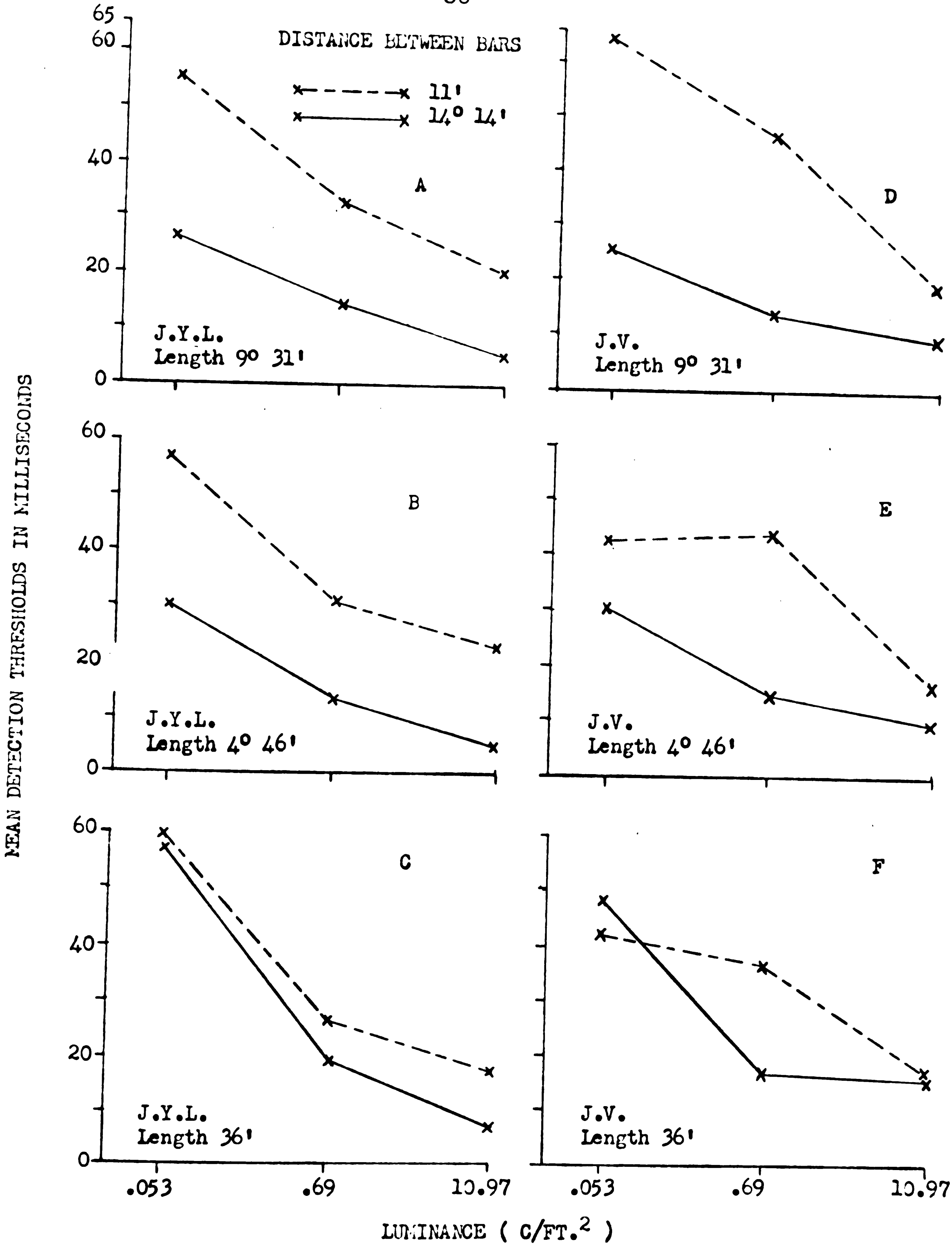

Fig. 9. Visual acuity as dependent upon bar length and distance between the bars. In parts A and D the length of the bars and line subtends 9° 31', in parts B and E 4° 46', and in portions C and F 36'. In each case the broken line represents the narrowly spaced bars (11'), the solid line, the widely spaced ones (14° 14').

length (4^{o} 46'), and portion C for short bars (36'). An overall inspection of the three graphs shows that when the bars were close to the line, whatever the length of the line, this one required a fairly long time in order to be detected. When the bars were far apart, however, the duration required decreased as the line extended. Finally, the facilitating effect of an increase in luminance is clearly apparent in this situation also.

