Spatial and Temporal Determinants Of The Increment Threshold Edge Effect

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Abstract

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The following experiments were designed to examine the role of spatial and temporal parameters in the increment threshold edge effect. As a first step Experiment 1 investigated the role that spatial parameters play in the edge effect. Sensitivity to a test stimulus was investigated for a number of test flash and background sizes. The results of this experiment sugest that the edge effect is specific to the combination of a small test flash and a large background.

The second experiment addressed the hypothesis that several reports of failures to find an edge effect could be accounted for by exposure duration of the background stimulus rather than on the basis of stimulus size. An effect of background exposure duration upon edge effect magnitude was demonstrated in Experiment 2.

The third and final experiment examined the relation between edge effect magnitude and the temporal separation between the onsets the test flash and background stimuli. This relation was examined for a number of background sizes.

The combined results indicate that the magnitude of the edge effect is dependent upon an interaction of spatial and temporal background

parameters. An increase in the size of a briefly exposed background stimulus will give rise to an edge effect where one was not observed previously. The background duration below which one will not find an edge effect decreases as the background size increases. In addition, when the background size and/or duration were insufficient to produce an edge effect with simultaneous onsets of the stimuli, no threshold elevation was evident at the edge even when the sensitivity was assessed after the cessation of the background stimulus.

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The basic problem for any sensory system is to detect the presence of energy changes in the environment. The problem of detection is one which is centered around how much stimulus energy is necessary for an observer to say it has been seen with some certainty. Classically, the minimum amount of energy necessary for detection has been called the threshold. Gustav Fechner defined the threshold stimulus as one that "lifted the sensation or sensory difference over the threshold of consciousness" (Fechner, 1860). William James speaks of thresholds in the following manner: "There is a real sensation of difference, aroused by the shock of transition from one perception to another which is unlike the first". (James, 1890, p.495).

Visual Thresholds

It is conventional to speak of two kinds of detection thresholds: absolute thresholds and difference thresholds. The absolute threshold is defined as the smallest amount of stimulus energy necessary to produce a sensation. The difference threshold is defined as the amount of change in stimulus intensity required to produce a just noticeable difference (jnd) in the sensation. Absolute thresholds are merely a special case of difference thresholds that involve a detection of change from zero to some finite intensity. Difference thresholds involve a discrimination of one finite value from another. The stimulus parameters that have been shown to influence absolute thresholds yield similar effects on difference thresholds.

The ability of the human visual system to detect a spot of light varies with a number of factors. The most important of these are the stimulus intensity, stimulus duration and stimulus area. One measures a different type of threshold depending upon which of these variables is manipulated. In general the greater the magnitude of any of these, the lower is the threshold. Within a photopic range of intensities a lawful relationship exists between the intensity level of a stimulus and the size of the threshold. This relationship is known as Weber's Law. The size of an increment that has to be added to a given stimulus to allow one to detect a change is a constant proportion of the original stimulus intensity. There is a trade-off between stimulus duration and intensity in vision, at least for periods of .1 sec or less. That is, the product of luminance and exposure duration needed for detection is constant. This relationship is described by Bloch's law. Thus, for a given stimulus we may increase the likelihood of detection by either increasing the intensity or by increasing its duration. However, beyond the critical duration the probability of stimulus detection is not affected by stimulus duration, but depends only upon stimulus intensity. Target area is linearly related to threshold up to a critical area. There is a direct relationship between area and intensity. This is known as Ricco's law. The likelihood of stimulus detection can be increased by either increasing its intensity or increasing its area. For stimulus sizes beyond the critical point, increasing the area has a somewhat reduced effect. The effect of area on detection beyond the critical point is described by Piper's Law. A greater increase in area is needed to achieve the same reduction in threshold. In addition it has been shown by Owen (1972) that duration and area interact to determine sensitivity.

Threshold detection is also dependent upon a number of other stimulus properties. The stimulus wavelength and retinal location are two. The energy required for a response depends on the locus of the retinal field upon which light impinges. Experimental data on the relation between detection and retinal locus reveal a marked drop in threshold from the fovea to the periphery (e.g. Crozier & Holway, 1939). The threshold for white light is much higher in the fovea than in the periphery. The dark adapted eye is most sensitive to light of a wavelength of 510 nm. A considerable increase in energy however is required at the short and long wavelengths. Spectral sensitivity curves showing the absolute threshold as a function of stimulus wavelength have been obtained for cone (photopic) and rod (scotopic) vision. The periphery of the retina is most effectively stimulated by light with a wavelength of approximately 500 nm, and the fovea is most sensitive when the wavelength is about 560 nm (e.g. Wald, 1945). Much less energy is required at threshold for peripheral stimulation than for foveal stimulation. This indicates that rod receptors are considerably more sensitive than cones (this is true at all but the longest wavelengths).

Adaptation

The state of adaptation of the eye is also an important determinant of thresholds. A decrease in sensitivity following stimulation accompanies the process of light adaptation. The process of dark adaptation is accompanied by an increase in sensitivity following periods of nonstimulation. There exists a mass of experimental data which reveal a marked change in the thresholds during the course of adaptation (e.g. Aubert, 1865; Hecht, Haig & Chase 1937).

Crawford (1947) pioneered investigation into the changes during the first few seconds of light adaptation in a study in which foveal detection thresholds were assessed. He examined the variations in the threshold to a test stimulus immediately preceding, during and immediately following the presentation of an adapting stimulus by measuring the detectability of a 0.01 sec test flash from approximately 0.3 seconds before the onset of the adapting stimulus to 1 sec after cessation of the adapting luminance. Data reported by Crawford confirm the rapid rise and fall in threshold but also suggest that visual sensitivity undergoes a complex sequence of losses and gains during a brief intense light flash. These sensitivity changes are illustrated in a figure adapted from Crawford in Figure 1. An initial rise in threshold is evident while the test stimulus precedes the adapting stimulus. It rises rapidly to a maximum that occurs approximately at the point representing the simultaneous presentation of the test and adapting stimuli. From this maximum the threshold decreases rapidly at first, then more slowly, reaching a new steady level while the adaptation stimulus is still present. In a similar manner the threshold begins to rise when the test flash just precedes the cessation of the adapting stimulus, reaches a maximum at a time which corresponds, approximately, with the temporal coincidence of the test flash and the end of adaptation. After the second maximum the threshold decreases rapidly, then slowly, to the resting level of the dark adapted threshold. The amount of the initial threshold rise is a function of the intensity of the adapting light. Dim adapting lights yield small threshold rises when extinguished, especially in the scotopic range. The response to intense stimulation occurs rapidly. This rapid response occurs at the termination of stimulation as well as to the onset of stimulation.

Following the brief and rather small threshold rise, the threshold drops. The threshold curve falls very abruptly at first, then levels off into slower dark adaptation rates. Later research has since shown that a rapid fluctuation in the ability to see the stimulus spot is not

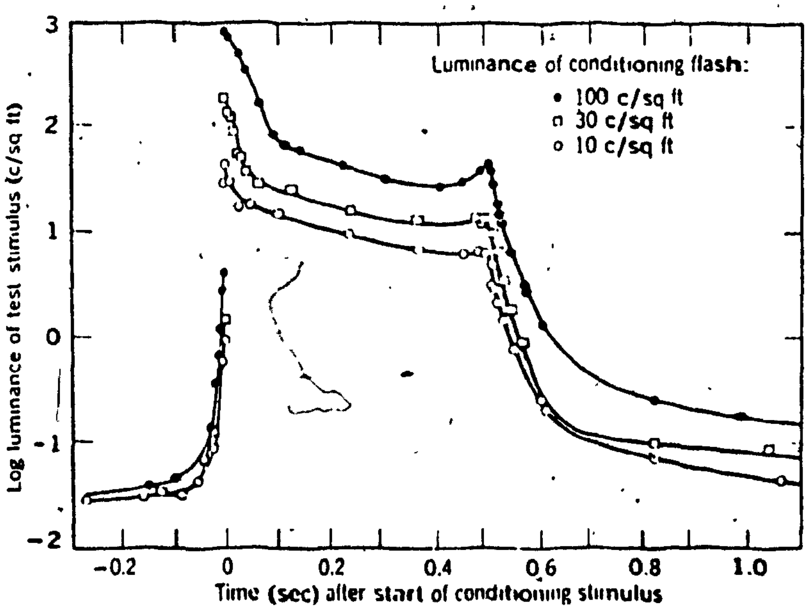


Figure 1. Crawford's measurements of the threshold during brief light-adaption to flashes. The duration of the conditioning flash was 0.5 sec in each case and each flash began at time zero. (From Crawford, 1947.)

a special case peculiar to short flashes which give incomplete light adaptation. Fluctuations occur whenever dark adaptation or light adaptation begins, implying that "Crawford effects" are quite general (e.g. Baker, 1949).

The general question about the effect of adapting luminances on thresholds has been reinvestigated extensively. Boynton & Treidman (1953) determined the time course of the change in threshold from 0.4 seconds preceding to 1 second following the onset of the adapting stimulus. The data in general are very similar to the early data reported by Crawford (1947). Boynton, Bush & Enoch (1954) have reported that a depression of sensitivity with indirect adaptation (peripherally presented adapting stimulus) shows the same time course as direct foveal adaptation. The extent of their effect can be predicted on the basis of direct adaptation effects from scattered light from the indirect stimulus.

Baker (1949) studied the long term changes in the threshold during the course of adaptation to various luminances. He measured the time course of change in threshold from 5 to 1000 msec after the onset of the adapting stimulus to 4 retinal adapting luminances between 5 and 5000 trolands. Baker (1963) also collected more detailed data on changes that occur at the time of cessation of the adapting stimulus and confirmed the initial results obtained by Crawford. Threshold measurements were taken at various intervals relative to the extinction of a large adapting field. In this manner, Baker collected data for different adaptation luminances and with the image of the test flash positioned in the fovea and periphery. In both regions he found that the threshold began to rise just before the adaptation field was extinguished. It reached a peak at about the instant of extinction, and declined with increasing slope after extinction. The higher the preadaptation luminance, the slower was the subsequent recovery. In addition, the elevation of threshold immediately preceding the adapting field is more pronounced the higher the luminance of the preadapting field.

Threshold changes over time have also been investigated under conditions where the onset and cessation of the adapting luminance represent a change from one suprathreshold level to another. In these cases we are dealing with classic difference thresholds rather than transitions from absolute to difference thresholds. A detailed study of this problem has been reported by Hattwick (1954). Using a preadaptation stimulus of 3.83 log trolands and a test field of 1 degree exposed in the fovea for 0.02 sec he determined the changes in the increment threshold during the process of adaptation to four lower luminance levels. He also measured the time course for the absolute threshold in the dark. The curves showing adaptation to the four lower luminance levels were all of similar form, but displaced along the y-axis. But the curve representing adaptation to complete darkness crossed the early portions of of the other curves and finally terminated at the lowest level. In a similar experiment Baker (1963) investigated the changes in threshold when the onset of the adapting stimulus represented a change from one finite luminance to another higher luminance. The functions obtained are similar to those obtained by Baker when the increment threshold (ΔI) was measured for adapting luminances beginning with a value of zero luminance. The magnitude of the dip in threshold depends on the magnitude of the difference between the preadapting and the adapting luminances.

As well as considering the influence of adapting field luminance and duration on increment thresholds, it is necessary to consider what role might be played by the size and shape of the adapting field. Blachowski (1913) has shown that as the size of the surround stimulus is increased, increment threshold (△ I) decreased. More recently, Westheimer (1967) has shown that the threshold for a superimposed test spot could be raised by increasing the area of surround illumination and could be decreased by decreasing the surround illumination. This is a manifestation of excitatory and inhibitory interaction of adaptation stimuli. Illumination of retinal regions in the immediate neighbourhood of the area tested acts to raise the adaptation level, and illumination of those furthur removed acts to lower it.

The relative spatial position of the test flash with respect to the background has also been studied extensively. The results of several experiments indicate that the threshold is increased in the region of a boundary which exists in a nonuniform field (eg. Fiorentini, Jeanne, & Toraldo di Francia, 1955). This particular phenomenon of a decrease in sensitivity near a border has been termed edge accentuation.

Kruger & Boname (1955) provided evidence that a constant relationship holds between the log increment threshold and its distance from the center of the adapting field. The increment threshold was lowest in the center and was highest near the border. Such differences are not due to differences in absolute retinal sensitivity in as much as when absolute thresholds were measured the threshold remained constant across the background area. In an interesting examination of the nonuniform field on thresholds, Yonemura (1962) had subjects move a test spot towards an adapting field border until it was no longer visible. The higher the luminance of the test spot the closer it could be brought to the edge of the adapting field before it disappeared. Harms &

Aulhorn (1955) and Fiorentini, Jeanne, & Toraldo di Francia (1955) measured discrimination thresholds for small test spots as a function of their location in relation to boundaries in the background field. A sharp decrease in sensitivity was evident on the light side of a boundary. This change in sensitivity was found to be greatest at high luminances, for longer stimulus durations, and at locations further removed from the fovea.

The decrease in sensitivity measured near a background edge is found whether one approaches the edge from the high or low luminance side. Wildman (1974) studied the edge effect on both sides of the edge by varying its spatial position with reference to a fixed test flash. He found that the test flash threshold rose the closer it was to the edge of an illuminated area and that it also gradually fell the further it was moved into the darker region. It was determined that the threshold rise on the illuminated (high) side was dependent upon the intensity of the illuminated field. Threshold elevation was absent at a low intensity (0.6 log troland). In a further investigation of the low side edge effect. Wildman attempted to determine the contribution of light scattered from the high side of the edge on threshold determinations made on the low side of the edge. Wildman reasoned that if the rise in increment threshold at some point on the low side of an edge was due entirely to scattered light then the equivalent veiling luminance that raised the threshold as much will also bleach the receptor photopigments as much. The equal bleach would be reflected in identical subsequent dark adaptation following scatter-light bleach and equivalent-veil bleach. Dark adaptation curves following scatter-light bleach and equivalent veil bleach were similar. The results indicated that low side edge effects are merely due to stray light in the eye.

The rise in threshold that is of interest is that which is observed when sensitivity is measured on the high side of the edge.

It has been postulated that eye movements may contribute to this edge effect (Teller, 1965). When a subject views a nonuniform field such as a luminance edge, abrupt changes in luminance at retinal regions stimulated by the edge occur constantly as a result of small eye movements. These intensity changes at an edge could then give rise to the higher increment thresholds in the vicinity of the edge by giving rise to local rapid light adaptation effects. In order to determine the role of eye movements in the edge effect Lukas, Tulunay-Keesey, and Limb (1980) measured increment thresholds for a small, briefly presented test line as a function of distance from a high-contrast luminance edge under both stabilized and unstabilized viewing conditions. In an unstabilized condition normal motions of the retinal image were allowed whereas for the stabilized condition the effect of eye movements were compensated, rendering the image stationary relative to the retina. It was found that the edge effect was reduced by about 50% under stabilized conditions. Little difference was found between stabilized and unstabilized conditions when the background was briefly presented. These data indicate that edge effects observed under unstabilized conditions might be attributed to eye movements. Similar data has been reported by Teller (1968) and Tulunay-Keesey and Vassilev (1974). The general conclusion is that eye movements, although not necessary for an edge effect appear to enhance the effect. It should be pointed out that although it is not clear from these particular experiments, the effect of eye movements is likely to be a peripheral rather than a cortical one.

While the phenomenon of edge accentuation is well documented, there is a discrepancy in the literature related to the magnitude of the edge effect in the fovea. On the one hand, there are several reports that threshold elevations present near a border measured in the fovea are in the range of 0.3-0.5 log units (Fiorentini et al, 1955; Fiorentini, 1957; Fiorentini & Zoli, 1966; Matthews, 1966; von Bekesy, 1968; and Vassilev, 1970a). On the other hand, Aulhorn & Harms (1956), in an experiment in which they presented the background edge at different distances from the fixation point, reported that the edge effect was quite diminished near the fovea. An edge effect was observed, however, 5 degrees from the fovea. A very small foveal edge effect was also reported by Payne (1970).

Two hypotheses have been put forth to explain this discrepancy in the literature, one pertaining to psychophysical methods employed and another pertaining to the actual stimulus parameters employed in the experiments. The explanation which is of interest here is the latter. For an evaluation of the psychophysical methods employed see Teller (1965).

Test Flash Parameters

A study of the stimulus parameters that influence the magnitude of the edge effect was conducted by Vassilev (1973). He noted that a comparison of the results from different experiments revealed that those investigators who did not find a significant edge effect used small test stimuli. In the experiments where a foveal edge effect was clearly demonstrated the best stimuli were several spots or a bar parallel to the boundary. However, no direct comparison could be made with reference to the stimulus parameters since different psychophysical methods were employed in the various experiments. Vassilev (1973) investigated directly the dependence of the foveal edge effect upon test stimulus form, size and duration and the results of this investigation will be summarized below.

Vassilev (1973) measured increment thresholds as a function of the distance to a light-dark boundary for a small circular test stimulus (3.9 min diameter) and for a rectangular bar stimulus (6 min x 47 min). The threshold curve for the bar stimulus showed a typical edge effect with the threshold at the boundary being 0.3 log units higher than that measured at the center. The threshold curve for the circular stimulus was much less influenced by its proximity to the boundary There was very little difference between the thresholds obtained at the center and at the edge. On the dark side of the edge, while both curves were elevated near the boundary, the increment threshold for the bar stimulus was more elevated than that for the disk.

Vassilev (1973) also investigated the role of stimulus size. These data suggest that manipulating the size of a target stimulus keeping the form unchanged, might influence the magnitude of the edge effect. For circular stimuli a 5 min diameter seemed to be optimal for producing an edge effect. When the target stimulus was a bar, a target of 4 min width showed maximum threshold elevation. Threshold elevation with disk stimuli was only observed at distances smaller than 7 min from the boundary. The threshold elevation with bar stimuli could be seen at larger distances as well. In an investigation of bar length he found that a marked increase in the edge effect could be found when the length of the test bar was increased.

Vassilev investigated the importance of target duration with two test stimuli: a 4 min disk and a 6 min x 47 min bar. They were presented for either 10 or 100 msec. No significant differences in the forms of the curves for 10 or 100 msec were found. For the disk stimulus, however, an increase of duration seemed to enhance the edge effect. The threshold for a 100 msec duration is more elevated near the boundary than the threshold of a 10 msec disc. Vassilev notes that increasing the duration makes the results with the disk comparable to the results with the bar.

The data of Vassilev (1973) do suggest that the use of different test stimuli is one of the sources of the contradictory results in the literature on the edge effect. Test stimulus form, size and duration appear to be important determinants of the magnitude of the edge effect. A similar systematic investigation into the background parameters has not been carried out. There are some indications that variations in these parameters may also play a role in the determination of the edge effect.