Data obtained when J.V. was the observer are in general similar to those of the former observer. A Kendall coefficient of concordance is significant at $p < .01$. Figure 8C shows the effects of increasing the length of the line when the bars were very far apart (and considered to be nonexistent). At low illumination especially the time was reduced when the length was increased.

Figure 8D resembles Figure 8B for medium and high intensities. At low illumination, however, duration was increased for seeing the long line as compared to the other two lengths.

Parts D, E, F show the same trend notices for J.Y.L., that is when the bars were far apart, the length of the line seemed to be a decisive factor for its visibility. When the bars were close to it, time was comparatively increased. While for J.Y.L. this effect was manifested at all three levels of photic intensity, it was more pronounced at medium intensity in the case of the second observer.

To this point, the results yielded by the six experimental situations have been reviewed separately. Figures 10 and 11 present an overall comparison of all the situations, with the exception of Situation 6 which, using different lengths of line and bars is not directly comparable. Thus in Figure 10, which represents data for J.Y.L., a comparison of Situations 1 and 2, when the bars were far apart (first and second blocks of columns from the left) indicates that a darkened fore period shortened the time required for visual acuity at medium intensity only: at this level it took the observer 5 milliseconds to detect the line when the fore period was unilluminated as compared to 22 milliseconds in the reference situation (Situation 1).

When the distance between the bars subtended 11' (fifth and sixth blocks from the left), it became much easier to detect the line when the pre-exposure was darkened than when it was illuminated and contained the two bars. This facilitatory effect was maintained over the three levels of intensity used.

There was not much difference, except at low illumination, between Situations 1 and 3 when the distance between the bars was wide (first and third blocks from the left), but when it subtended only 11' (fifth and seventh blocks) a lighted fore period without any borders required less time for detection of the line as compared to a fore period with the presence of borders. These results suggest that borders