Background Parameters

We have already seen that test flash duration is an important determinant in the increment threshold edge effect. The effect of the duration of edge presentation has been explored by Novak & Sperling (1963) and Matthews (1966). The data indicate that the largest edge effects are seen with continuously presented background edges. Novak & Sperling report no edge effect with a background duration of 10 msec but they do report a small change in sensitivity at the edge when its duration is increased to 50 msec. Matthews compared increment thresholds at various distances from a boundary when the edge duration was either 2 msec, 100 msec or continuously presented. A sharp rise in the increment threshold was observed when the test flash was adjacent to the continuously presented boundary. However, when exposure of the edge was brief, the increment threshold no longer exhibited this peak. Matthews reports no change in sensitivity near an edge for a 2 msec background edge, but does report a small edge effect with 100 msec background presentation. Wildman (1974) also investigated the role of the background duration parameter on the magnitude of the increment threshold edge effect. He flashed both the target spot and the adapting field in his experiment for 2 msec. There was a complete absence of the high side edge effect at all of the adapting luminances used. The data on background duration suggest that the neural effect of the edge on the test flash takes some time to develop. With briefly presented background edges the neural effect of the edge stimulus is too incomplete to influence the increment threshold. It is important to note that although these data indicate that edge effects are difficult to observe at brief background or edge durations, there are some reports in the literature of edge accentuation with briefly presented edge stimuli. For example, Petry, Hood & Goodkin (1973) observed an edge effect in an experiment in which the background edge duration was as brief as 18 msec. In the typical edge effect experiment, an edge is presented continuously which idealizes the conditions for the development of the neural effect.

Petry, Hood & Goodkin (1973) noted that the absence of a relative increase in increment threshold for briefly presented edge stimuli reported by Novak & Sperling (1963) and Matthews (1966) was in apparent contradiction with the appearance of Mach bands under similar conditions. Mach bands are a perceptual phenomenon traditionally cited as as an example of the effect of lateral inhibition in the human visual system. The presence of Mach bands is not limited to short exposure durations. Matthews (1966) reported the appearance of Mach bands under the same 2 msec exposure duration condition that did not yield an incremental threshold edge effect. Petry et al (1973) looked for a buildup in time of the edge effect in order to account for its absence with short edge presentations. They suggest that it is not the short exposure duration per se which is responsible for the absence of an effect in such conditions but rather that it is necessary to present the incremental spot subsequent to the cessation of the brief duration edge. They suggested that presenting the test flash simultaneously with the edge does not allow the necessary inhibition to develop. In looking at the time course of the development of the edge effect Matthews (1966) showed that the increment threshold does not asymptote until the edge stimulus has been presented for 500 msec. Petry et al measured the increment threshold for a spot at different distances from an edge with both the test flash and edge presented for 18 msec. Their relative onsets were varied from -50 to +50 msec. When the test flash was presented 10 msec before or after the edge, no relative increase in threshold was observed at the edge. This result is consistent with the Matthews (1966) and Novak & Sperling (1963) data. As the incremental spot was presented after the offset of the edge stimulus by 30 and 50 msec, the data clearly revealed an increase in the increment threshold at the edge relative to its value at the center of the background. The magnitude of the edge effect under these conditions was comparable to that found with longer duration stimuli. On the basis of these findings, Petry et al argue that the important variable for obtaining an edge effect is the time relative to background onset of the edge at which the test flash is presented (stimulus onset asynchrony or SOA). The implication is that in those conditions in which an edge effect was not found one might have been evident if the thresholds were measured at a positive stimulus onset asynchrony (i.e. background onset precedes test flash onset).

In an experiment which did employ positive SOA's Limb and Tulunay-Keesey (1981) examined changes in threshold at onset asynchronies of 0, 50, and 200 msec., with briefly presented edges. In this particular experiment the maximum edge effect was found near an SOA of zero.

Burkhardt (1966) also attempted to determine the time course of an edge effect. He measured increment thresholds over a wider range of SOA values in 100 msec intervals. He compared threshold sensitivity to a target at the center and at the edge of the background. The results indicated little change in the magnitude of the edge effect as a function of the SOA of the test flash and background stimuli. Over a range of SOAs the threshold function at the center and the threshold function at the edge were similar. Although threshold measures were dependent upon SOA; edge effect magnitude was not. The notion that edge effects take some time to develop does not, in light of Burkhardt's data, appear to be sufficient to explain the background duration data. Although Burkhardt measured increment thresholds over a wide range of SOA values, he did so in 100 msec intervals. It is difficult then to determine whether or not the maximum edge effect might have been found at some SOA value between 0 and + or - 100, had thresholds been assessed within those intervals.

Petry, Hood & Goodkin (1973) reported a maximum edge effect with brief duration stimuli only if the probe was measured after the offset of the background. Petry & Hood (1978) also compared center and edge thresholds as a function of SOA. They used a range of SOA values from -30 to +50 msec. An examination of their SOA functions at the center and edge does not reveal differences of the magnitude reported by Petry, Hood & Goodkin (1973). The results from the experiments investigating edge effect magnitude at various SOAs do not indicate clearly the role that this parameter plays in the determination of increment threshold edge effects.

Although the role of target parameters in the determination of the increment threshold edge effect is well defined, the role of the background parameters is not as clear. The literature to date points to an importance of both spatial and temporal background factors in the magnitude of the edge efect. When edge effects are examined with a brief duration background some authors report the presence of edge effects (e.g. Petry, Hood & Goodkin, 1973; Limb et al, 1981); while others report an absence of threshold elevation near an edge when the background is brief (e.g. Novak & Sperling, 1963). Petry et al (1973) have suggested that with briefly presented background stimuli the crucial variable for finding an edge effect is the time relative to background onset or offset at which sensitivity is measured. The present thesis is an attempt to further our understanding of the determination of increment threshold edge effects. In particular the experiments were designed with an aim of delineating the role of spatial and temporal parameters which are responsible for edge effects on brief backgrounds.

Experiment 1

The magnitude of the increment threshold edge effect appears to be dependent upon both spatial and temporal parameters. These dependencies have not been thoroughly investigated and as such can only be inferred from the data of a number of different studies. Investigations of the effect of background presentation indicate that the magnitude of the edge effect decreases as the exposure duration of the background is reduced. The largest edge effects are observed with continuously presented backgrounds (Novak & Sperling, 1963; Matthews, 1966), but edge effects can be observed with backgrounds presented as briefly as 18 msec (Petry, Hood & Goodkin, 1973).

A study conducted by Petry & Hood (1978) is one which points to the importance of these parameters. There were two differences between their paradigm and typical edge effect studies. The first of these was the size of their background field. Petry & Hood measured the increment threshold for a small test flash (1 min diameter) on a relatively small background field of 36 min diameter. Typically one assesses the threshold for a small test flash against a large background stimulus. The second difference was their background exposure duration. The ideal conditions for finding an increment threshold edge effect employ a continuously presented background. Petry & Hood exposed both the test flash and the background for 8 msec in a metacontrast paradigm.

The purposes of Petry & Hood's (1978) experiment were to compare sensitivity to a probe at the center and at the edge of a stimulus during metacontrast masking and also to determine the relation between brightness and sensitivity during metacontrast masking. Metacontrast masking refers to the situation where the brightness of a target stimulus is reduced when its presentation is followed by that of a mask stimulus to an adjacent area. Petry & Hood's metacontrast paradigm involved a target disk which was masked by a surrounding annulus ring. Since masking has been characterized as a contour interaction they reasoned that a measure of the sensitivity to a test stimulus at the center and the edge of a disk which was being masked by a ring would provide an indication of contour effects. If metacontrast did involve contour interactions sensitivity differences at the center and edge of the disk would be expected.

One of their control conditions is of particular interest in the present context. This was a condition in which only the disk stimulus was present and as such allows comparisons with standard edge effect data since, in this condition, there was no metacontrast. In short, it comprised an edge effect experiment. The thresholds were obtained at the center and at the edge of the background stimulus. There was no evidence of threshold elevation at the edge with respect to the threshold assessed at the center. A comparison of the Petry & Hood study with others would suggest that the absence of an edge effect was due to either their atypical spatial or temporal parameters. It should be emphasized, however, that these are atypical for an edge effect paradigm but not for a metacontrast paradigm.

The following experiments to be reported in this thesis represent an attempt to determine the contribution of spatial and temporal parameters involved in edge effects. As a first step, Experiment 1 investigated the role that spatial parameters alone play in the edge effect. It was designed to examine the spatial paramters for briefly presented backgrounds. The question specifically addressed concerns whether the presence of an edge effect is dependent upon background size when the SOA between the test flash and the background stimulus is zero. Sensitivity to a test stimulus exposed at the center and edge of a background was investigated for several test flash and background size combinations which were presented at an SOA of zero. If the edge effect is dependent upon background size when the onsets are simultaneous, differences in the magnitude of the effect would be expected in these conditions. Three background stimuli were employed in combination with two test stimuli. The exact stimulus conditions for Experiment 1 are illustrated in Table 1.

Method

Subjects

Five adult observers, one male and four females, participated in this experiment. Each observer had uncorrected or corrected acuity to 20/20 (contact lenses) as measured with the Keystone Visual Skills tests.

Apparatus and Stimuli

All stimuli were presented in a conventional three-channel Maxwellian view optical system to the right eye of the subject. A general plan of the apparatus is illustrated in Figure 2. An observer's head was fixed with the use of a bitebar and viewing was through a 3mm artificial pupil. All but the smallest stimulus in this experiment were made by drilling holes in metal squares. The smallest stimulus used, which subtended 5 min in diameter, was constructed by drilling an appropriately sized hole through two layers of black film. All stimulus field stops were positioned one focal length behind the final lens in the system.

The test flash stimulus was inserted in one channel of the optical system. The second channel contained the background disk stimulus, and the third contained the fixation stimuli. The light sources in all but

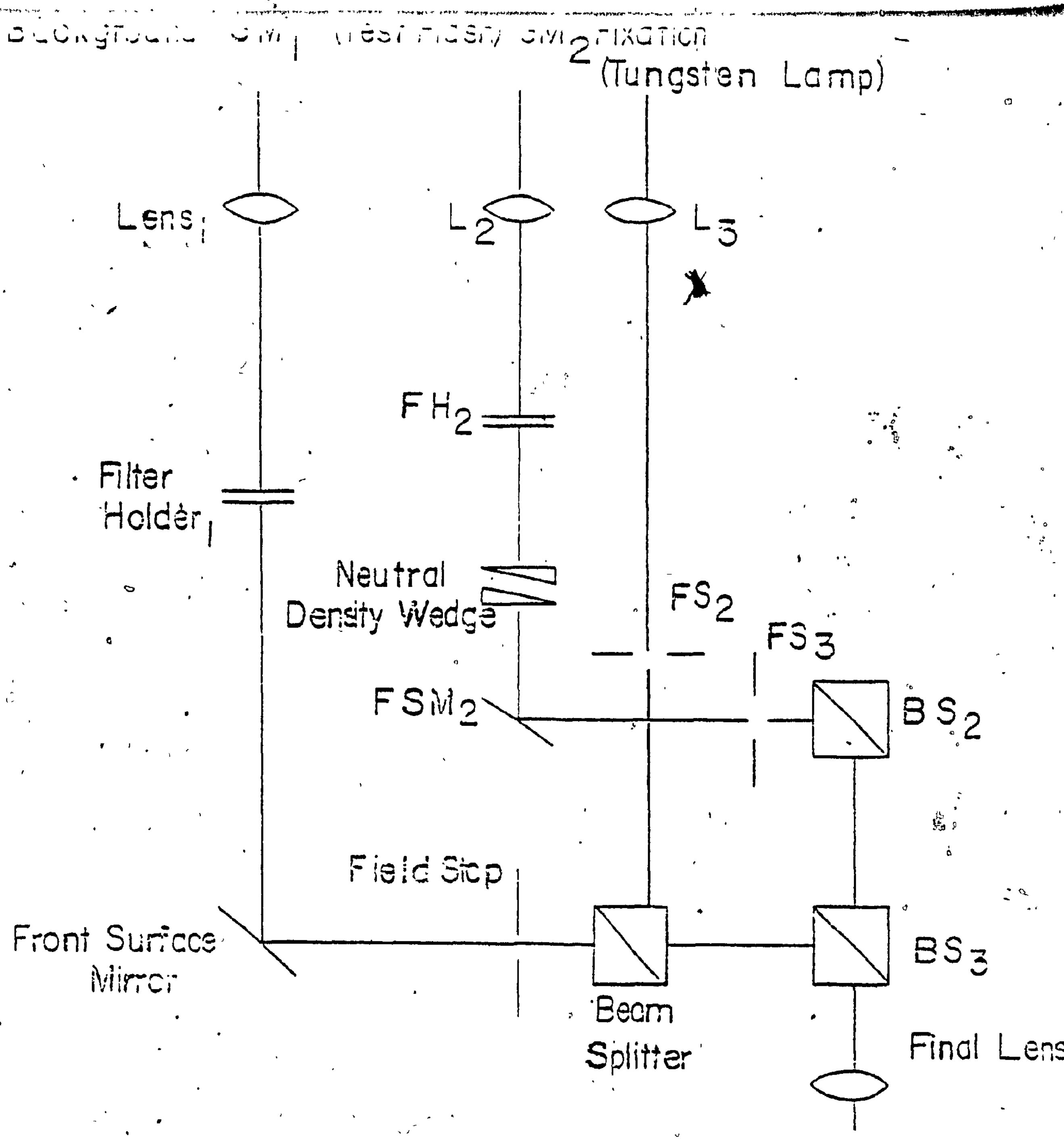


Figure 2. Maxwellian-view optical system.

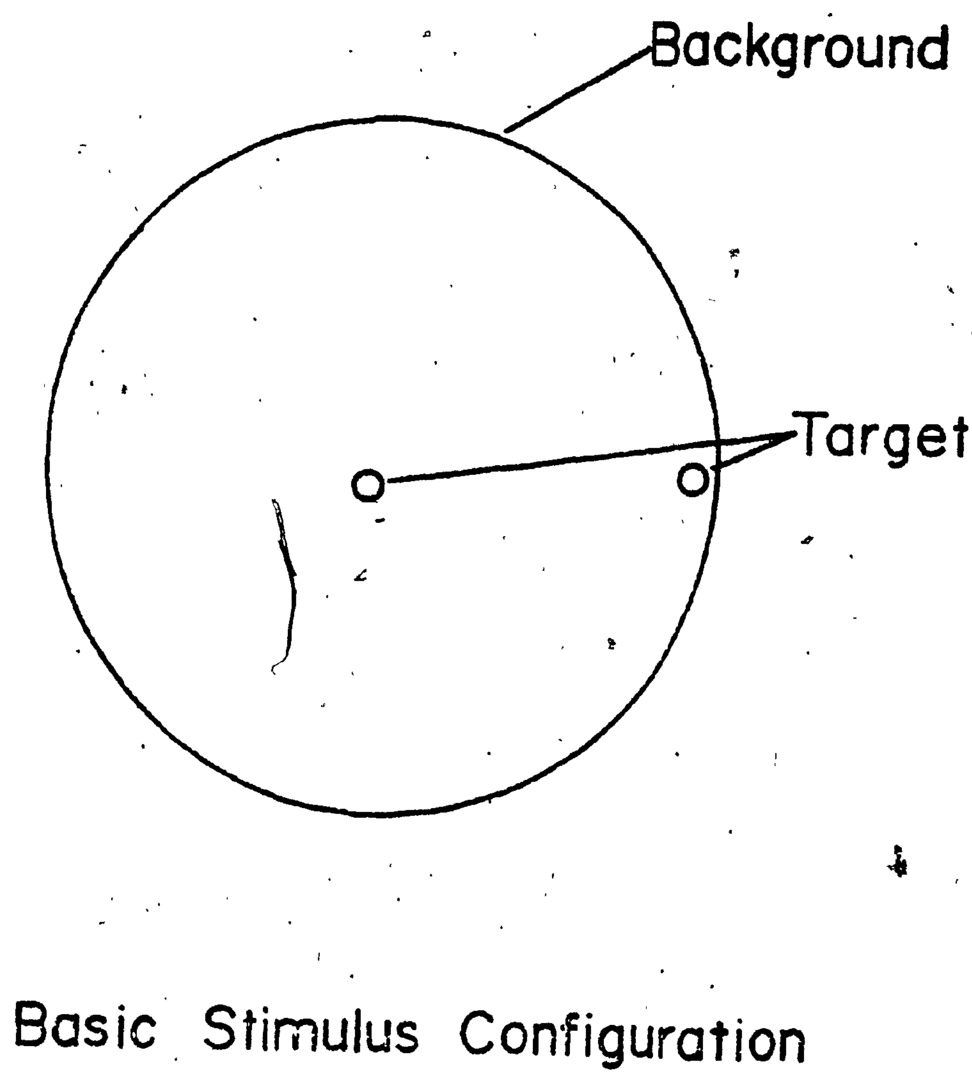


Figure 3. Basic configuration of stimuli employed in these experiments.

one channel were Sylvania glow modulator tubes (R1166). The source in the fixation stimulus channel was a tungsten lamp. Two red fixation points were vertically aligned and were separated by 40 min of visual angle. Observers were asked to fixate between these points. A motor driven neutral density wedge in the test flash channel was used to control the test flash intensity. The wedge was controlled by the experimenter and its position was monitored on a digital voltage meter. The retinal illuminance in the background channel was 3.0 log trolands as measured with a Spectra spotmeter and calculated according to the procedure outlined by Westheimer (1966).

Small mirrors were mounted in the stimulus channels just beyond a light source such that reflections from each stimulated a photocell mounted in the background disk channel. The output of the photocell was fed into the vertical amplifier of an oscilloscope. In this manner all stimulus flashes could be monitored so that trials in which any of the temporal waveforms were aberrant would be discounted. All stimulus events in the experiment and their timing were programmed with Coulbourn Instruments logic circuitry.

Table 1

Test and Background Conditions of Experiment 1

Test Flash Diameter	Background Diameter
5 min	20 min
5 min	3 degrees
5 min	6 degrees
45 min	3 degrees
45 min	6 degrees

Procedure

The observer's task was to report whether the test flash was present on a given trial. An ascending method of limits modified by the addition of catch trials was used. Increment thresholds for the test flash were measured at two spatial positions, at the center and at the edge of the background disk. At the edge the target spot was positioned so that it abutted the edge of the background stimulus. The test flash stimulus was positioned adjacent to the edge of the background stimulus when edge thresholds were assessed. An illustration of the basic stimulus configuration of Experiment 1 can be seen in Figure 3. The onsets of the test and background stimuli were always simultaneous. All stimuli were flashed for 40 msec.

The main manipulation involved the background and test flash diameters. Sensitivity to a 5 min diameter test stimulus was assessed either on a 20 min, a 3 or 6 degree diameter background disk. The sensitivity to a 45 min test stimulus was assessed on a 3 or 6 degree background.

Observers were dark adapted for 10 minutes at the beginning of each experimental session and there was a 10 second dark interval between trials. On forty per cent of the trials no test flash was presented. These catch trials were assigned randomly within each session. There were four replications for each data point. Data collection was blocked by stimulus size and test flash position.

Results and Discussion

The false alarm rates in Experiment 1 ranged from 2-3% of all blank trials presented. This indicated that the criterion used by the observers' remained consistent throughout the experiment. Similar false alarm rates (2-6%) were present for all of the experiments reported in this thesis.