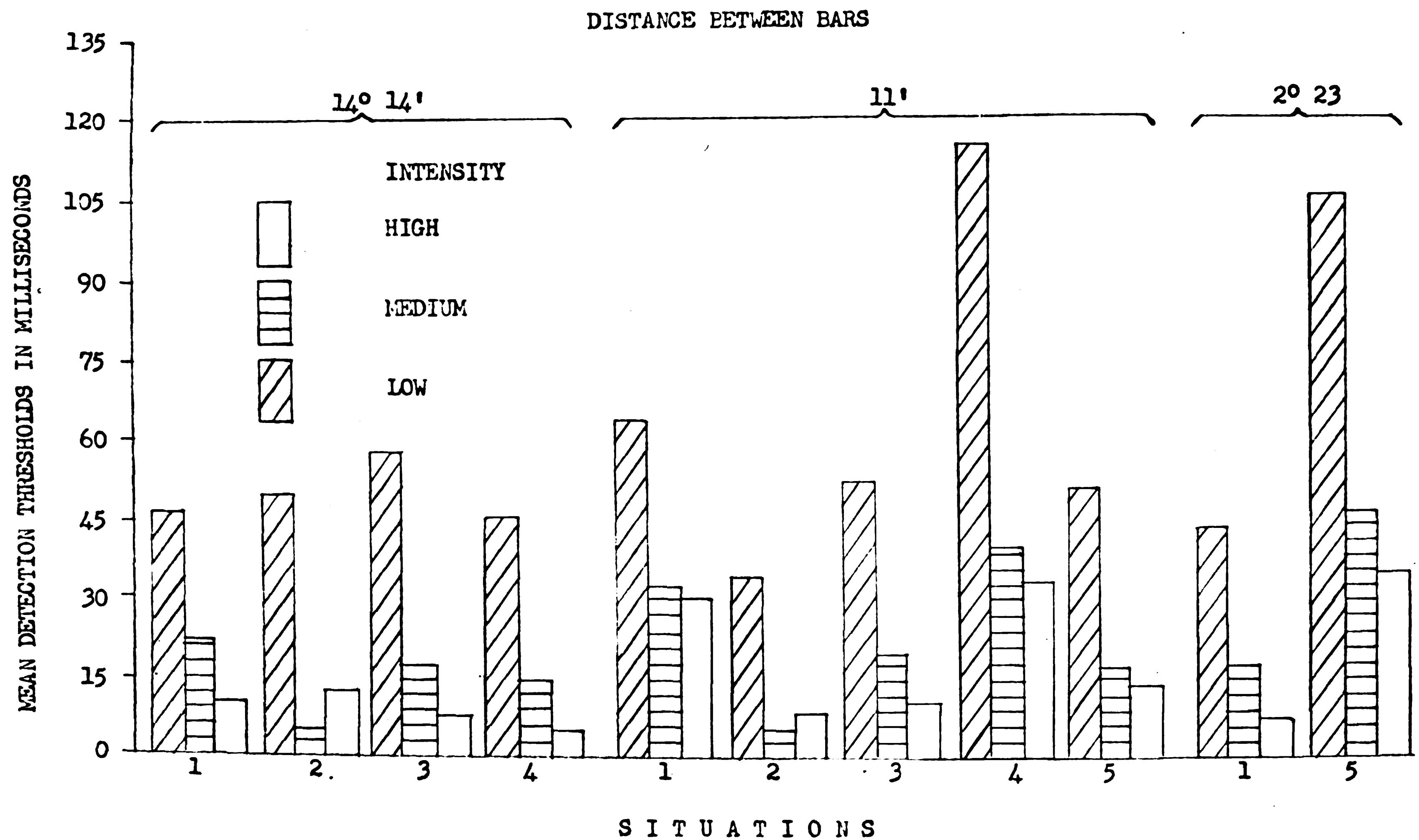

Fig. 10. Comparison of duration thresholds for five of the experimental situations. For Situation 5, the distance indicated is the one used in exposure period. Data for J.Y.L.

in near vicinity but appearing together do not exert the depressing effect noticed when some of these borders appear before others (bars presented before the line).

In Situation 4, where the bars vanished in exposure period, the block representing the condition when the bars were far apart (fourth block) resembles the block for the reference condition (first block). This is an expected result because in the present situation as well as in the standard one there were no borders in the vicinity of the line. When the bars were close together, Situation 4 required more time than Situation 1 (fifth and eighth blocks). This indicates that borders in close vicinity which vanish while new contours are forming exert a greater inhibitory influence on these than borders which are stable.

In Situation 5, if the condition where the distance between the bars was 11' in exposure period (ninth block) is compared to the reference situation (fifth block from the left), one can observe an improvement in visual acuity with a shifting of the bars toward the line. This improvement is maintained over the three levels of intensity used. When the distance, in exposure period, subtended 2^{o} 23', shifting of the bars away from the line greatly impoverished visual acuity, as compared to using steady borders (the two last blocks to the right).

An overall inspection of this figure shows that threshold duration for detection of the line was comparatively longer when the two bars, near one another in fore period, disappeared simultaneously with the appearance of the line (Situation 4), and also when the bars, close to the line in fore period, were shifting away from it in exposure period (Situation 5).

Figure 11 presents a comparison of data for the second observer (J.V.). For example, a comparison of Situations 1 and 2 (first and second blocks of columns) indicates that when the bars were far apart, a darkened fore period comparatively impoverished visual acuity in all three levels of intensity, but the effect was much more noticeable at high intensity. This is contrary to what has been found when J.Y.L. was the observer. When the bars were close together it can be seen that at low illumination a dark fore period required much more time comparatively (fifth and sixth blocks from the left). The reverse was true at medium illumination, while no difference seemed to exist at high illumination.

When a lighted fore period without any borders was used (Situation 3), and bars appeared at 14^{o} 14' one from the other in exposure period, the results were almost identical to those yielded by the reference condition (first and third blocks). So, for this observer as well as for the previous one, when the bars were presented with the line but at a great distance from it, the result did not differ from what was obtained when the bars were present

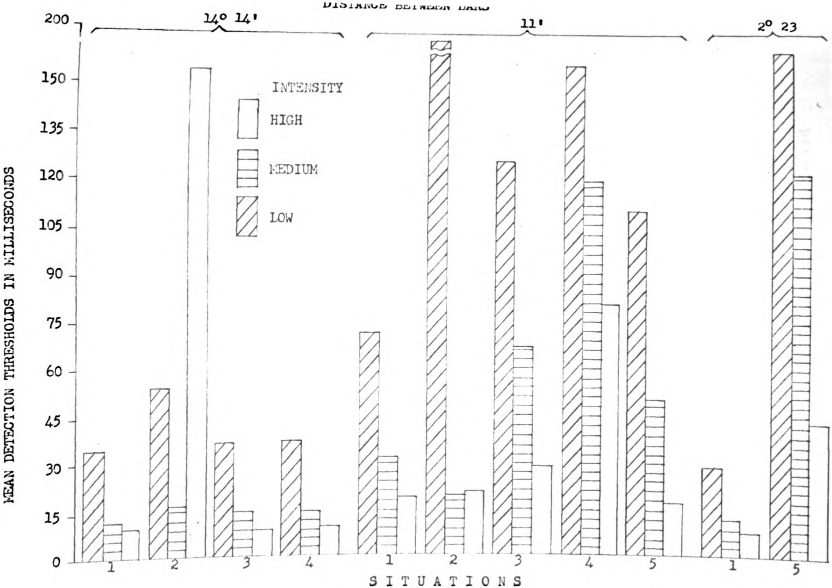

Fig. 11. Mean detection thresholds for five of the situations, with J.V. as the observer. For Situation 5, the distance indicated is the one used in exposure period.

in fore period. This suggests that at such a distance the presence or absence of borders does not exert any influence upon visual acuity.

This observer, however, contrary to J.Y.L., required more time to detect the line when the two bars, absent in fore period, appeared with the line and close to it in exposure period (fifth and seventh blocks).

In Situation 4, when the bars were far apart the results were very similar to those yielded by Situation 1 (first and fourth blocks). This is what was obtained when J.Y.L. was the observer. But when the bars were close together, the present situation in which borders vanished in exposure period, required much more time than Situation 1 (fifth and eighth blocks). Again this is in agreement with results found for the other observer.

A comparison of Situation 5 with Situation 1 clearly indicates that at low and medium intensities, a shifting of the bars toward the line required more time for its detection than Situation 1, where the bars remained close to the line (fifth and ninth blocks). This is contrary to what was observed in the case of J.Y.L. A possible explanation is that if, for any reason the line can be detected before any apparent movement is seen, then shifting of the borders toward it improves visual acuity. But if it takes so much time to detect it that some apparent movement is first perceived, this phenomenon will make detection of the line more difficult. This will be explained more fully in the appropriate section.

When the two bars were shifting away, being set 2^{o} 23' apart in exposure period, one can notice, as was the case with J.Y.L., that visual acuity was greatly impoverished in this condition, compared to what was obtained with the same distance in Situation 1 (the last two blocks).

A comparison of Figure 11 with Figure 10 indicates that for this observer as well as for J.Y.L. visual acuity was markedly impoverished in Situation 4 where borders near one another disappeared simultaneously with the presentation of the line, and in Situation 5, when the bars, close to the line in fore period, were shifting away from it in exposure period. However, in the case of J.V., Situation 2 comparatively required much more time than the same situation for J.Y.L. Thus, when the bars were close together (sixth block) a low illumination greatly impoverished visual acuity in the case of J.V. Equally, when the bars were far apart (second block) a high illumination yielded the same result.

DISCUSSION

The purpose of the experiment was to examine diverse spatial and temporal manipulations of target borders upon detection of a fine line. The dependent variable was duration of stimulation. The main assumption, underlying the whole research was that, as contour formation takes time to achieve completion (Werner, 1935), variations in duration would be an excellent index of facilitatory or inhibitory effects of contours upon one another. As compared to some standard condition, an increase in duration would indicate depressing or inhibitory effects, while a decrease in duration would indicate a facilitatory effect. In a certain way the results of the present study are not directly comparable with those found when time was unlimited or sufficiently long so that it did not become a significant factor in the outcome. As duration is a very important variable in any neurological process, it was thought that it would allow one to better understand the processes at work. For example, with a target presented for approximately .2 second (which is relatively brief anyway), no difference would be found between any of the variables investigated in the present research. However, when time becomes the dependent variable, the results have shown that inhibitory, and occasionally facilitatory effects could be clearly demonstrated. For this reason it is the belief of the author A. that time should be more extensively utilized as a dependent variable in studies on visual acuity than it has been till now.

Distance of borders.--Studies on visual acuity have shown that borders interacted. Yet, this interaction was found to be limited to a relatively small distance, that is around 4' (Fry & Cobb, 1935; Kravkov, 1938). Targets usually consisted of a single bar or line of varying width, or of twin parallel bars the interspace between which was to be detected.

In brightness discrimination, the interaction was found to cover relatively large areas (Fry & Bartley, 1935). The effect was found to be inhibitory when borders were parallel to one another, and facilitatory when they acted at right angle upon one another.

The present study shows that when a line is to be detected there is an inhibitory effect of borders at a comparatively short distance, and at least for one observer a facilitatory effect at a greater distance.

In order to see the importance of the inhibitory effect of borders in near vicinity, the length of the two vertical bars and of the line was increased in Situation 6. It has been found in the past (Hecht, Ross & Mueller, 1947; Ogilvie & Taylor, 1959) and in the present research when the bars were far apart, that when it is presented alone a longer line is more easily perceived than a shorter one. So, the length of a line has a facilitatory influence upon its detection. On the other hand, borders close to it have an inhibitory effect. The results indicate that the depressive effect of borders was progressively increased and it compensated for the facilitatory effect of length. For one observer, approximately the same duration was required to detect any of the lines when the vertical bars were close to it. For the other, the longer line required even more time indicating that the inhibitory influence of borders was increasing more rapidly than the facilitatory effect of length.