In only one condition was there an elevation of the increment threshold near an edge. The increment threshold for the 5 min test flash assessed against the 6 degree diameter background disk was reliably elevated at the edge as compared to the center (minimum $t(6)=3.93, p<.05$). The data from this condition are plotted in Figure 4. No significant change in the threshold as a function of spatial position was evident for any of the other test and background stimuli (maximum $t(14)=1.94$ $p<.05$). Increment thresholds assessed at the center and at the edge for the other conditions are plotted in Figures 5 to 8.

The present results replicate those of Petry & Hood (1978), in that an edge effect was not found when the increment threshold for a small test flash stimulus (5 min) was assessed at the center and edge of a small background stimulus (20 min) presented simultaneously. However, with more conventional spatial parameters, a large background (6 degrees) and a small test flash (5 min), an edge effect was present. This indicates that when stimuli are flashed for a brief period one can still find an edge effect if the size parameters are appropriate. These data also suggest that Petry & Hood's failure to find threshold elevation near an edge may, in part, have been a consequence of their choice of test flash and background disk diameters.

A comparison of the increment thresholds for the two test flash diameters (5 min and 45 min) assessed against the 6 degree background disk indicates that the magnitude of the edge effect is not determined by background size alone. There was no evidence of threshold elevation near the edge of the 6 degree background field when sensitivity was assessed with a 45 min test flash. A marked elevation of threshold near the edge of this 6 degree background field was present when sensitivity was assessed with a 5 min test flash.

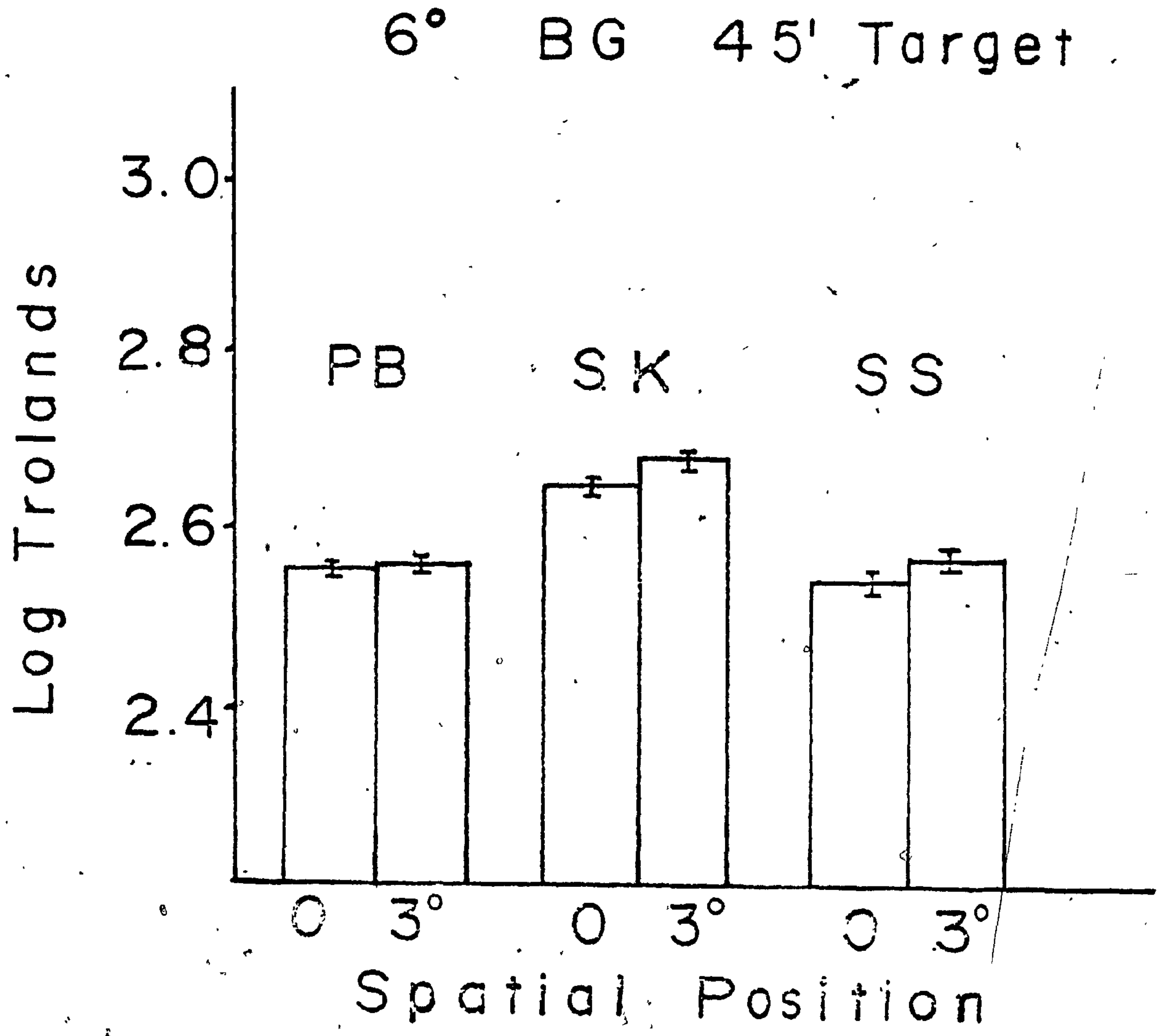


Figure 5. Increment thresholds for a 45 min diameter test flash measured at two spatial positions, 0 and 3 degrees from the center of a 6 degree diameter background stimulus.

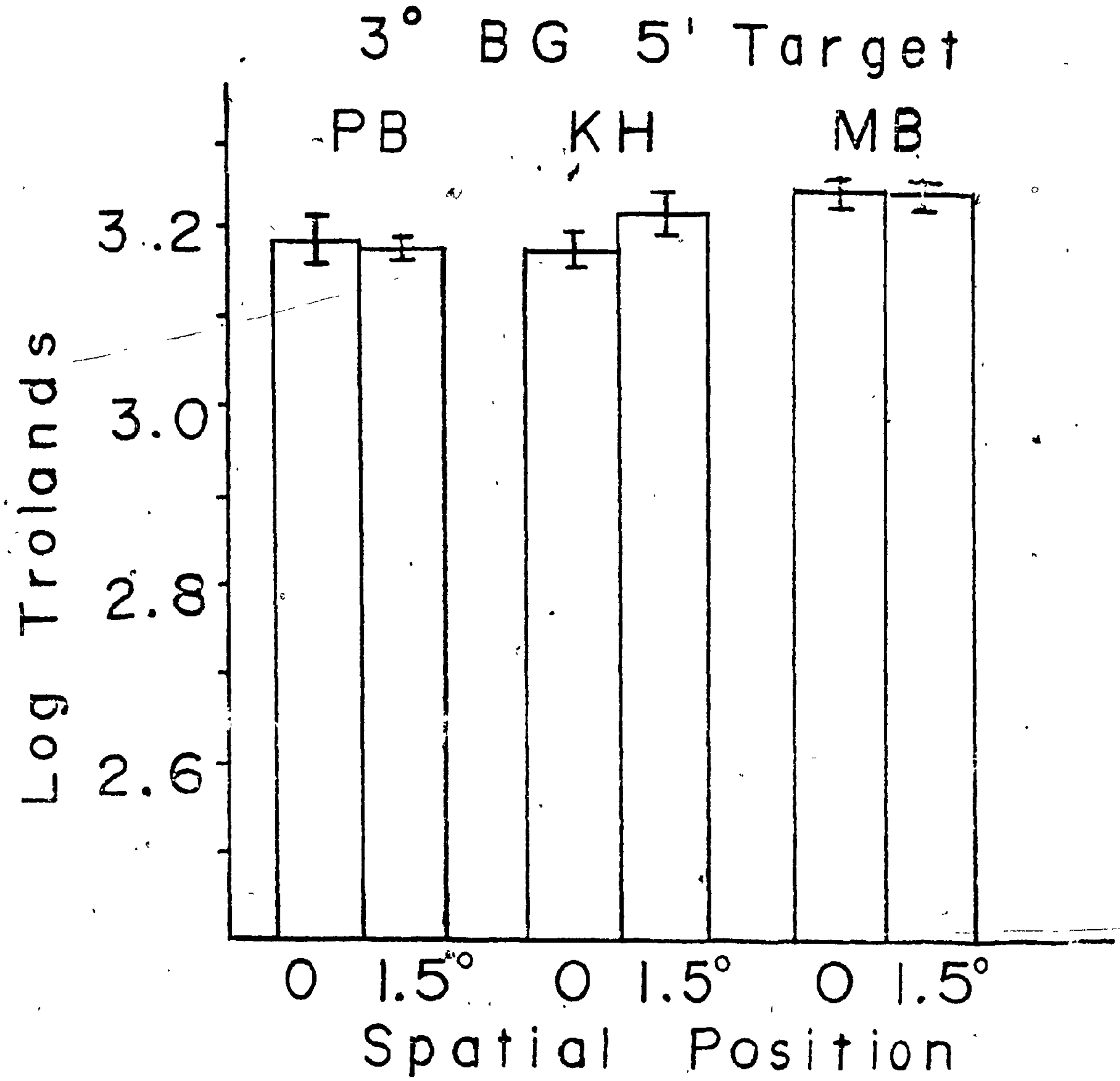


Figure 6. Increment thresholds for a 5min diameter test flash measured at two spatial positions, 0 and 1.5 degrees from the center of a 3 degree diameter background stimulus.

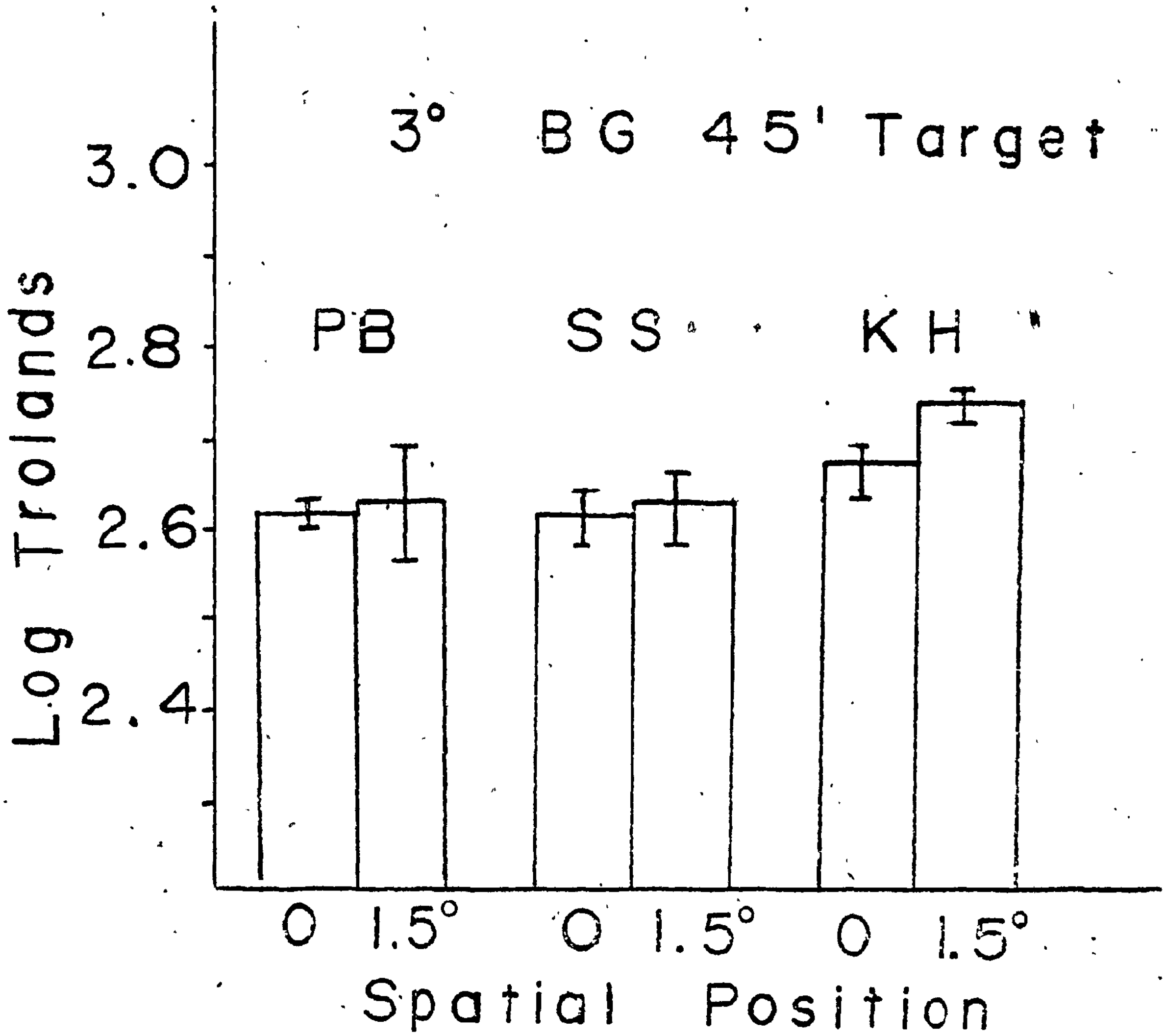


Figure 7. Increment thresholds for a 45 min diameter test flash measured at two spatial positions, 0 and 1.5 degrees from the center of a 3 degree diameter background stimulus.

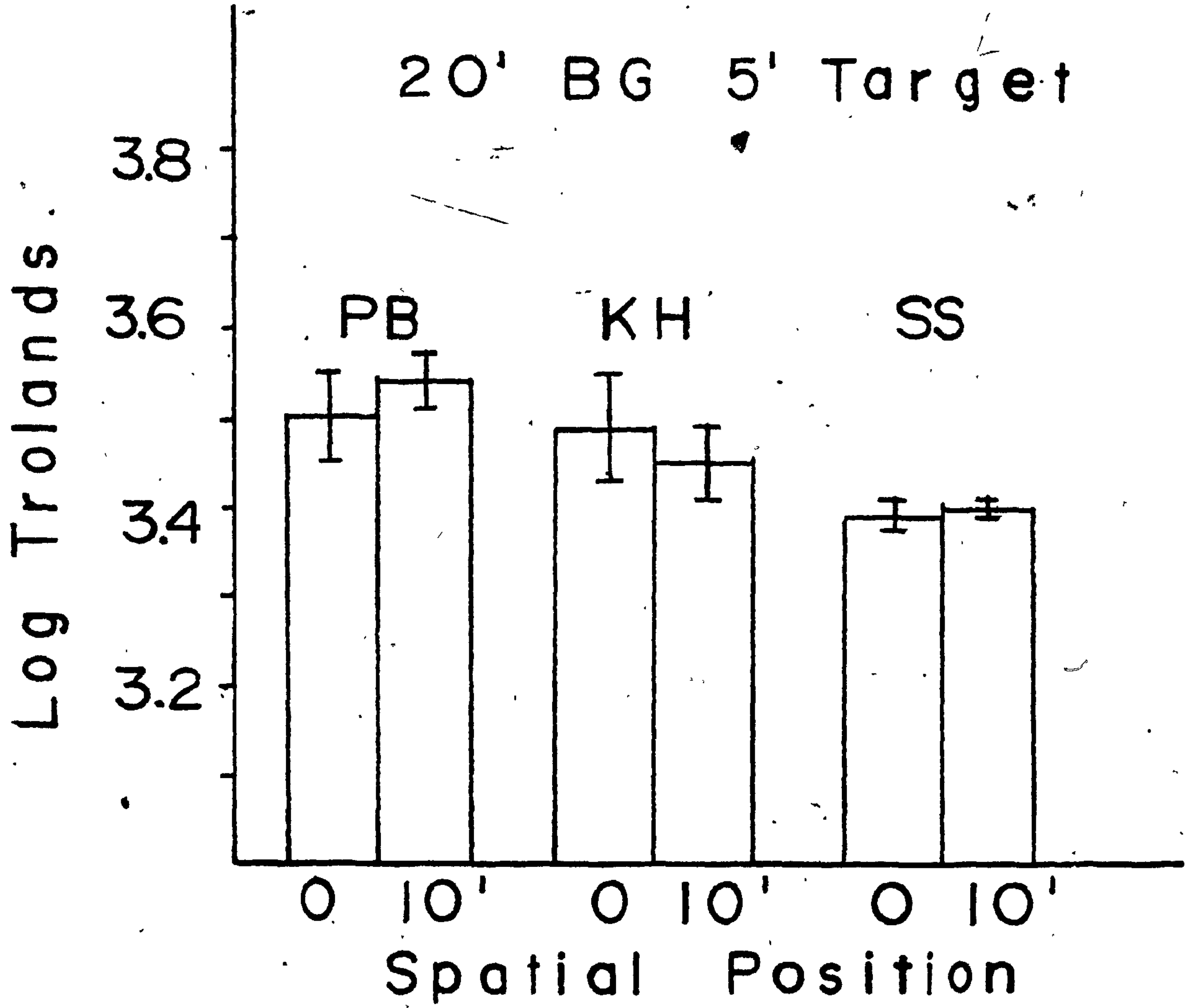


Figure 8. Increment thresholds for a 5 min diameter test flash measured at two spatial positions, 0 and 10 minutes from the center of a 20 min diameter background stimulus.

However, a comparison of the thresholds obtained with the 5 min test flash indicates that the magnitude of the edge effect is not determined by test flash size alone either. An edge effect is found when the sensitivity to the 5 min test flash is assessed on the 6 degree diameter background. However, when the sensitivity to the same 5 min test flash is assessed against the 20 min or 3 degree diameter background there is no evidence of a decrease in sensitivity near an edge. Whether one will observe threshold elevation near an edge appears to depend upon both the background and test flash sizes. Since threshold elevation was only evident in one condition of Experiment 1, the effect appears to be specific to a small test flash and a large background stimulus.

Although the absence of an edge effect with the small background stimulus at an SOA of zero of this experiment replicates the finding of Petry & Hood (1978), it is also true that neither of these results is compatible with those of Burkhardt (1966). Burkhardt did find threshold elevation near an edge with a small (44 min) background stimulus. A crucial difference between these studies and Burkhardt's was the exposure duration of the background stimulus. While in the present study and that of Petry & Hood the background stimuli were flashed briefly (40 and 8 msec respectively); Burkhardt employed a background duration of 1 second. A comparison of the three experiments suggests that with a small background stimulus one will fail to find threshold elevation near an edge unless the background duration is long. The present data from the 20 min condition in conjunction with the data from Petry & Hood show that for small, brief background stimuli there is no threshold elevation near an edge with simultaneous onsets of the stimuli.

It is interesting to note, however, that the absence of threshold elevation near an edge in Experiment 1 was not restricted to the smallest background stimulus. No change in the increment threshold as a function of spatial position was evident in the 3 degree background condition either. This is particularly surprising since a 3 degree background has been employed previously and has yielded an edge effect (e.g. Wildman, 1974). Although Wildman reported an edge effect for a 3 degree background stimulus presented continuously, none was evident when the background was exposed for 2 msec. This suggests that in this experiment an edge effect in the 3 degree background condition was missed by choosing too short a background duration (40 msec).

If the results of the 3 degree condition of Experiment 1 are a consequence of the background exposure duration then it is clear in light of the 6 degree finding of Experiment 1, that the increment threshold edge effect is dependent upon both spatial and temporal parameters. By manipulating background size, an edge effect can apparently be produced under the particular temporal conditions of Experiment 1. When the 3 degree disk is flashed briefly (40 msec) and simultaneously with a 5 min test flash, thresholds at the center and edge were similar. The same brief, simultaneous presentation of a 6 degree disk with the 5 min test flash yields sensitivity differences at the center and edge. It is clear that if either a manipulation of the spatial or temporal parameters in a condition where no edge effect was otherwise present results in an edge effect then there exists a spatial and temporal interaction in the determination of the magnitude of the increment threshold edge effect.

Experiment 2

An edge effect was absent in a condition of Experiment 1 where one might have been expected on the basis of previous results (e.g. Wildman,1974). Although Wildman (1974) reported an edge effect on a 3 degree diameter, none was evident for the 3 degree background of Experiment 1. As argued earlier, this finding might be accounted for on the basis of the background exposure duration.

The idea that background exposure duration is an important variable is reinforced by the following points. Firstly, edge effects on the high side of an edge are often explained as resulting from neural interactions such as lateral inhibition. Lateral inhibition is a neural interaction that operates between regions that are separated spatially on the eye. The frequency of neural firing is reduced by inhibitory input from a neighbouring cell which exhibits a high level of firing. Lateral inhibition has been demonstrated in the Limulus eye by Hartline (1949); and also in the mammalian eye by Kuffler, (1953). For the high side edge effect, lateral inhibition is assumed to be responsible for increased activity levels near an edge. Neural firing is thought to be higher for those elements at the edge since they receive less inhibition from neighbouring units which are responding to the adjacent area of lower luminance. The high side edge effect reflects a relative lack of inhibition at the edge as compared with that at the center. At the center the neighbouring units are responding to areas of higher luminance and thus these units exert more lateral inhibition upon the central area where thresholds are being measured. The increased increment threshold at the edge is presumed to be a consequence of a relative lack of inhibition at the edge. There are many electrophysiological results showing that inhibition takes place only after some delay (e.g. Eccles, 1964). The assumption that background duration is a significant factor in the determination of the edge effect is consistent with the fact that lateral inhibition takes time to develop. Secondly, there is direct empirical evidence that the mechanism responsible for the edge effect takes time to develop. Limb and Tulunay-Keesey (1981) have reported that the edge effect builds up over a period of approximately 75 msec. Thirdly, Novak & Sperling (1963) and Matthews (1966) have demonstrated an edge effect dependence upon background exposure duration. Novak & Sperling report no edge effect when the background duration is 10 msec, but they do begin to see an edge effect at 50 msec duration and report that the effect is fully developed when the background exposure is 500 msec. Similarly, Matthews reports no edge effect at 2 msec but does find one if the background duration is increased to 100 msec or is presented continuously.

A critical difference between Experiment 1 and those of Novak & Sperling (1963) and Matthews (1966) is that in Experiment 1 the interval between trials was dark. The inter-trial interval (ITI) in the Novak & Sperling and Matthews' experiments was lit. Although they have demonstrated that the edge effect is dependent upon background duration, their results may be specific to a lit ITI. It is necessary to determine if the edge effect is dependent upon background duration when the ITI is dark as well.

The aim of Experiment 2 was to determine if the results of the 3 degree condition could be attributed to background exposure duration. It involved an investigation of center and edge thresholds accompanied by a systematic increase in background diameter. The increment threshold for a small probe stimulus (5 min) was measured at the center and at the edge of the 3 degree diameter background stimulus for a number of background exposure durations.

Method

Subjects

Two of the observers from Experiment 1, S.K. and P.B., participated in this experiment.

Apparatus and Stimuli

The apparatus used in Experiment 2 was the same Maxwellian view optical system described previously (Fig.2). The 5 min diameter and the 3 degree diameter stimuli from Experiment 1 were used in this experiment.

Procedure

The procedure was identical to that employed in Experiment 1. The only difference involved the background exposure durations. These were 40, 100, 150, 200,and 250 msec. In addition the increment thresholds were assessed on a continuous background.

Results and Discussion

No change in the increment threshold as a function of spatial position was evident for either subject when the background duration was 40 msec. This replicates the data for the 3 degree condition of Experiment 1. When the background exposure duration was increased to 100 msec there was an increase in the increment threshold at the edge as compared to the center for both subjects. Threshold elevation at the edge was present for all other background exposure durations investigated. The magnitudes of the edge effect at all durations beyond 40 msec were similar. For one observer, S.K., the magnitude was approximately 0.1 log unit higher on the continuous background than for the other durations. For both observers, the center thresholds did not appear to change as a function of the background duration. For both observers the thresholds measured at the center of the background stimulus remain fairly constant as exposure duration is increased. The results for Experiment 2 are plotted in Figures 9 and 10.

The results of this experiment suggest that the absence of threshold elevation near the edge of the 3 degree background in Experiment 1 was due to the background exposure duration. In Experiment 1 no edge effect was found with a 40 msec background exposure duration of either a 3 degree or a 20 min disk. These results confirm the hypothesis that at least in the 3 degree condition an edge effect was missed by choosing too short an exposure duration in Experiment 1. These data indicate that the same effect of exposure duration that has been noted in experiments employing lit ITIs (Novak & Sperling, 1963; and Matthews, 1966), is present when the ITI is dark.

As indicated earlier there is an additional consideration in these experiments; that of the general luminance level of the ITI. Although the results of Experiment 2 clearly show that the background exposure duration is a critical determinant of the edge effect even when the ITI is dark, it is likely that the general state of light adaptation also contributes to the determination of the edge effect. It has been shown that the magnitude of lateral inhibition is attenuated in the dark (e.g. Barlow, Fitzhugh & Kuffler, 1957). Assuming that edge effects are a consequence of an increase in neural activity near an edge as a direct result of decreased lateral inhibition, relative to that exerted at the

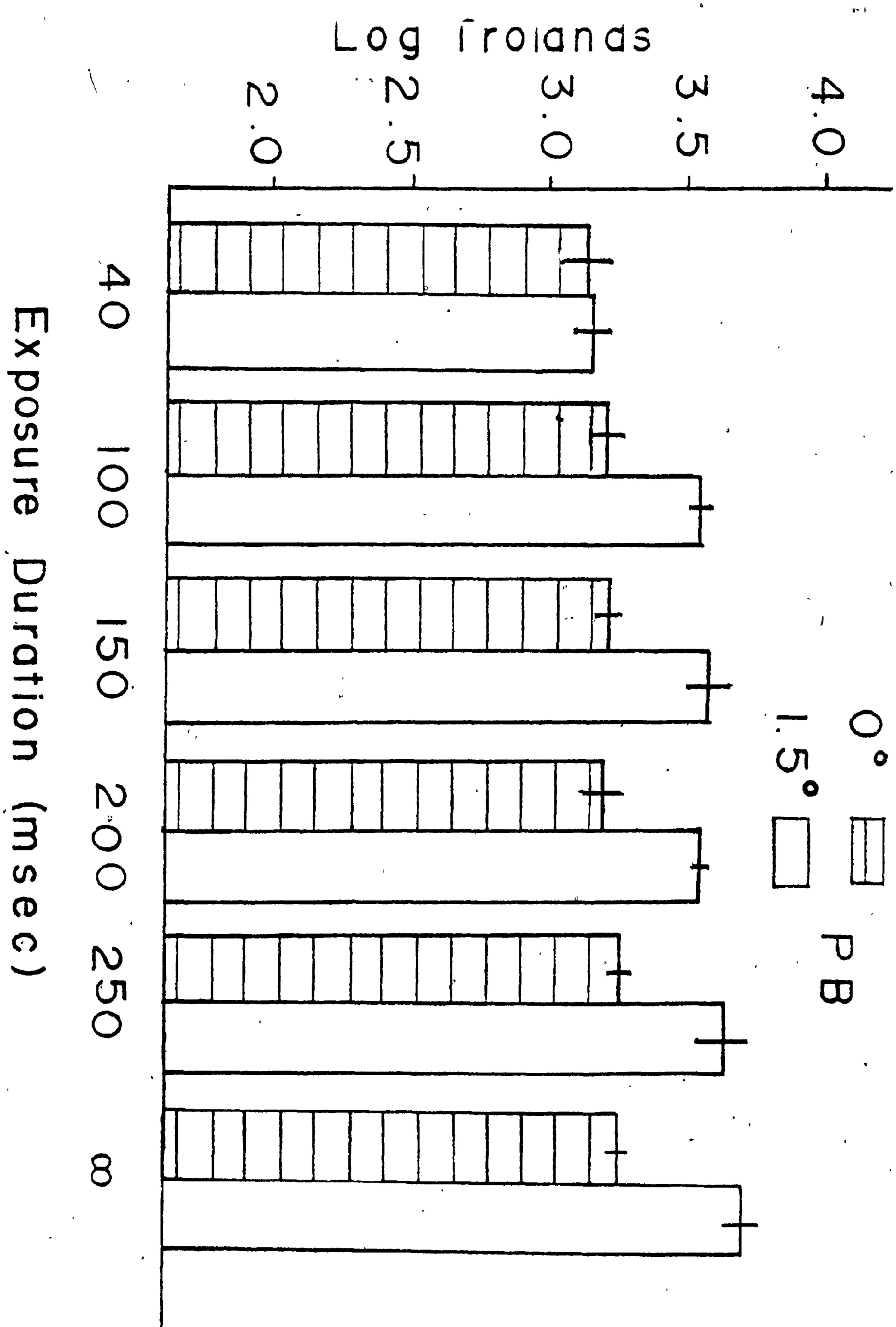


Figure 9. Increment thresholds for a 5 min test flash measured at two spatial positions, 0 and 1.5 degrees from the center of a 3 deg. background as a function of exposure duration.

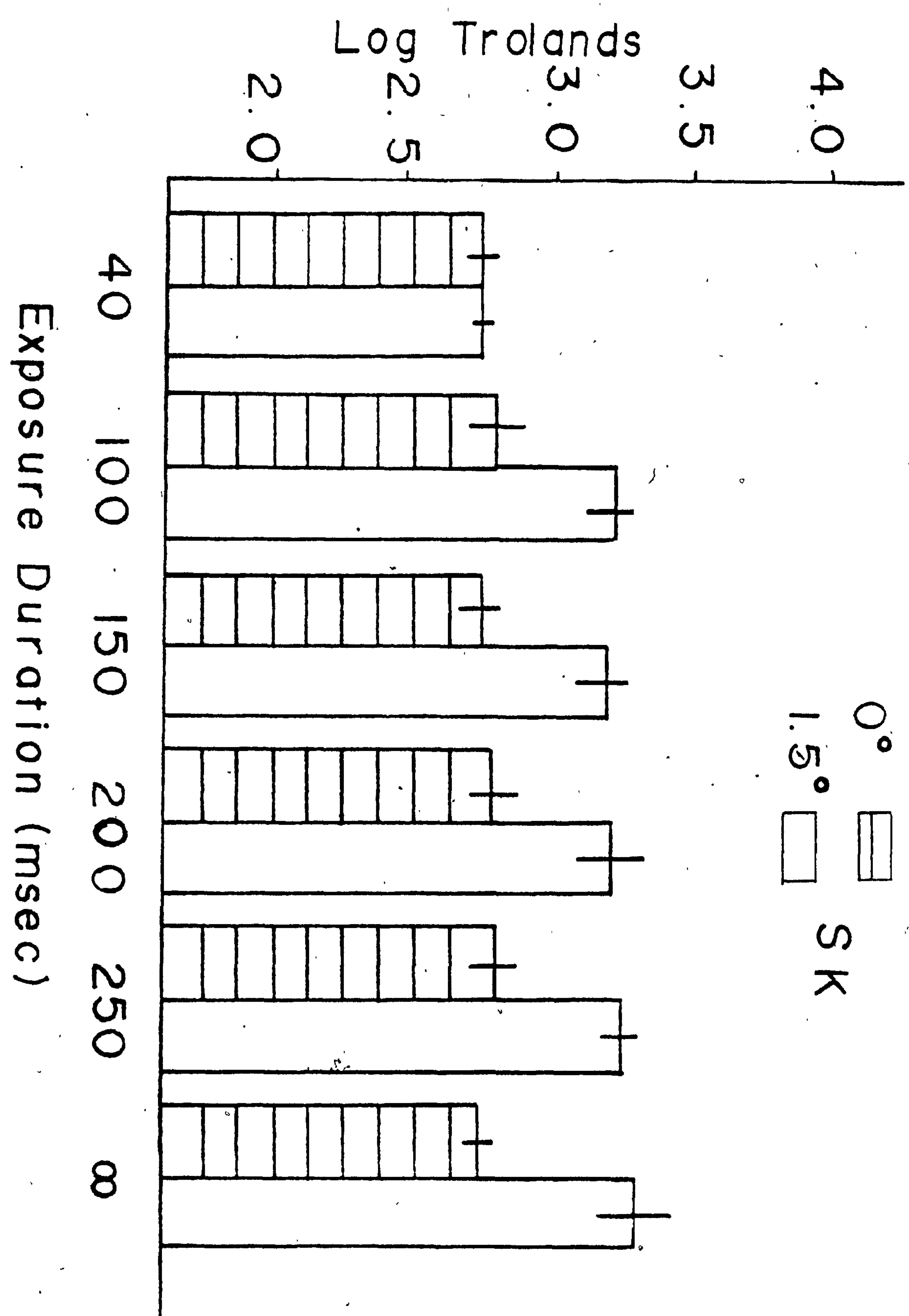


Figure 10. Increment thresholds for a 5 min test flash measured at two spatial positions, 0 and 1.5 deg. from the center of a 3 deg. background as a function of the exposure duration.

center, this suggests that the probability of finding an edge effect increases with increases in light adaptation. A greater amount of lateral inhibition will be associated with more light adapted conditions. Perhaps the critical duration below which one will not find an edge effect in the dark-adapted eye is higher than that for a more light-adapted eye. It would follow from this that with briefly presented backgrounds the likelihood of obtaining an edge effect increases if the ITI is lit rather than dark. This cannot be easily verified by a comparison of experiments employing lit and dark ITIs since such a comparison will be confounded by other variables. For example, an experiment which reported an edge effect with an 18 msec background duration (Petry et al 1973) and a lit ITI used a larger background stimulus than that of Experiment 1, where an edge effect was reported for a 40 msec presentation of the stimuli and a dark ITI.

What is being suggested is that, all other things being equal, the minimum background exposure duration that will yield an edge effect in the light adapted eye will be lower than that found in the dark adapted eye. At long background durations in the dark adapted eye, the eye becomes adapted to the luminance level of the background stimulus. The longer the background duration, the more light adapted the eye will become. It also follows that the shorter the background duration, the less light adapted the eye will become. In a condition in which the ITI is dark, the general source for lateral inhibition is the background stimulus. As the background duration is lowered, lateral inhibition decreases. Eventually some critical duration will be reached at which the contribution of lateral inhibition is not sufficient to produce the increased neural activity associated with the edge effect. At or below this duration no edge effect will be present. However, in a condition which employs a lit ITI the magnitude of lateral inhibitory influences stems not only from the background duration but also from the adapting stimulation present between trials. For a duration at which the contribution of lateral inhibition is not sufficient to produce the increase in neural firing associated with edge effects, an edge effect may still be obtained since the added contribution of lateral inhibition from the adaptation field suffices to produce the increased neural activity necessary to observe an edge effect.

Taken together Experiments 1 and 2 point to the importance of both spatial and temporal background parameters in the magnitude of the increment threshold edge effect. When test flash and background onsets are simultaneous, background size and duration determine edge effect magnitude. In both experiments there was no evidence of threshold elevation near the edge of a 3 degree background field exposed for 40 msec. In Experiment 1 threshold elevation at the edge was obtained by increasing background diameter. In Experiment 2 threshold elevation at the edge was obtained by increasing the background exposure duration.

The results of these experiments point to the presence of a spatial and temporal interaction in the determination of the edge effect. It would appear that the larger the background stimulus diameter, the lower the minimum exposure duration at which one will find an edge effect. For example, with a 6 degree diameter background stimulus 40 msec is above the minimum duration at which an edge effect will be present; but 40 msec is below the minimum duration for obtaining an edge effect on a 3 degree diameter background. We can assume from the results of Experiment 2 that this minimum duration for the 3 degree diameter background is somewhere between 40 and 100 msec.

The results thus far indicate that when test flash and background stimuli are presented simultaneously, whether or not an edge effect will be observed is the result of an interaction between spatial and temporal parameters. Experiment 1 clearly demonstrated the dependence of the edge effect upon background and test flash sizes. In Experiment 2 the dependence upon background exposure duration was exemplified. The evidence for an interaction of the spatial and temporal parameters is derived from the fact that an increase in either of these parameters was sufficient to produce an edge effect in a given condition in which an edge effect was otherwise absent.

Experiment 3

It is clear from the combined results of Experiments 1 and 2 that when test flash and background onsets are simultaneous background size and duration play a large role in determining the magnitude of the edge effect. In Experiment 1 it was shown that an edge effect can be produced under conditions where none was evident simply by increasing the background diameter from 3 to 6 degrees. In Experiment 2 it was shown that an edge effect could be produced by increasing background duration, while maintaining a particular spatial relation.

Up to this point the discussion has centered around data for simultaneous presentations of the target and background stimuli. In an investigation of the reported absence of edge effects with brief background presentations Petry, Hood & Goodkin (1973) have demonstrated that temporal separation between the onsets of a test flash and background stimulus (stimulus onset asynchrony or SOA) is also an important parameter. When the test flash onset precedes the background onset the SOA is negative, when the background onset precedes the test flash onset the SOA is positive. Their data revealed that the magnitude of the edge effect for a briefly presented background stimulus is highest at a nonzero SOA. That is, a test flash presented 50 msec after the edge resulted in a larger edge effect than a test flash temporally coincident with the edge. These data suggest that in the 3 degree background condition of Experiment 1 perhaps an edge effect was missed by the choice of SOA as well as by the choice of exposure duration.

The potential importance of SOA is consistent with the idea that the mechanism responsible for the edge effect takes time to develop. If this is the case, then probing for sensitivity at a positive asynchrony should enhance the probability of observing an edge effect. Limb and

Tulunay-Keesey (1981) examined the buildup of the edge effect by plotting the temporal course of an increment threshold measured at various locations relative to an edge which was presented for 500 msec. The test flash was presented for 16.7 msec at various times relative to the onset of the edge, SOAs of 0 msec, 50 msec,and 200 msec. The spatial positions varied from 1 min to 40 min away from the edge. They found that the threshold increased over a period of 75 msec and that a steady value was reached after 100-150 msec.