The principle stated by Fry and Bartley and already utilized elsehwere (Fry & Cobb, 1935; Kravkov, 1938) seems applicable to explain this depressive effect of borders at short distances. Therefore, the processes into play are assumed to function in the following way. The two parallel bars lead to the formation of their respective contours during the fore period. In exposure period, when the line appears, the contours corresponding to its projection on the retina are depressed by those contours already present, and more time is required for these new contours to complete and the line to be seen.

More specifically, when the bars are near one another, their action can be analyzed in this way: first, being much wider than 4', their respective inner and outer borders do not interact significantly. If the retinal image of these bars were a perfect replicate of their physical properties, their projection would cover approximately 180 microns in width, one minute corresponding, in the typical emmetropic eye, to a retinal distance of approximately 5 microns (Westheimer, 1963). But because their projection is Gaussian (Fry & Cobb, 1935) or approximately so (Westheimer, 1963), it will spread over many more microns and there will be an overlapping of the two gradients. From this point onward, and for the very reason that neurological studies on contour formation are still in their infancy, the author cannot but provide a very general description of what he believes to take place. It is assumed that detection of the line and the bars depends on the activity of off elements in the retina or elsewhere along the pathway. With a sudden decrease in illumination, as is the case when the bars are projected, off cells are activated. However, not all the off cells reached by the gradient-wise projection of the bars are affected in the same way. Below the point corresponding approximately to the border of the bar in the gradient (Figure 12), there will be an increased activity of off elements, while above that point these off elements will be inhibited. Thus the difference in activity on either side of the border is augmented and leads to the perception of a sharp edge. Some evidence for such a process at the cortical level is presented by Jung (1961). When the line is presented, its

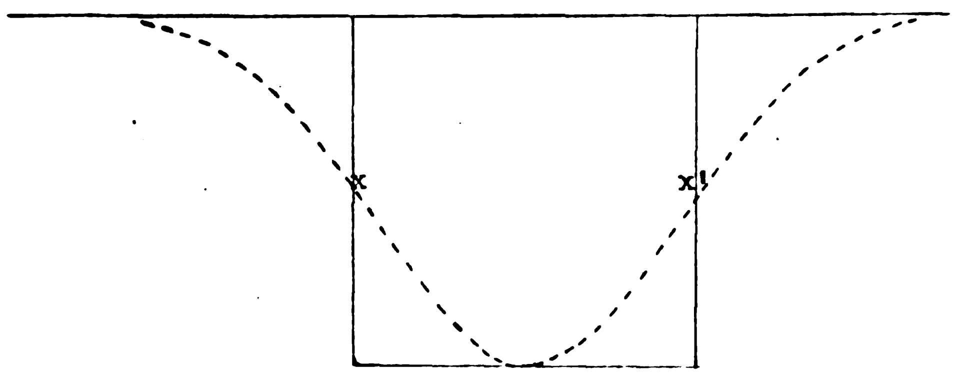

Fig. 12. Gradient-wise projection of a dark bar upon the retina. Solid lines represent distribution of radiation in the target; broken lines, the retinal distribution of radiation. The part of the curve below the two points corresponding approximately to the borders of the bars (x and x') is characterized by an increased activity of off elements, while above these points there is an inhibition of activity of the same type of receptors. Thus the perception of a sharp edge depends on the difference in activity of off receptors above and below the transition points. (Note: the transition points are not necessarily exactly at the juncture between the solid and broken lines. There are conditions (Kravkov, 1938) wherein these points are shifted on a lower part of the inversed curve and, as a result, the bar is perceived as thinner).

contour processes have to form in that area of overlapping gradients where inhibition of activity is relatively great. Therefore, it will take time for the contour of the line to overcome that inhibitory influence and reach completion.

When illumination is increased, the line contours are affected in three ways. First, the contours are enhanced because, the gradient becoming steeper, the difference between the two types of activity of off elements at the borders becomes greater. But, the line being narrow, its two adjacent longitudinal borders are near one another and they interfere more and more in the building up of their respective contours as intensity is increased. Perceptually the line is seen as thinner. The facilitatory effect of an increased steepness of the gradient, however, overcomes the depressive effect of short distance between the line contours and detection is facilitated (Kravkov, 1938). Third, the bars also have much steeper gradients, the activity of off fibers, below the transition point is much greater and inhibition should be more serious above the transition point. As a result the facilitatory effect of increasing illumination upon detection of the line would be more or less counterbalanced by the contours having to build up in an area of greater inhibition.