There have been a few other experiments which have investigated edge effects as a function of the stimulus onset asynchrony. Limb and Tulunay-Keesey (1981) found that an edge effect was present at all SOAs investigated in an experiment in which an edge was created by briefly increasing the luminance in one-half of the background field. However, in this particular experiment the choice of SOAs was limited to five nonzero SOA values. Burkhardt (1966) has reported that edge effect magnitude does not change as a function of SOA. Since the SOA intervals chosen by Burkhardt were 100 msec, the results are not directly comparable to the results of others (e.g.Petry, Hood & Goodkin, 1973; Limb & Tulunay-Keesey, 1981).

Petry & Hood (1978) also measured increment thresholds at the center and edge of a briefly presented background as a function of SOA. Their SOA functions at the center and edge for two observers do not reveal reliable differences between center and edge measurements which would suggest a robust edge effect. For the most part, their center and edge threshold curves for this condition overlap. In a comparison of the Petry & Hood (1978) experiment with that of Petry, Hood & Goodkin (1973) a difference in background size is evident. Petry & Hood flashed a small 36 min diameter background stimulus for 8 msec. Petry, Hood &

Goodkin (1973) flashed a large 4 x 10 degree background stimulus for 18 msec. Both background duration and size have already been determined as contributing factors in edge effect magnitude. Although the background durations in these two experiments are different, it is unlikely that a difference of 10 msec is responsible for the difference in their results.

Experiment 3 was designed to further investigate the effect of SOA on the magnitude of the edge effect by measuring center and edge thresholds as a function of SOA against variable diameter background stimuli.

Method

Subjects

The two observers from Experiment 2, and a third observer, S.S., who participated in Experiment 1 were the observers in this experiment.

Apparatus and Stimuli

The apparatus and stimuli used in Experiment 3 were the same as those of Experiments 1 and 2.

Procedure

The general procedure employed in Experiment 3 was similar to that of the previous two experiments. Increment thresholds were measured at the center and edge of three different background stimuli. The background diameters used were 40 min, 3 and 6 degrees. The target stimulus was 5 min in diameter and all stimuli were flashed for 40 msec. The following stimulus onset asynchrony values were used:

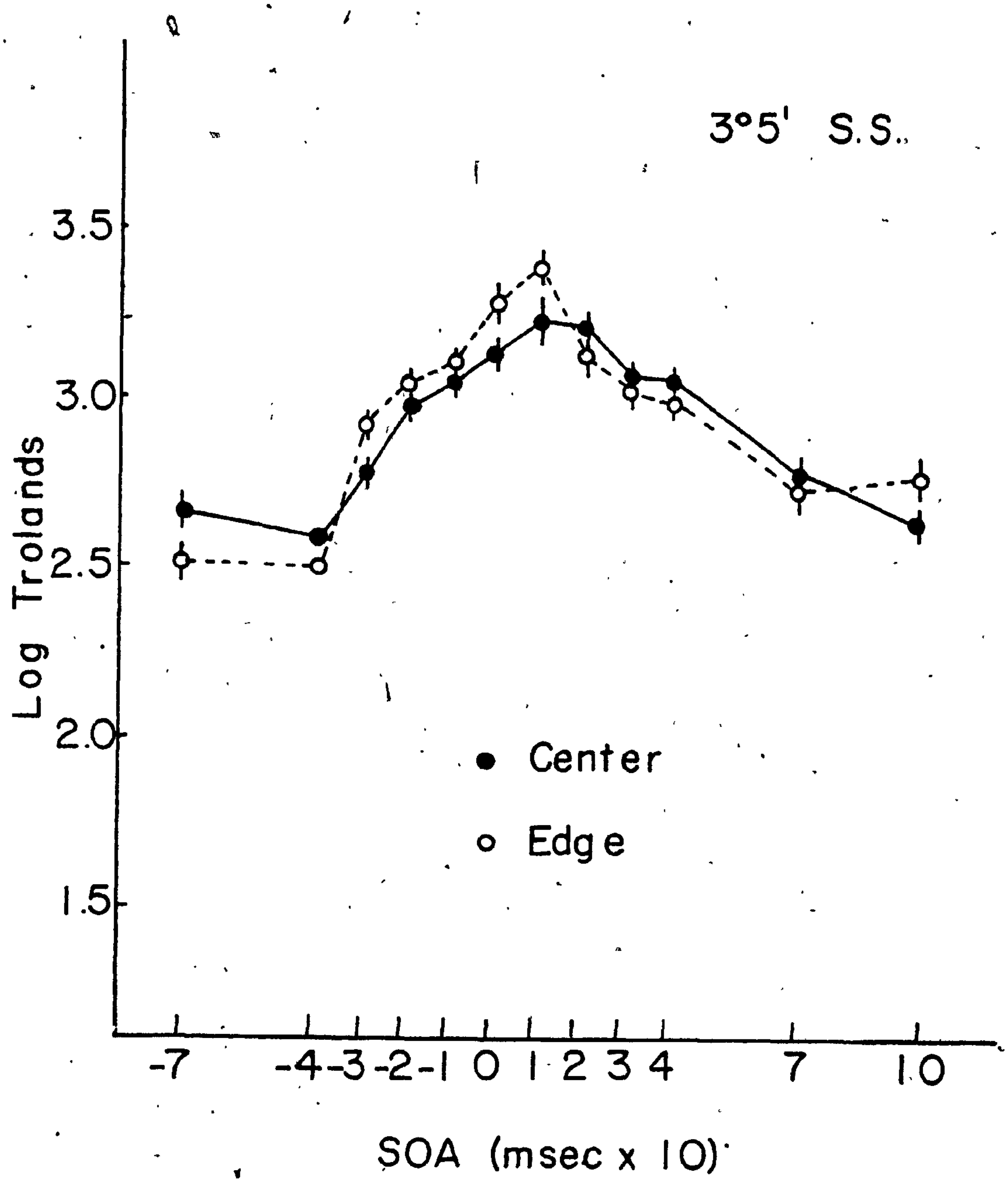


Figure 11. Increment thresholds for a 5 min test flash measured at the center and edge of a 3 degree diameter background stimulus as a function of stimulus onset asynchrony for subject S.S.

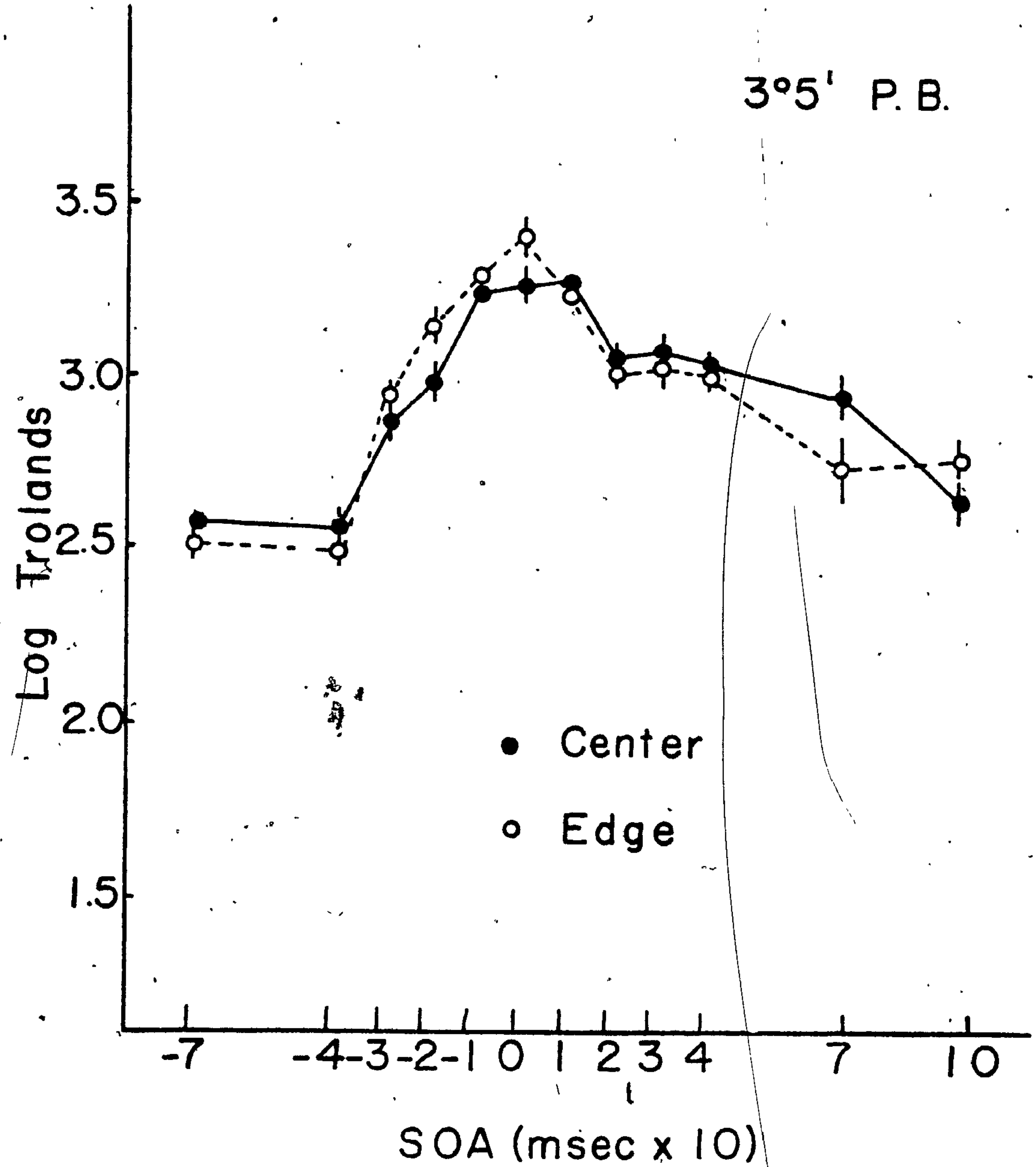


Figure 12. Increment thresholds for a 5 min test flash measured at the center and edge of a 3 degree background stimulus as a function of the stimulus onset asynchrony between the test flash and background for subject P.B.

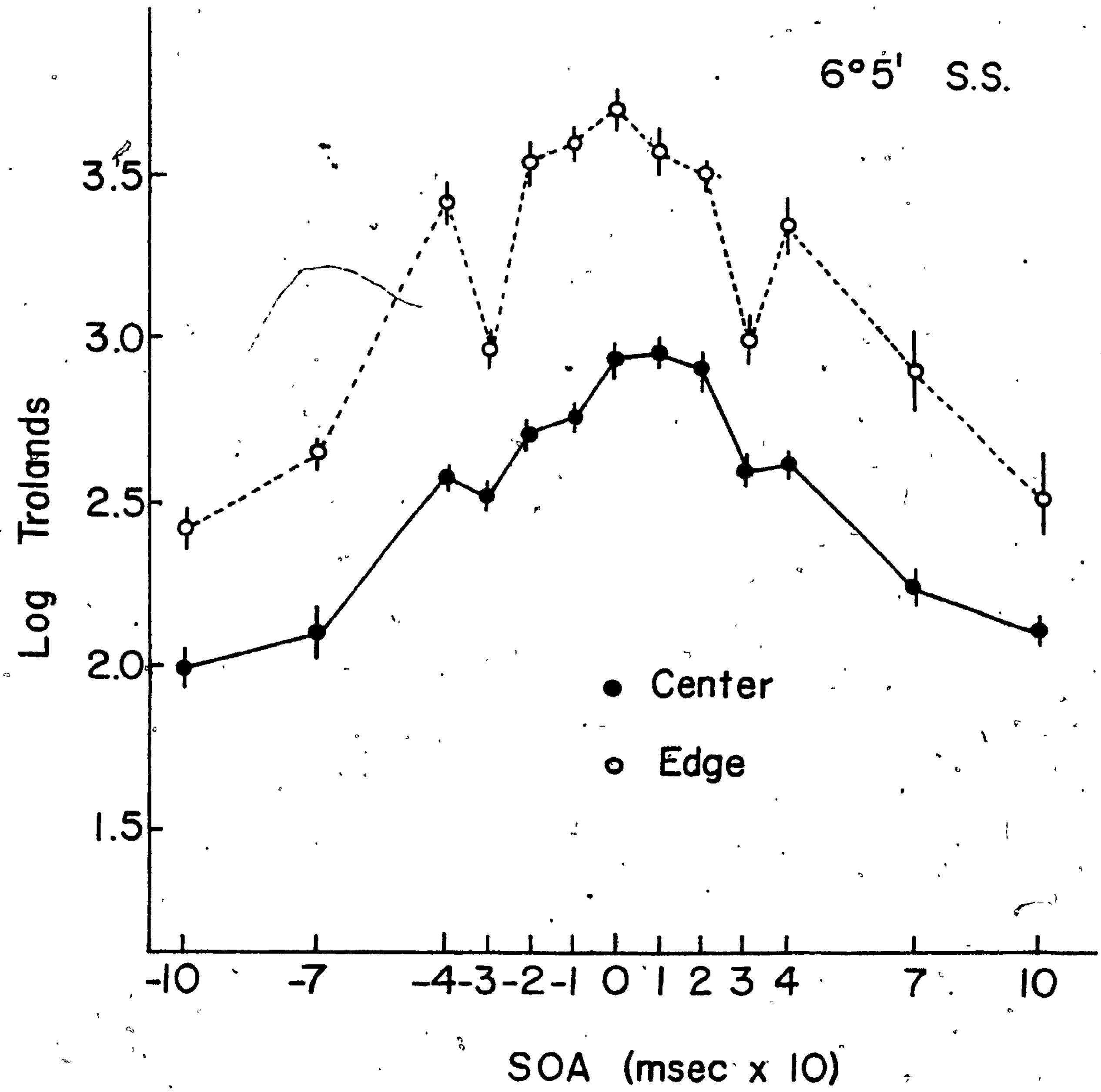


Figure 13. Increment thresholds for a 5 min test flash measured at the center and edge of a 6 degree diameter background stimulus as a function of stimulus onset asynchrony for subject S.S.

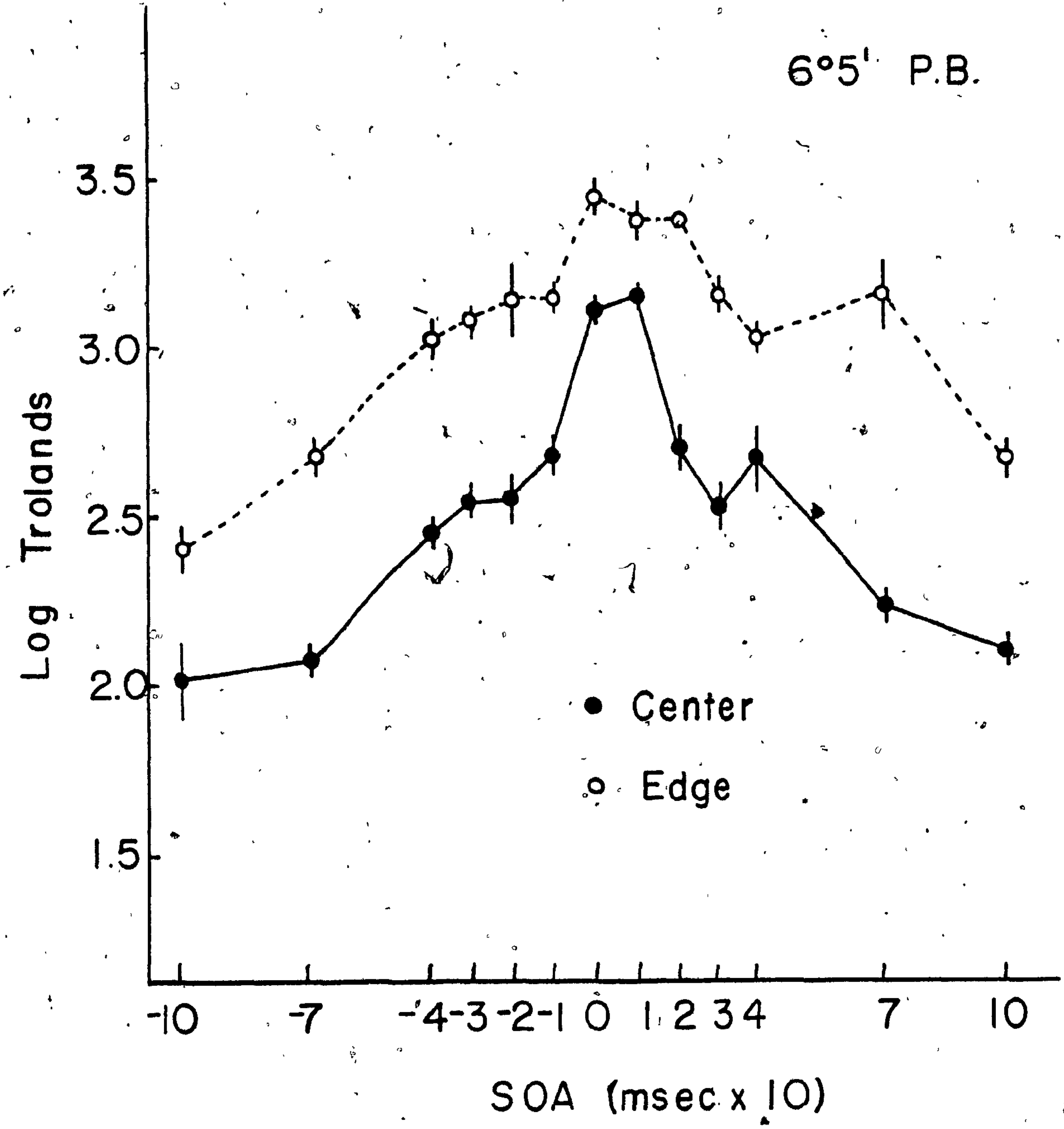


Figure 14. Increment thresholds for a 5 min test flash measured at the center and edge of a 6 degree background stimulus as a function of stimulus onset asynchrony for subject P,B.

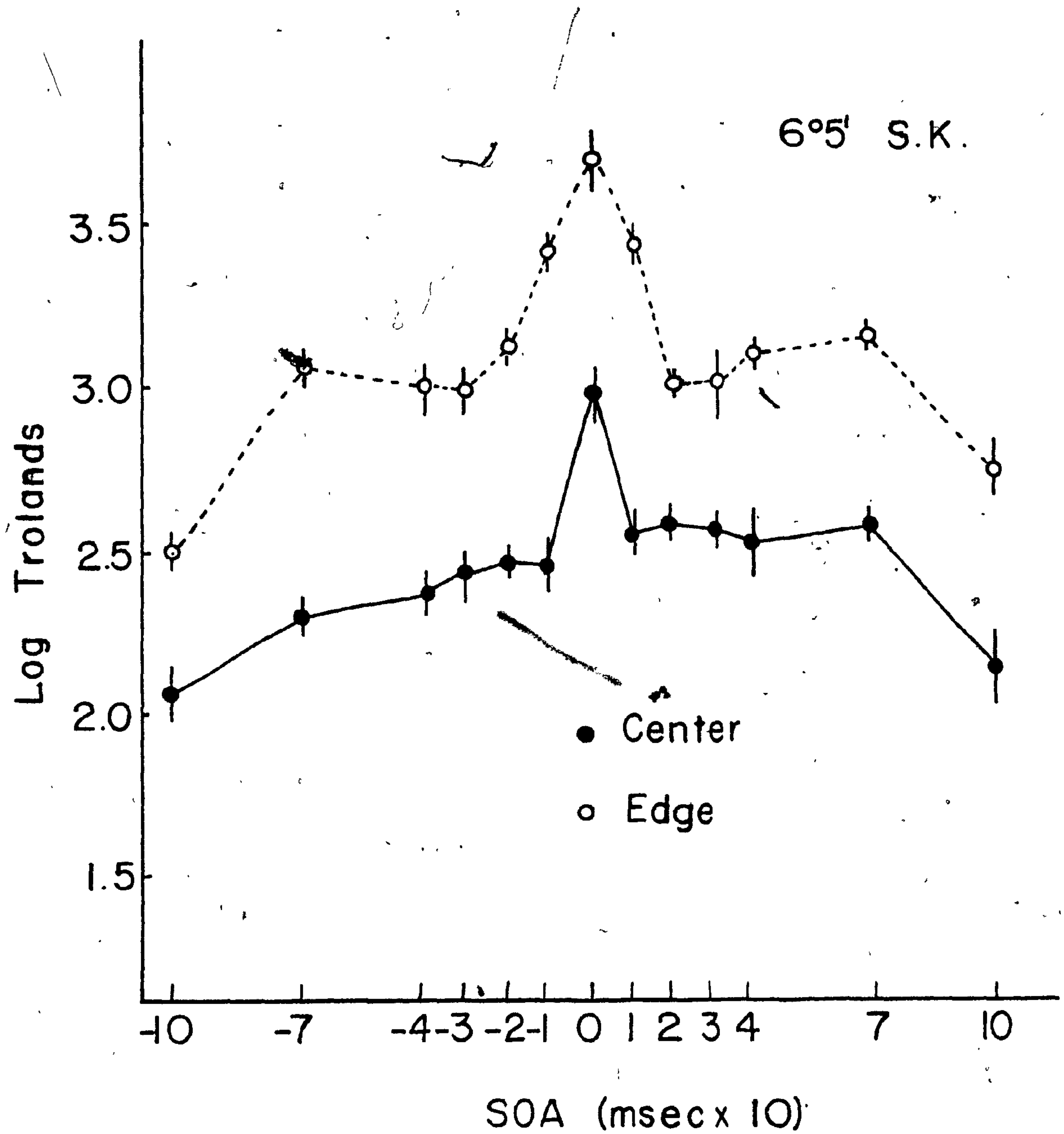


Figure 15. Increment thresholds for a 5 min test flash measured at the center and edge of a 6 degree background stimulus as a function of stimulus onset asynchrony for subject S.K.

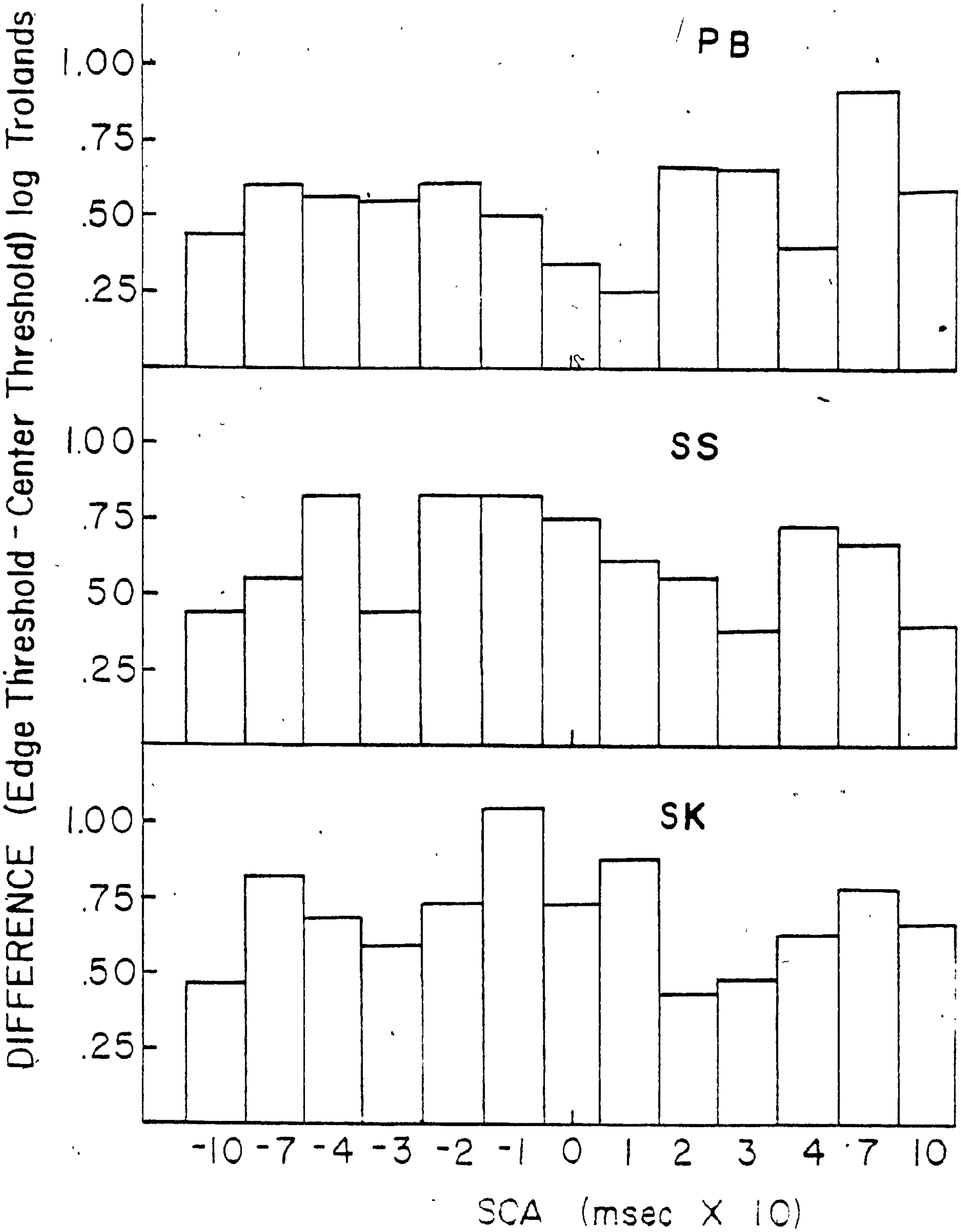


Figure 16. The data from Figures 13, 14 and 15 have been replotted here. The bars represent the difference between thresholds measured at the edge and the center of the 6 degree background stimulus as a function of stimulus onset asynchrony (SOA).

-100,-70,-40,-30,-20,-10, 0, +10, +20, +30, +40, +70 +100 msec. The stimulus onset asynchrony is negative when the test flash onset precedes the background onset; it is positive when the background onset precedes the test flash onset.

Results

The SOA functions obtained at the center and edge of the 3 degree background field reveal similar shapes. The data from this condition for two observers, are plotted in Figures 11 and 12. It can be seen from these figures that the evidence of threshold elevation near the edge for any of the SOA values examined is weak at best. Considering the number of points, the occasional lack of overlap between standard errors would be expected due to chance variation.

The SOA functions obtained at the center and edge of the 6 degree background are plotted in Figures 13, 14 and 15. For all three observers thresholds obtained at the edge were higher than those obtained at the center at all SOA values. For observer S.S. the range of the differences between the center and edge was from 0.27 to 0.80 log trolands. A maximum edge effect was observed at an SOA of -40 and the smallest edge effect was obtained at +30. The range of edge effect magnitude for observer P.B. was from 0.25 to 0.75 log trolands. A maximum edge effect was observed at an SOA of +70, while the minimum was observed at an SOA of +10. For observer S.K. the range of edge effect magnitude was between 0.38 and 1.12 log trolands. Maximum edge elevation occurred at -10 and the minimum at an SOA of +20.

The SOA functions obtained at the center and edge of the 40 min background are plotted in Figures 17, 18 and 19. The SOA functions obtained at the center of this background disk were higher than those

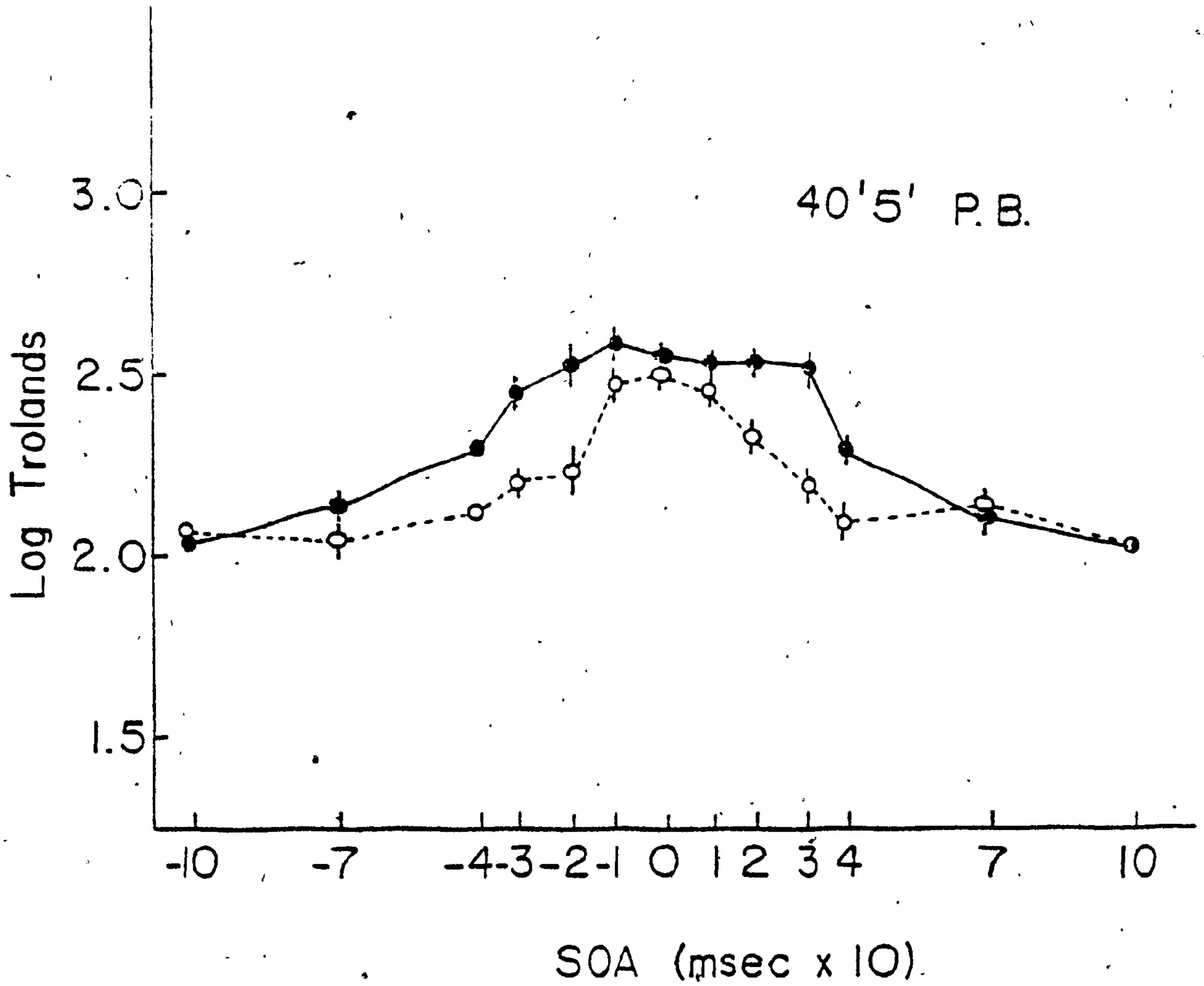


Figure 17. Increment thresholds for a 5 min test flash measured at the center and edge of a 40 min diameter background stimulus as a function of stimulus onset asynchrony for subject P.B.

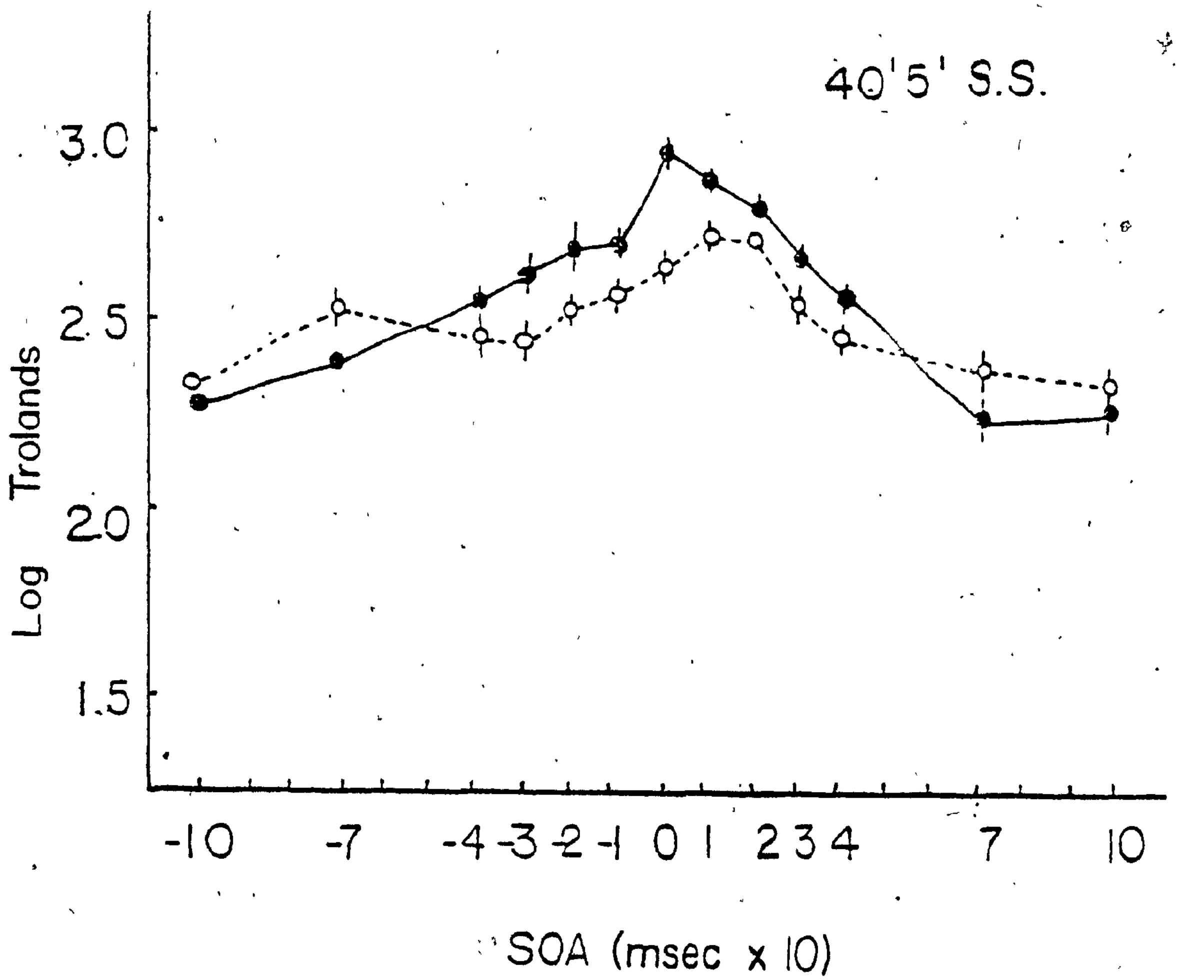


Figure 13. Increment thresholds for a 5 min test flash measured at the center and edge of a 40 min diameter background stimulus as a function of stimulus onset asynchrony for subject S.S.

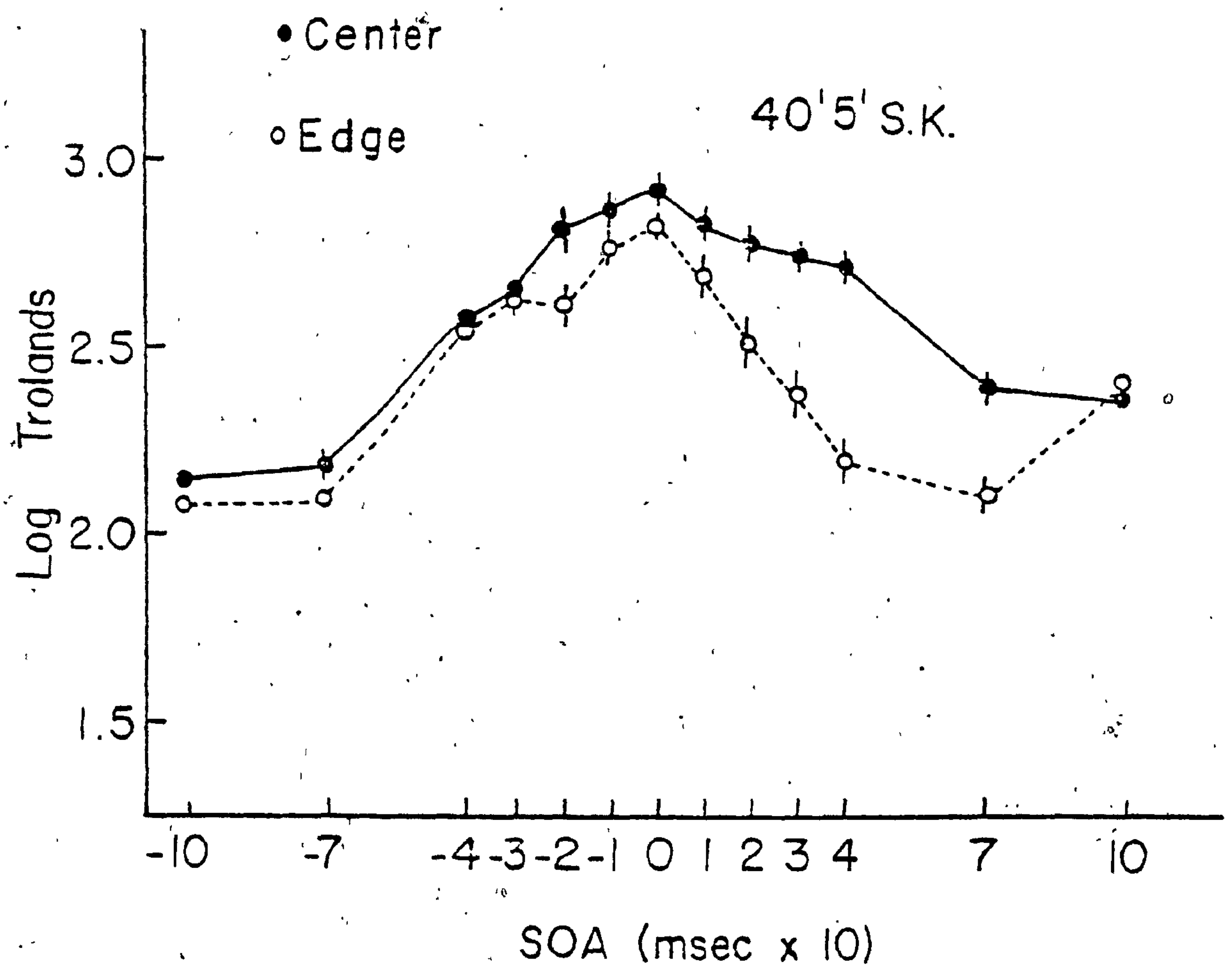


Figure 19. Increment thresholds for a 5 min test flash measured at the center and edge of a 40 min background stimulus as a function of stimulus onset asynchrony for subject S.K.

obtained at the edge for all three observers at most of the SOA values examined in this condition. This is a reversal of the edge effect. For observer S.S. the center thresholds were higher at all SOA values except +70, +100, -70 and -100. The difference scores ranged from .05 to .18, with the maximum difference obtained at an SOA of 0, and the minimum at an SOA of +100. For observer P.B. the center thresholds were higher at all SOAs except +70, and -100. The range of the differences was from .01 to 0.15. The maximum difference was obtained at +30 and the minimum at +100. For observer S.K. the center thresholds were higher than those at the edge for all SOAs except +100. The range of difference scores was from .02 to .50. The maximum difference was obtained at +40, and the minimum at +100.