When the distance between the retinal projection of the inner borders of the two bars covers about 1° 12' or 360 microns, the results obtained (at least for one observer) imply that the line contours are facilitated. Thus the mechanism is different from what has been proposed to explain inhibition. Nothing in the studies on the relation between contour formation and visual acuity can be helpful in this particular case, because the distances investigated were much smaller, subtending a few minutes of arc. Therefore suggestions concerning the mechanism at play have to be sought elsewhere. The structure of the retina, for example, may be thought to have something to do with the outcome. According to Østerberg (1935) the distribution of cones in the fovea decreases sharply as one goes from the center to about 3° peripherally. Thus, at a distance of 1° from the center there are more than twice the number of cones per unit-area than at a distance of 2°. The A., however, does not see how the structure of the retina, per se, would create facilitatory conditions for the formation of contours. If so, the facilitatory effects should be even greater when the bars are very close to the line, which was found not to be the case.

Another possibility would be that the area of depressed activity mentioned above is succeeded by one of enhanced activity of off fibers, and the line contours would build up at the location where facilitatory effects are maximal. Thus line contours would reach completion in less time and the line would be seen faster. This is highly conjectural and the author does not know of any neurological evidence to support it.

The facilitatory effect discussed till now was much less evident in the case of J.V. As it was discovered after the experiment proper that this observer was suffering from a mild degree of hypermetropia, it is not impossible that this defect of refraction, by changing the shape of the blur gradient concealed the other phenomenon.

To summarize the discussion to this point it can be said that even in the fovea there is a long range interaction between processes developing spatially, and this type of interaction does not seem to depend on the same mechanism as the short range interaction. Further psychophysical researches, as for example variations in the size and location of bars, in their length respective to the length of the line, etc., and also neurophysiological researches are needed before any precise mechanism can be described.

Absence of borders in fore period.--Another question worth of interest was this one: If previously formed contours exert a depressing influence upon the building up of new contours in their immediate surround, what would happen when all borders are presented at the same time? It was expected (Situation 3) that the bars contours, forming at the same time as the line contours, would depress these to a lesser degree than when previously formed. More specifically, the bars and the line contours, having to build up simultaneously would interfere. The bar, however, being wide, would normally lead to stronger contours, and the line, on account of its being narrow, would give rise to comparatively weak contours, so that any interference would be to the detriment of the line contours. But as the bars contours are forming simultaneously with the line contours, they would inhibit these less than if they had achieved completion before the line contours begin building up.

That expectation, however, receives only partial support. In the case of one observer, less time was required for detection of the line when the bars were presented simultaneously with the line and close to it than when they were projected in fore period. But, contrary to this there was a depressive effect for the other observer. Those two kinds of data are difficult to integrate in a simple explanation. Further research is needed before one can elucidate the conditions wherein each one of these effects is at play.

When the fore period was dark (Situation 2) again no borders were present. This situation, however, is very different from the previous one and it may lend itself to complex phenomena an explanation in terms of contour formation will have to deal with.

For one, illumination is much more effective in such a situation. To be specific, the retinal elements activated by a steady illumination do not fire maximally and repeatedly, they alternate in their activity, as Bartley has explained (1958b, 1961; Bartley & Nelson, 1963).

But, when brief individual pulses (33 and 66 milliseconds) are used, it has been found by Bartley and collaborators (Nelson, Bartley, and Jewell, 1963) that these pulses, when separated by null periods of slightly more than two seconds, were seen as brighter than a steady illumination of the same intensity.

The present situation in which the fore period was dark and the whole target, with bars far apart, was suddenly highly illuminated for a brief period of time is comparable to the situation investigated by Bartley and co-workers. For example, the duration of presentation of the target, in J.Y.L.'s case, lasted on the average 13 milliseconds before he could detect the line, while it lasted 154 milliseconds in the case of the other observer. One can deduce that if for any reason the line is not detected almost immediately, that is when intensity is still fairly inefficient (Bunsen-Roscoe Law), a duration will be reached which leads to brightness enhancement, due to all or almost all of the available elements firing together. This will interfere with transverse or lateral activity necessary for visual acuity (Bartley, Nelson, and Soules, 1963). The line will be seen only when duration is long enough for the retinal elements not to fire maximally and all together, but to alternate, permitting resumption of activity across the different channels. Thus brightness enhancement will be responsible for the wide gap between 13 and 154 milliseconds. It is worth mentioning, at this point, that J.V. often complained that he was dazzled by the presentation of the target and asked the Experimenter to wait longer between successive presentations.