Discussion

It would appear from the results of Experiment 3 that the magnitude of the edge effect is not always dependent upon the stimulus onset asynchrony of the test and background stimuli. The data from the 3 degree background condition at an SOA of zero replicate the results of Experiment 1 and Experiment 2; that there was no evidence of an edge effect when measuring the sensitivity to a small test flash against a briefly (40 msec) presented 3 degree background. The SOA functions found in this condition are similar to those reported by Petry & Hood (1978) in that the curves for the center and edge for the most part overlap. There was no change in the magnitude of the edge effect as a function of SOA and as such these results indicate that the absence of an effect for a brief, 3 degree background stimulus is not specific to an SOA of zero.

Edge effects were present for all SOAs when the background stimulus was a 6 degree diameter disk. It is necessary to examine the SOA functions for this condition closely to determine the effects of SOA on the magnitude. Petry et al (1973) reported that maximum threshold elevation at the edge occurred at an SOA value of +50 msec, which indicates threshold elevation at the edge after the cessation of their 18 msec background. In the present experiment the SOA which is closest to the SOA of +50 in the Petry et al experiment is an SOA of +70. For Petry et al an SOA of +50 was a threshold measurement 32 msec after background offset. The SOA of +70 in the present case measures thresholds 30 msec after the offset of the 40 msec background stimulus. To determine if the present results are consistent with those reported by Petry et al one must look at the relative magnitude of the edge effect at the +70 SOA. The "edge effect" magnitudes (center-edge differences) are replotted in Figure 16. Maximum edge effect magnitude for one observer (P.B.) was in fact obtained at +70 msec. It is evident from Figure 16 that the smallest edge effects for this same observer were around an SOA of zero (+10, and 0). The results for this observer do appear to be consistent with the results reported by Petry, Hood & Goodkin (1973). Maximum edge elevation for the other two observers in this experiment was present at negative asynchrony values (-10 and -40 msec). The edge effect for the +70 SOA for these two observers was near the maximum magnitude of edge elevation. For observer S.S. the edge effect magnitude was 0.80 log trolands at its maximum and 0.65 at +70. For observer S.K. it was 1.12 log trolands at its maximum and 0.65 at +70. It can be seen from Figure 16 that the minimum edge effect magnitudes for these two observers, S.S. and S.K., were not centered around an SOA of 0 as they were for P.B. Although the functions relating edge effect magnitude and SOA for this condition do not confirm the details of the findings of Petry et al (1973) the general results do. The magnitude of the edge effect does vary with the SOA of the test flash and background for all observers in this condition. As can be seen from Figure 16 although one can observe differential magnitude of the effect as a function of SOA, the edge effect does not vary in a consistent manner for all observers. Further, the results of this condition do not confirm Petry, Hood & Goodkin's (1973) hypothesis that maximum edge elevation will be observed after the cessation of the background.

Petry, Hood & Goodkin (1973) compared increment thresholds obtained when the test flash was positioned 3 min from the edge with thresholds obtained when the test flash was positioned 30 min from the high side of an edge for a number of SOAs which ranged from -50 to +50 msec. The thresholds measured 3 min from the edge were higher than those measured 30 min from the edge at SOAs of +30 and +50 msec. At the other SOAs there were no differences between the thresholds at these two spatial positions. Petry et al concluded that for brief duration backgrounds an edge effect will only be evident at positive stimulus onset asynchronies. In their experiment the increment threshold curves obtained when the increment spot was presented 30 and 50 msec after the onset of the edge stimulus clearly show a relative increase of the increment threshold at the edge. The curves obtained for the SOAs of -50, -30, -10, 0, and +10 msec do not show an increase in the increment threshold at the edge. It is on the basis of these results that they conclude that the edge effect is confined to positive stimulus onset asynchronies. However, it is not clear that the findings of Petry, Hood & Goodkin (1973) contradict the present finding that the edge effect is not confined to positive stimulus onset asynchronies. In order to determine whether or not there was a threshold rise near an edge Petry et al made a comparison between thresholds measured near an edge (3 min) with thresholds measured away from the edge (30 min). It is on the basis of this comparison that they conclude that there is no evidence of an edge effect at the SOAs of -10, 0 and +10. Their conclusion that the edge effect is confined to positive SOAs would be a valid one if a comparison could be made between increment thresholds measured near the edge (3 min) with increment thresholds obtained at some point further from the edge than 30 min. It is possible that an edge effect would have been evident had thresholds also been measured at some point beyond 30 min. The data from Petry, Hood & Goodkin for the SOAs of 0 and +10 have been replotted in Figure 20. Hypothetical data points have also been added to illustrate how the presence or absence of an edge effect could be further determined by the addition of data from increment thresholds measured at a point further from the edge than 30 min. If the increment threshold at a further point was similar to that measured 30 min from the edge, then one could conclude that there was no edge effect associated with those SOA values. However, if this threshold measurement was lower than that near the edge (3 min), or 30 min from the edge, there would be evidence for an edge effect since this would represent a relative increase in threshold near an edge. In the absence of these data one cannot choose between these two interpretations of their results. The possibility exists that an edge effect may have been evident in the Petry et al data for the near zero SOAs, if thresholds near the edge were compared with thresholds obtained further from the edge or those obtained in the absence of the edge.

Limb & Tulunay-Keesey (1981) conducted an experiment which corresponds closely to that of Petry et al (1973). Increment thresholds

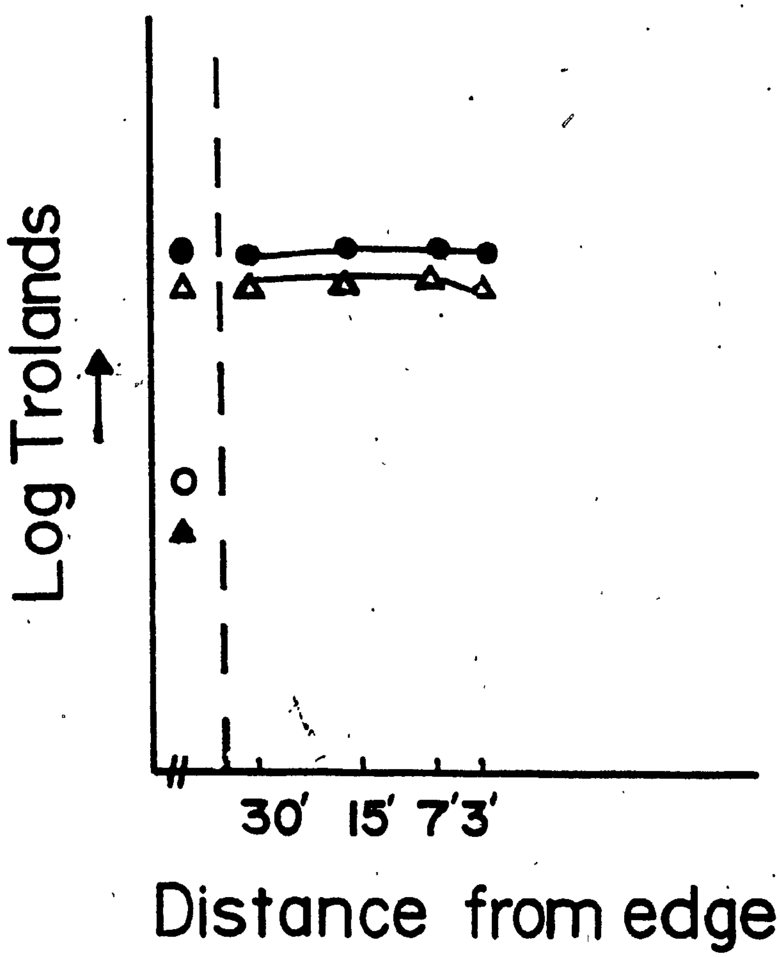


Figure 20. Data replotted from Petry, Hood and Goodkin (1973). To the right of the dotted line are increment thresholds as a function of distance from an edge.
SOA=0
SOA=+10
To the left of the dotted line, the points represent hypothetical dat for measurements of the increment threshold at a spatial position greater than 30 min from the edge.

● △ if the increment thresholds fell at these points along the y-axis, there would be evidence for an absence of an edge effect at these SOAs.

○ ▲ if the increment thresholds fell here there would be evidence for the presence of edge effect for these SOAs.

were determined on the light side of a vertical edge that was created by increasing the luminance in one half of their background field. Measurements were taken on five asynchronies and were varied in 16.7 msec steps. Thresholds measured when the edge was positioned 1 min from the edge were compared with thresholds measured 100 min from the edge. They report that the difference in threshold was greater with a +50 msec asynchrony than it was for +16 msec. However, they also report that the edge effect is also greater at -50 msec than for +16 msec for both observers. One can only infer the magnitude of the effect for simultaneous presentations, since Limb et al did not use an SOA of zero. The data of the present 6 degree condition is generally consistent with the results of Limb & Tulunay-Keesey (1981). Both studies show edge effects occurring at both positive and negative asynchronies of the test flash and background onsets. As pointed out earlier, it is possible that the results of Petry et al (1973), which indicate the edge effect as being specific to positive asynchronies, were a consequence of the particular comparison of spatial locations relative to the edge employed in their experiment. Edge effects may have been evident across a wider range of SOA values in the Petry et al study if the increment thresholds had been assessed for furthur distances from the edge.

There are other aspects of the data from this condition which warrant further consideration. For example, one can observe the presence of a secondary maxima at a positive SOA. The exact temporal location of this secondary maxima differed with the observers, but it was present both when thresholds were measured at the center and at the edge. The rise at this point was more dramatic for the edge measurements. This finding is best illustrated in the data for observer S.S. in Figure 13. The presence of secondary maxima appear to be associated with background offset since they occur at or around the time of background cessation. This sudden rise in the thresholds could be related to attenuation in sensitivity that has been observed at background offsets (e.g. Crawford, 1947; Baker, 1963).

The data from the third condition of Experiment 3 is somewhat puzzling. Across a range of SOA values the threshold curve obtained at the edge is lower than the threshold curve measured at the center. This result is of course in the opposite direction to that predicted by edge accentuation. This result is further complicated by the fact that the stimulus parameters employed are very similar to those used by Petry & Hood (1978). Although reliable differences in center and edge thresholds are not evident in Petry & Hood's SOA curves, an examination of their data reveals that for one observer (S.P.) the threshold curve for the center was generally higher than that for the edge. Differences between the center and edge measurements were apprximately 0.1 log trolands, which is well within the range found in the present 40 min condition. We have previously speculated that a robust edge effect was absent in the Petry & Hood (1978) paradigm because the background duration used was too short for an edge effect to be found with such a small background. Since the present condition also involves a briefly exposed, small diameter background one might have predicted that no edge effect would have been evident. Indeed there is no evidence of an edge effect for a small, brief background at any SOA for the 40 min background stimulus.

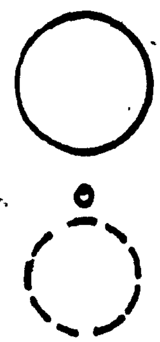
The surprising finding is that the thresholds measured at the center were higher than those measured at the edge. If we assume that these particular conditions employing brief, small backgrounds are out of the range for finding increment threshold edge effects, the data for this condition must reflect some other phenomenon. The general form of the center and edge threshold curves for this condition indicate that the increment thresholds for the test flash are higher at SOA values closer to zero and that the thresholds fall off as the onset of the test flash is moved further from the onset of the background stimulus. The SOA curves of Petry & Hood (1978) reveal the same form. These functions are similar to Type A masking functions which are found in experiments demonstrating masking by light and as such may reflect effects of masking of the test flash by the background.

Visual masking refers to a situation in which some measure of the impact of a visual test stimulus is reduced by the presentation of another (mask) in close temporal contiguity. In masking by light, the mask consists of a flash of homogeneous illumination over an area that completely contains the contours of the test stimulus. Masking effects are usually most severe at an SOA of 0, and the threshold gradually declines with further increases in SOA, (e.g. Sperling, 1965). Both the paradigm employed in the 40 min condition of the present experiment and that employed by Petry & Hood (1978) fit the description of the masking by light paradigm described above. In addition the SOA functions obtained at the center and edge of these disks appear to be masking functions. It would seem fair to state, on this basis, that what was observed under these conditions were masking effects. In this context, then, there seems to be more masking evident when the test flash is superimposed on the center of the disk, than when it is superimposed at the edge. This conclusion is reached on the basis of the lower thresholds obtained at the edge in the 40 min condition of Experiment 3.

There are no experiments in the flash masking literature which have manipulated the spatial position of the test flash with respect to the background mask. To determine why the thresholds were lower at the center than at the edge one can only make inferences based upon what is known about visual masking. If we assume that there is a radial area around the target within which a mask can extend its influence, then a manipulation of the spatial position of the test flash may be conceptually equivalent to decreasing the mask luminance. What is critical in determining the effectiveness of a mask stimulus is its spatial energy within the critical area around the target. The spatial energy refers to the product of the mask luminance and area. How the luminance is distributed in space is not critical, rather it is the total luminance within the area that is important. When the test flash is moved from the center to the edge of a background disk, the spatial energy is effectively decreased. (Figure 21 provides a representation of how the spatial energy is changed as the test flash is moved from the center to the edge.) For a test flash located at the edge of the disk, the background surrounds the test flash on only one side. Moving the test flash from the center to the edge of the background disk should produce a similar effect to decreasing the mask luminance. Both involve a reduction in the spatial energy associated with the mask stimulus. Boynton & Kandel (1957) and Boynton (1958) have demonstrated that the amount of masking increases with increases in mask luminance. Therefore in a masking by light paradigm one would expect greater masking effects for a target presented in the center than one presented at the edge. The displacement of the center and edge threshold curves may represent differing amounts of masking of the test flash at these two spatial positions.

However, it has been noted that this displacement, where evident, is less prominent in the Petry & Hood (1978) experiment than in the

Figure 21. A representation of how the spatial energy is changed as the test flash is moved from the center to the edge of the background.



BACKGROUND STIMULUS

TEST FLASH

Critical area around target within which the mask can influence test flash detection.

present study. One potential contributory difference between the two experiments was the adapting backgrounds upon which the test flash and background disk stimuli were superimposed. Boynton & Kandel (1957) have demonstrated that there is less masking in the light adapted than in the dark adapted eye. The stimuli in the Petry & Hood study were flashed against a 10 degree lit field while, in the present experiment the stimuli were flashed against a dark background. The difference in the adapting fields in these two experiments might also be expected to yield different amounts of visual masking. When the stimuli are presented against a lit field, then the difference in spatial energy between the center and edge spatial positions is less than it would be when the stimuli are presented against a dark background. In the first case when the test flash is at the edge it is surrounded by the mask on one side and an adapting field of lower luminance on the other; in the second case the test flash located at the edge is surrounded by the mask on one side and a dark field on the other. This can account for the finding that the displacement between the center and edge threshold curves was greater in the 40 min condition of Experiment 3 than in the Petry & Hood (1978) study.

In Experiment 3 the role of background size in the determination of the magnitude of the edge effect observed in Experiment 1 has been reconfirmed. Edge effects were present for a 6 degree background field at all SOAs, whereas there was no evidence of threshold elevation near the edge for the 3 degree and 40 min background stimuli. Since there was an absence of threshold elevation over the entire range of SOAs in these conditions, its absence is attributed to the brief background duration employed and not to the time relative to background onset at which thresholds were assessed.

The functions relating edge effect magnitude and SOA for the condition in which edge effects were present do not reveal a systematic variation of the edge effect per se with SOA. The SOAs revealing maximum edge effects varied with each observer. A comparison of the SOA curves at the center with those at the edge do however indicate some, perhaps subtle, differences in shape. The rate of the drop in thresholds to a stable value is faster for thresholds measured at the center. Sudden increases in threshold which are most likely due to background offset are of a greater magnitude for thresholds measured at the edge than at the center.

The functions for center and edge thresholds for the 40 min condition of Experiment 3 are interpreted as masking functions. It was concluded that the SOA functions obtained at the center and at the edge of this condition reflect masking of the 5 min test flash by the 40 min background light flash. In addition the results of Petry & Hood (1978) are also interpreted as representing similar masking functions.

General Discussion

The experiments in this thesis investigated the role that background stimulus parameters play in the determination of the increment threshold edge effect. One major point that can be made concerning the findings is that the magnitude of the edge effect appears to be dependent upon an interaction of spatial and temporal background parameters. An increase in the exposure duration of a small background stimulus is sufficient to produce an increase in the threshold at an edge where the effect was otherwise absent. As well, an increase in the size of a briefly exposed background stimulus will give rise to an edge effect where one was not observed previously. The background duration below which one will not find an edge effect decreases as the background size increases. Similarly, for a given background size the probability of finding an edge effect increases with background duration. A second major point can be made on the basis of the results of Experiment 3. When the background size and/or duration were insufficient to produce an edge effect with simultaneous onsets of the background and test flash stimuli, no threshold elevation was evident at the edge even when sensitivity was assessed after the cessation of the background stimulus. In this case the magnitude of the edge effect did not appear to be a function of the stimulus onset asynchrony between the test flash and background stimuli. When the background size and/or duration was appropriate for observing an edge effect with simultaneous stimulus onsets edge effects were present for a wide range of stimulus onset asynchronies. The magnitude of the edge effect was variable across SOA for a given subject, however no consistent pattern of edge effect magnitude as a function of SOA was evident across subjects.