When the two bars were close to the line, however, a well marked decrease in duration was observed at high intensity in the case of J.V. and a slight one in the case of J.Y.L. (for this observer the threshold was already very low and a significant decrease could not be expected).

These results imply that the lateral activity of strong contours (bars contours) in the vicinity of the line contours present longitudinal activity in the different channels from being maximal. Thus, if brightness enhancement can depress weak contours (as is the case in visual acuity), strong contours in proper location can inhibit brightness enhancement. This hypothesis is certainly worth being investigated more thoroughly.

Puzzling results are the ones obtained by the two observers at low photic intensity. Here again, visual acuity was facilitated for J.Y.L. while it was greatly inhibited for J.V. As illumination was low, brightness enhancement cannot be responsible for the longer duration required by J.V. Brief, when there are no borders present in fore period, be this one illuminated or dark, the outcome is this: one of the observers requires less time in both situations than when borders are present in fore period, while the other requires more time. In presence of such contrasting results the A. can only recommend that more researches be performed on the problem.

Absence of bars borders in exposure period.--The results clearly suggest that contours which come undone while new ones are forming up in close vicinity exert a strong depressive influence upon these new contours and their formation is delayed. What is assumed to take place is this: when the bars disappear, their corresponding contours start vanishing. The activity of off fibers dies out and on fibers start firing. At first, some strong interaction between these two types of elements would take place. Because the withdrawal of illumination corresponding to the bars was gradient-like, this interaction would take place in the retinal area covered by the bars and also would spread over several microns on either side, covering the interspace between them. The line contours, having to form in that specific region would take more time to reach completion. Evidently, the exact mechanism remains to be worked out. Whatever be this mechanism, however, the results, in the case of the two observers, clearly indicate that destruction of contours markedly affect the formation of new ones in their immediate surround, the two processes going in opposite direction.

Shifting of border positions.--The results show that less time is required for detection of the line when the bars are shifted toward it in exposure period than when they are shifted away from it. When the bars, close together in fore period, are farther away in exposure period, this is what is assumed to take place: the bars contours completed in fore period have to vanish in exposure period while other contours corresponding to their new position are forming. But the vanishing contours are close to the line contours which are forming. It has been found, in Situation 4, that this created much interference. It is worth mentioning at this point that for the two observers the results obtained in the present condition and in Situation 4 are comparable. Evidently the main role was played by those contours which were decaying and not by those which were forming at some distance and simultaneously with the line contours.

When the shifting was toward the center in exposure period, the contours of the bars, formed in pre-exposure, began to decay, but being at a certain distance from the center, they did not exert any serious interference. At the same time, contours corresponding to their new position were building up in close vicinity to the line contours. The bars being wider, their contours were more accentuated than those of the line and the interference was at the expense of these latter which required more time to complete. This interference, however, was not as marked as when the bars shifted away, because the two gradients, forming together, were in the same direction, while in the other condition, they were in opposite direction: one was building up while the other was decaying.

Second, because the bars and line contours are building up simultaneously, less interference should be expected than if the bars contours had been formed previously. This expectation receives only partial support. It is validated in the case of J.Y.L. who required less time for seeing the line when the bars were shifting toward it than when they remained close to it in fore and exposure periods (Situation 1). In the case of J.V. it does not hold. When strong and weak contours were forming together (the present Situation as well as Situations 2 and 3) he consistently required more time than when already formed contours interfered with new ones. This consistent difference between the two observers is puzzling and the conditions in which it manifested itself should be further investigated.

Another phenomenon which, in the case of the second observer, seems to have affected his results in Situation 5 is apparent movement. It appears as though if the line cannot be perceived before any apparent movement is experienced, then this one will play a major role in the outcome. In the present Situation some apparent movement was experienced by the two observers. For example, when the target in which the bars were set at a medium distance was replaced for a period of 25 milliseconds or so by the one in which the bars were close together, a kind of rapid movement first toward the center and then toward the periphery was observed, it was like two bars colliding and then swinging back to their original position. This movement became really annoying, though, only when the second target was presented for as long as 65 milliseconds approximately, this annoying effect becoming more serious as duration was increased. At high photic intensity the effect was found to be much less distracting. Also, fixation became a very important factor: with proper fixation apparent movement became less objectionable.

When the situation was reversed, that is when the target wherein the bars were close together was presented first, the distracting effect of apparent movement seemed less marked and one had to reach a longer duration, or approximately 145 milliseconds, in order to be affected by it.

One of the observers (J.Y.L.) could detect the line before reaching any of the values at which apparent movement was clearly manifested. He remained well below 65 milliseconds when the bars were shifting toward the center, and also he remained much below 145 milliseconds in the other condition.

As for J.V., in the two conditions his results are above those needed for experiencing beta movement. Moreover he often complained about some movement producing a strong distracting effect.

A comparison of the outcome in the present Situation with some of Werner's results (1935) is interesting: when two targets were presented in rapid succession, he found that the contour corresponding to the second one, at a certain

critical interval, might prevent the formation of the contours of the first one. This critical interval was found to be the one at which apparent movement was optimal.

So, it seems reasonable to assume that if the conditions for producing apparent movement are met, visual acuity will be significantly decreased. In the case of J.Y.L., such conditions would have probably be attained by the Experimenter using a thinner line or a lower degree of photic intensity, for example.

To summarize and conclude it may be said that visual acuity is affected by the presence of borders in vicinity.

(1) Distance between borders is one of the factors affecting detection of a fine line. When these borders are near the line, more time is required for its detection than when they are far out. At a certain distance, however, they have a facilitatory effect upon visual acuity.

(2) The length of borders in near vicinity destroys the facilitatory effect of an increase in length of the line.

(3) Removal of adjacent borders at the same time as the line is presented has a strong depressive effect upon visual acuity.

(4) Equally, a shifting of borders away from the line requires more time for its detection.

(5) A shifting of borders toward the line is facilitatory in the case of one of the observers, and inhibitory in the case of the second one.

(6) Also, for one of the observers simultaneous presentation of the two adjacent borders and the line has a facilitatory influence upon visual acuity, while the effect is inhibitory for the other.

The results are discussed in terms of contour formation. They suggest that any factor which hinders visual acuity does so by interfering with this neural process. Among the factors found to play a significant role are the presence of other contours in vicinity, their order of formation, and their destruction.

SUMMARY

This investigation examines the effects of adjacent borders upon detection of a fine line.

A review of the literature on contour processes indicates that borders near one another exert a mutually depressive influence. This influence was shown to extend to distances as far as four degrees on the retina. If in a set-up traditionally used for studying visual acuity bars are introduced at different distances from a fine line to be detected, one would expect visual acuity to be impaired when these bars are in close vicinity of the line. As the distance is increased the depressing effect of these bars should progressively decrease. As far as the present author knows, no study has been undertaken to investigate this.

Second, such a depressive effect, if present, can be better understood by performing temporal manipulations of borders. Thus, varying the order of presentation of the bars and the line should reveal significant interactions between contours. It should also throw some light on the relationship between contour formation and visual acuity. Such manipulations have not been tried, however.

It was the purpose of this author to examine those points, or more generally to analyze some of the implications of relating visual acuity and contour processes.

In the present investigation two trained observers were tested for visual acuity under three different levels of photic intensity in situations involving spatial and temporal manipulations of borders.

The apparatus was a modified Gerbrands Tachistoscope. The material consisted of transparent cardboards which held the fine line to be detected and the dark bars assumed to exert an influence upon its detection.

The experiment comprised two parts. In Part One six situations were investigated:

(1) The distance between the two dark bars and the line was decreased in five steps from 14° 14' to 11'.

(2) The fore period was dark; the line and bars appeared together in exposure period.

(3) The fore period was lighted, but the vertical bars appeared simultaneously with the line in exposure period.

(4) The two bars vanished while the line appeared in exposure period.

(5) The two bars were shifted toward the center or toward the periphery.

(6) The length of the line and of the two bars was varied in three steps from 36' to 9° 31'.

Part Two was performed as a check on the reliability of data in those situations where the two observers disagreed. Thus Situations 2, 3, and 5 were re-examined.

The ascending method of limits was utilized throughout the whole experiment.

The results indicate that visual acuity is affected by the presence of borders in vicinity. (1) Distance between borders turned out to be a significant factor. When these borders were near the line, more time was required for its detection than when they were far out. At an intermediary distance, however, they had a facilitatory effect upon visual acuity. (2) The length of borders in near vicinity counterbalanced the facilitatory effect of an increase in length of the line. (3) Removal of adjacent borders at the same time as the line was projected has a strong depressive effect upon visual acuity. (4) A shifting of borders away from the line also required more time for its detection. (5) A shifting of borders toward the line was found to be facilitatory in the case of one observer, and inhibitory in the case of the second one. (6) Equally, for one observer simultaneous presentation of the two adjacent borders and the line had a facilitatory influence upon visual acuity, while the effect was inhibitory for the other.

The results were discussed in terms of contour formation. They suggest that any factor which impairs visual acuity does so by interfering with this neural process. Amont the factors found to play a significant role are the presence of other contours in vicinity, their order of formation, and their destruction.

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