The increment threshold edge effect found on the high side of an edge has been interpreted as an effect of lateral inhibition (e.g. Fiorentini et al, 1955). Lateral inhibition was first discovered in the eye of the horseshoe crab, Limulus polyphemus (Hartline 1949, 1969). The limulus has a compound eye which is divided into ommatidia, or receptors. Each of these can be stimulated separately and has an optic nerve fiber leading off from it. A lateral plexus of neural elements interconnects the optic nerve fibers and enables each receptor to affect its neighbours. Recording from a single ommatidium of the crab eye, Hartline (1949) found that the discharge of the ommatidium varied with its position with respect to a light-dark border. It was maximally excited when just on the light side of the border and maximally inhibited when just on the dark side. The output of the Limulus eye, when stimulated by a step change in intensity (an 'edge) can be predicted. All receptors on the light side of the step will be excited equally, on the darker side all receptors will be excited equally but to a lesser degree. A receptor in the middle of the lighter side will be strongly inhibited by its neighbours, since its neighbours on the darker side are less strongly excited and thus exert less of an inhibitory influence on it. Thus the firing rate should increase as the border is approached on the lighter side. There is more inhibition from the lighter side of the stimulus on receptor cells that are close to the border but are on the darker side. Thus the firing rate is less than that of receptors in the middle of the darker side. It has been proposed that lateral inhibition of this type might be the neurophysiological basis for the variations in visual threshold near a border.

Kuffler (1953) demonstrated that the output of ganglion cells in the cat retina have receptive fields with analagous properties to the ommatidia in the Limulus. He reported that receptive fields can consist of two regions, an approximately circular center and an annular surround, whose influences on a cell are always opposite and antagonistic. Diffuse illumination falling onto both center and surround excites these cells only weakly. However, when the illumination is nonuniform, as it is near an edge, the cell may respond strongly. This closely resembles the analogous function in the Limulus eye. Baumgartner (1961a) has also demonstrated that on-center cells with their center regions located just on the bright side of a border will be the most activated and that those onthe dark side will be the most inhibited. Cells whose receptive fields are located at some distance from a border will be only slightly affected by it. This antagonistic organisation between the center and surround of retinal receptive fields has been found in most mammalian visual systems.

Hubel and Wiesel (1960) showed that the receptive fields of the monkey retina resemble those of the cat. Since the structure of the human retina closely resembles that of the primate retina (Boycott & Dowling, 1969), it is likely that the same basic receptive field organisation does exist in the human retina as well. Although such neurophysiological research on human subjects has been sparse, receptive fields can be inferred from psychophysical experiments in human vision. The neuronal receptive fields as measured in animals and the subjectively estimated receptive fields (often called perceptive fields) in man are found to obey similar laws.

It seems probable that an antagonistic lateral interaction between center and surround regions of retinal receptive fields is an important determinant of contrast effects in human vision. The responses of individual ganglion cells to borders can be generalised to populations of cells over an area of retina. Associated with the border region is the greatest retinal activity. It is thus that the retina is particularly responsive to sharp contrast borders. Ratliff (1961) offerred the following explanation of contrast effects. Contrast effects may be expected to be greatest at or near the boundary between a dimly illuminated region and a brightly illuminated region of the retina. A unit within the dimly illuminated region, but near the boundary, will be inhibited not only by dimly illuminated neighbours but also by brightly illuminated ones. The total inhibition exerted on such a unit will be greater than that exerted on other dimly illuminated elements that are farther from the boundary. As a result its frequency of firing will be lower. A unit which is located within the brightly illuminated field, but near the boundary, will have a higher frequency of discharge than other equally illuminated units that are located well within the bright field but are subject to stronger inhibition since all their immediate neighbours are also brightly illuminated. Thus the differences in activity of elements on either side of the boundary will be exaggerated, and the discontinuity in this pattern of illumination will be accentuated in the pattern of response. This enhanced difference in firing rates gives rise to the increase in increment threshold measured on the high side of the edge.

There have been a number of studies which have reported that threshold elevation at the edge is not present for a briefly exposed background stimulus when the background and test flash onsets are simultaneous (e.g. Pétry & Hood, 1978). However, the present results indicate that it is not the brief background exposure alone which is critical in these reported absences of an edge effect, rather, the brief background exposure duration combined with a small background diameter acts to reduce the likelihood of detecting an increment threshold edge effect. Separate findings in the literature also point to the probable importance of such a spatiotemporal interaction. For example, Limb & Tulunay-Keesey (1981) find increased thresholds near an edge when their large background is exposed for as little as 16 msec. Burkhardt (1966) has found an edge effect for a small 44 minute diameter background which was presented at a longer duration of one second. In light of this spatiotemporal interaction one can conclude that although the exposure duration used by Limb et al (1981) was very brief, the use of a large background stimulus allowed an edge effect to be observed under their conditions. Although the background diameter used by Burkhardt (1966) was small, the use of a long exposure duration of the background compensated for this and an edge effect was observed.

There is extensive psychophysical and physiological evidence that lateral inhibition takes time to develop (e.g. Ratliff & Hartline, 1965). That the high side edge effect is dependent to some extent upon background duration, is assumed to reflect the action of slowly developing lateral inhibitory effects in the human eye. Thus a dependence of the magnitude of the edge effect upon background duration is consistent with an explanation of the effect in terms of lateral inhibition. Assuming that such lateral interactions are the causal mechanism underlying edge effects, extremely short flashes should fail to yield edge effects because of development time.

The investigation of the effect of the stimulus onset asynchrony should also reflect the neural development of the edge effect. The presentation of the test flash at different times relative to the background onset should allow one to measure sensitivity at several temporal points during the development of the background edge. If we assume again that lateral inhibition is the causal mechanism underlying the edge effect we might expect to observe the edge effect only when sensitivity was measured at some time after background onset. Measuring the sensitivity at a positive SOA would ensure that some lateral inhibitory effects had developed. Although both duration and stimulus onset asynchrony may reflect the neural effects of the development of lateral inhibition, they in fact probably reflect different neural effects. A manipulation of background duration influences the magnitude of the edge effect. An increase in the background duration increases the neural effect, so that an edge effect will be observed where one previously had not been observed. However, a manipulation of the stimulus onset asynchrony should allow one to sample a given effect of some given magnitude at different times during its buildup. Although Petry, Hood & Goodkin (1973) have reported edge effects at only positive SOAs, in the present Experiment 3 and in the experiments reported by Limb & Tulunay-Keesey (1981) edge effects were also present at negative asynchronies. As well, there have been numerous reports of edge effects with simultaneous presentations of the test flash and background (e.g. Burkhardt, 1966). This may appear to be inconsistent with an explanation of the edge effect which assumes that the neural effect of the edge takes time to develop, since at negative asynchronies the test flash onset precedes the background onset. However, the neural time of the stimulus does not correspond directly to its physical presentation time. It is likely that at the negative asynchronies at which an edge effect is observed, a sufficient neural effect of the test flash overlaps with the neural effect of the background so that detection of the test flash is still interfered with by the background. Thus even when the background follows the test flash onset in time, some neural effect of the edge may interfere with the sensitivity to the test flash.

In both Experiments 1 and 3 edge effects were found for a large background stimulus, under conditions which did not yield threshold elevation at the edge for smaller backgound stimuli. A dependence of the edge effect upon the size of the background stimulus was repeatedly demonstrated in this thesis. The greater magnitude of the edge effect which is observed with a large background stimulus may reflect one of three possible changes in sensitivity on the larger background. The first possibility is that the edge effect is due to a change in sensitivity near the edge which accompanies a change in background size. As the background diameter is increased from 3 to 6 degrees, the increment threshold near the edge increases. Alternatively, an edge effect may be observed as a consequence of both an increase in sensitivity at the center and a corresponding decrease in sensitivity at the edge when background diameter is increased. With these particular changes in sensitivity, one would expect that the increment threshold measured at the center of the 6 degree background would decrease and that the increment threshold measured at the edge would increase. Thirdly, an edge effect may be due only to a change in sensitivity at the center. If so one would predict that with an increase in background diameter from 3 to 6 degrees the increment threshold at the center may have decreased. The latter two possibilities may be evaluated by comparing the increment thresholds obtained on the center of the 3 degree disk with that measured on the 6 degree disk to determine if there were any sensitivity changes at the center of the backgrounds associated with the change in background diameter. It is clear from comparisons of the thresholds measured at the center of the 3 and 6 degree diameter background stimuli employed in Experiments 1 (Figures 4 and 7) and 3 (Figures 11-15) that there is no increase in the threshold as a function of background diameter. One can conclude therefore, that the edge effect observed in these experiments reflects a real change in sensitivity at the edge of the two background stimuli. It is clearly not a result of changes in sensitivity at the centers of the background stimuli as a function of increased background size.

Many other investigations of visual system sensitivity have noted a change in sensitivity as a function of background size. A prime example of the space dependent variation of the psychophysical threshold is Westheimer's sensitization effect. Sensitization refers to a decrease in increment thresholds which accompanies increases in background size. Westheimer (1965) showed that the increment threshold for a small test spot located at the center of an illuminated disk varies with the diameter of the disk. For rod vision the threshold for the test spot rises with increasing diameters of the disk, reaching a maximum when the disk diameter is approximately 45 minutes (peak diameter). For disk diameters larger than this peak diameter, the threshold falls again, dropping as much as a log unit as the disk diameter increases to approximately 1.5-2.0 degrees. This sensitization effect, that increases in diameter beyond the peak diameter lead to decreases in increment threshold has been replicated extensively (Westheimer, 1967).

Teller, Matter, Alexander & Phillips (1971) traced early light and dark adaptation curves with a test spot centered upon adapting disks of varying diameters. Their data show that early light and dark adaptation curves for small and large disks differ. Alexander (1974) reported that increasing background diameter yielded a monotonic decrease in spatial integration. Such space dependent variations in threshold are generally interpreted as a manifestation of the antagonistic center-surround interaction within receptive fields of retinal ganglion cells. Although the diameters associated with these desensitization and sensitization effects are well below the 3-6 degree range upon which the present conclusion is based, they nonetheless point to the fact that although the data do not reflect sensitization effects, they do reflect size dependent effects in the visual system.
It is clear that these data are not the result of a sensitization effect per se. However, they do appear to represent some lateral influence within the visual system. McIlwain (1964) described a facilitatory influence of stimuli presented in distant regions of the retina upon retinal ganglion cells and lateral geniculate neurons of the cat. This particular interactive effect was termed the periphery effect. It demonstrated that neurons in the central part of the retina were influenced from eccentric regions some distance from their receptive field center. Similarly, Frost, Scilley, and Wong (1981)

have noted an interactive effect between spatially remote stimuli upon neurons of the pigeon optic tectum. Data such as these may have implications for neural events underlying contrast. Perhaps these neural events which underly contrast involve many receptive fields interacting with each other. The present results are not a manifestation of this periphery effect, yet they may reflect a mechanism which also involves interacting receptive fields.

It is possible that the dependence of the edge effect on background size may be accounted for on the basis of lateral inhibitory effects. In order for the effects of background size on the increment threshold edge effect in general to be consistent with an explanation of the edge effect in terms of lateral inhibition, one need postulate that the the differences in lateral inhibition that one will observe between the center and edge of a large background stimulus, due to the changes only at the edge, will be greater than that observed on a smaller background. As a result of lateral inhibition, differences in neural activity from differentially illuminated regions on the retina are exaggerated and contrast is heightened.

It has been shown that the size of receptive fields increases as one moves from the fovea to the periphery (e.g Spillman, 1971). Associated with this is a reduction in the strength of inhibition towards the periphery as both the receptive field centers and total field size increases (Ransom-Hogg & Spillman, 1980). Bullier & Norton (1979) have reported that the strength of inhibition decreases as the diameter of the receptive field center increases in cat retinal ganglion cells. Spillman (1979) has demonstrated with human subjects that the maximum receptive field size in the fovea is somewhere around

10 minutes, while the maximum receptive field size observed in the periphery is around 3 degrees. In a comprehensive study using human observers, Weinstein & Arnulf (1946) demonstrated changes in area summation associated with retinal eccentricity. They studied area summation in the fovea as well as at 1, 7, 18, 20 and 35 degrees outside the fovea. Summation increased steadily from the foveal center to the 35 degree peripheral position. The results of a number of studies that attempted to estimate receptive field size psychophysically consistently report that there is a rapid increase in both the receptive field center and total receptive field size from the fovea out to about 10 degrees in the periphery. A greater amount of area summation at the edge of the 6 degree background, would predict a higher level of activity at this edge and hence increased thresholds. Increment threshold values increase proportionally with the level of background activity against which they are assessed (Weber's Law). Consequently, one would predict that the threshold measured at the edge of the 6 degree background stimulus, where the activity level is higher due to increased area summation, would be higher than at the edge of the 3 degree background. Thus the different results obtained when the increment thresholds were assessed at the edge of a 3 degree and a 6 degree background disk may reflect differences in receptive field size and consequent differences in area summation. On the basis of differences in receptive field sizes one can postulate that a greater "differential in inhibition" between the center and edge would be observed on the 6 degree background as compared with that of the 3 degree background.

One hypothesis that provides an alternative to the explanation of the edge effect in terms of lateral inhibition, is that the edge effect results from the operation of different types of visual cells. Enroth-Cugell and Robson (1966) first described two classes of visual cells which they termed X and Y cells. Later Cleland, Dubin and Levick (1971) extended the comparison between geniculate and retinal receptive fields along the dimensions of the X-Y classification of Enroth-Cugell & Robson (1966). On the basis of their findings they asserted that it would be more appropriate to speak of a sustained/transient rather than an X/Y classification. They reasoned that such terminology came closer to a physiological description of the respective families of ganglion cells.

These two cell types differ in several ways. One way that sustained and transient cells are differentiated is on the basis of their responsiveness to the spatial frequency components of a visual stimulus. Transient cells show selectivity for wide-bar, or low-spatial frequency patterns (Cleland et al, 1971); and are not sensitive to image blur (Ikeda and Wright, 1972,a). Sustained-type cells, on the other hand, respond selectively to narrow-bar, or high spatial frequency patterns and to sharply focused images. Other important properties that differentiate sustained cells from transient cells are their respective receptive field sizes and their distribution over the retina. At a fixed retinal location transient cell receptive fields are generally larger than sustained cell receptive fields. The number of sustained cell receptive fields is highest in the fovea and drops off sharply with increases in retinal eccentricity. Transient cells are sparse in the fovea and are more heavily concentrated in the parafoveal and peripheral regions of the retina. Thus the ratio of transient to sustained cells increases as one moves from the fovea to the periphery of the retina. Sustained type cells are more prevalent in the area of the retina where acuity is greatest, and the distribution of transient cells is highest in areas associated with diminished acuity. From the tests conducted by both Enroth-Cugell and Robson (1966) and Cleland et al (1971) it can be inferred that the sustained cells are capable of signalling steady, local changes in illumination. Transient cells are capable of signalling illumination over larger areas.

In the increment threshold edge effect the sensitivity to a given target stimulus is shown to increase as a function of the distance to an edge. An attempt has been made to explain this decrease in sensitivity near an edge in terms of a single channel mechanism of lateral inhibition within the visual system. However, it is possible that the edge effect may be accounted for on the basis of differential processing by the two functionally distinct cell types described above, that is within a sustained-transient dichotomy. Under different conditions sensitivity may be determined by either sustained or transient type cells. When sensitivity is measured in the vicinity of an edge, the determination of sensitivity may rely on processing by sustained-type cells. The processing of information which will determine sensitivity to a stimulus which is not near an edge could be dependent upon the responsiveness of transient-type cells.

A thorough investigation of the applicability of an explanation of the edge effect in terms of this sustained-transient dichotomy has not been carried out. In considering this explanation of the edge effect there are at least two underlying assumptions. First, an assumption is being made that the level of sustained background activity to the test flash is higher than the level of transient background activity. This assumption derives from the fact that increment thresholds increase near an edge, and the fact that increment thresholds are related to the level of local neural activity. Secondly, this explanation assumes that the processing of information that leads to the detection of the test flash is accomplished by transient cells away from an edge and by sustained cells near an edge. This change in which type of cell mediates detection must occur even though no characteristic of the target stimulus itself changes. These assumptions, especially the latter, need to be examined before one can accept an explanation of the edge effect in terms of a sustained/transient dichotomy. However, that a lateral inhibitory mechanism is not always appropriate to explain edge effect data suggests that it is a possibility worth exploring. An appeal to the sustained-transient dichotomy could explain threshold differences observed near to and away from an edge on the basis of two classes of cells which posess very different spatial summation properties.

The results of these experiments do show that the magnitude of the edge effect is larger for longer background exposures and larger background sizes. In Experiment 1 it was demonstrated that the magnitude of the increment threshold edge effect was dependent upon background size. Specifically, an edge effect was evident upon a 6 degree diameter background stimulus but not upon a 3 degree or a 20 minute diameter background stimulus. In Experiment 2 a dependence upon the background stimulus exposure duration was demonstrated. Although no edge effect was evident when the background stimulus was exposed for

40 msec, an increase in background exposure duration resulted in an increase in the magnitude of the edge effect. In so far as the conditions employed in these experiments are comparable to those of other experiments, these results support the suggestion that the use of different background stimulus parameters could account for some of the contradictory findings in the literature. There have been a number of reports that edge effects cannot be observed with briefly presented backgrounds. For example Matthews (1966) demonstrated that, given particular stimulus conditions, one could not produce an increase in increment thresholds near an edge if the background was exposed for a short duration of 2 msec. However, given the same stimulus conditions, an edge effect was evident when the background exposure duration was increased to 100 msec. Matthews stated that when exposures are brief a peak in threshold near an edge cannot be observed. A similar result was reported by Novak & Sperling (1963). When the background exposure duration was brief (10 msec) there was no evidence of threshold elevation near an edge. When the exposure duration was increased to 50 msec a slight increasein the threshold near the edge was evident. When the duration was 500 msec the test spot threshold near the edge was clearly higher than at other more remote points. However in contrast to these findings there are reports that edge effects can be observed when increment thresholds are measured against briefly presented background stimuli. Edge effects were observed in the present set of experiments for a background exposure duration of 40 msec. Petry, Hood & Goodkin (1973) contend that one can observe an edge effect even when the background is presented for as brief as 16 msec. Limb et al (1981) also observed edge effects with brief background exposure durations. It

is not merely that one cannot produce an edge effect with a briefly exposed background stimulus, but rather that an interaction of exposure duration with size is critical to the presence of an edge effect. The interaction between the spatiotemporal characteristics of the background is assumed on the basis of these results, to be sufficient to account for a number of findings in experiments investigating the magnitude of the edge effect for brief background presentations.

Although the increment threshold edge effect or edge accentuation is a well documented phenomenon, a review of the literature reveals discrepant findings. In particular there are numerous reports of substantial edge effects in the fovea (eg. Fiorentini et al 1955, 1966; von Bekesy, 1968); while other researchers report diminished edge effects in the fovea (Aulhorn & Harms, 1956; Payne, 1970). Vassilev (1973) attempted to determine the role that the stimulus parameters employed in various experiments might play in producing the discrepant results. Vassilev's experiments were restricted to an investigation of the test flash parameters employed in edge accentuation experiments. The data did suggest that the use of different test stimuli is a source of contradictory findings. The series of experiments presented here provide evidence that the use of different background stimulus parameters is also a source of discrepant results. The results of these experiments provides some assistance to those researchers investigating visual system sensitivity by way of the increment threshold edge effect. These data caution the researcher to choose carefully the stimuli to be employed in these investigations. It is evident from the work of Vassilev (1973) that careful attention should be paid to test flash parameters. It is now evident that just as careful consideration should be given to the choice of background stimulus parameters.

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