DETECTION OF STIMULUS INTENSITY CHANGES
IN THE PERIPHERAL RETINA

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STATEMENT BY AUTHOR

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF FIGURES</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>vi</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>v</td>
</tr>
<tr>
<td>INTRODUCTION AND HISTORY</td>
<td>1</td>
</tr>
<tr>
<td>Electrophysiological Considerations</td>
<td>2</td>
</tr>
<tr>
<td>Psychophysical Considerations</td>
<td>5</td>
</tr>
<tr>
<td>Behavioral Considerations</td>
<td>11</td>
</tr>
<tr>
<td>METHOD</td>
<td>15</td>
</tr>
<tr>
<td>Apparatus</td>
<td>15</td>
</tr>
<tr>
<td>Subjects</td>
<td>21</td>
</tr>
<tr>
<td>Procedure</td>
<td>22</td>
</tr>
<tr>
<td>RESULTS</td>
<td>26</td>
</tr>
<tr>
<td>DISCUSSION</td>
<td>30</td>
</tr>
<tr>
<td>SUMMARY</td>
<td>34</td>
</tr>
<tr>
<td>APPENDIX - METHOD USED TO CALIBRATE LIGHT</td>
<td>35</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>37</td>
</tr>
</tbody>
</table>
### LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>VISUAL DISCRIMINATOR</td>
<td>17</td>
</tr>
<tr>
<td>2.</td>
<td>BLOCK DIAGRAM OF ELECTRICAL APPARATUS</td>
<td>18</td>
</tr>
<tr>
<td>3.</td>
<td>RELATIONSHIP BETWEEN CURRENT CHANGE AND LIGHT OUTPUT</td>
<td>20</td>
</tr>
<tr>
<td>4.</td>
<td>PERCENTAGE OF CHANGES SEEN FOR SUBJECTS</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>KB, TJ, GS, AND GW</td>
<td></td>
</tr>
</tbody>
</table>
LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td>LAMP CURRENT READINGS AND LUMINANCES FOR REQUIRED CHANGES FOR EACH SUBJECT.</td>
<td>25</td>
</tr>
<tr>
<td>II.</td>
<td>SUMMARY OF TOTAL CHANGES SEEN</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>TOTAL CHANGES PRESENTED FOR ALL SUBJECTS</td>
<td></td>
</tr>
<tr>
<td>III.</td>
<td>STATISTICAL COMPARISONS BETWEEN TWO TYPES OF INCREASE (BASED ON: NUMBER SEEN/NUMBER PRESENTED)</td>
<td>29</td>
</tr>
<tr>
<td>IV.</td>
<td>STATISTICAL COMPARISONS BETWEEN TWO TYPES OF DECREASES (BASED ON: NUMBER SEEN/NUMBER DETECTED)</td>
<td>29</td>
</tr>
</tbody>
</table>
ABSTRACT

Recent studies involving reaction time (RT) have demonstrated that in the periphery, RT is faster to stimulus onset than to stimulus offset. A trend (not statistically significant) showing the opposite effect has been demonstrated in the fovea. The hypothesis was advanced that the peripheral retina was better equipped to detect stimulus onset or increment. To test this hypothesis "frequency of seeing" counts were taken in response to intensity increments and decrements of a peripheral stimulus. Preliminary investigation showed that for three subjects, decrements produced stronger sensory effects than correspondingly equal increments. The remaining subject reported the opposite effect: increments were subjectively larger than equal decrements.

The results were contradictory between subjects and therefore inconclusive. Two possible explanations of these results were offered: one based on detection theory and stating that unequal sensory experiences between increments and decrements give rise to different criteria as to what will be accepted and reported as a change; the other based on a functional difference between rod and cone units in the retina. It is concluded that the former hypothesis is probably operating under the stimulus parameters employed in the present study.
INTRODUCTION AND HISTORY

From the beginnings of experimental psychology in the nineteenth century, investigators have studied the underlying mechanisms involved in the receiving and processing of information concerning the world around us. The field of vision and visual perception has generated more investigation than any other. The visual receptors, or for that matter, receptors in all of the sense organs, serve specialized discriminatory functions in that they selectively signal certain changes in the environment. These signals, in turn, are transmitted to higher centers where they are processed and acted upon. Typically, most studies in the field have assumed a constancy in central mechanisms, so that any differences in behavior resulting from the presentation of two different types of stimuli could be attributed to differences in the ability of the sense organs to make discriminations concerning the two stimuli.

Such was the case in the present study. Of interest here was the ability of the peripheral retina to discriminate changes in luminance of a small stimulus spot. Both increments and decrements in luminance were presented with the magnitude of the changes being at or near the difference threshold for each subject. A "frequency of seeing" count was taken with the idea that any variation between the frequency of seeing increments or decrements
in stimulus luminance should tell us something about the mechanisms underlying the peripheral retina. To understand our reasoning certain historical considerations are mentioned below, before discussing the present study.

Electrophysiological Considerations

In a classic study, Hartline (1938) demonstrated that not all fibers in the optic nerve of the frog give the same kind of response to light. He found fibers that respond only to the onset of light (on), others that respond only to the offset (off), and still others that respond to both the onset and offset of the light (on-off). He also found the same effect, although to a lesser degree, in response to sudden increases and decreases in the intensity of a stimulus light flooding the eye. Of further importance is the finding that the responses, at a given light intensity, for all types of fibers are greater in the dark adapted eye than in the light adapted eye. In a following study, Hartline (1940) found the receptive field in the frog retina from which impulses in a typical fiber of the optic nerve could be elicited to be on the order of 1mm in diameter. He also demonstrated that the center of a given receptive field had a low threshold and that threshold increased as the stimulus moved toward the periphery.

Similar findings were reported by Kuffler (1953) in testing the retina of the cat with a test flash of 0.2mm. He found that the receptive fields could be divided into concentric rings according to their discharge patterns. For example, the center of the receptive field might yield only on discharges in response to
stimulation while farther out in the periphery of the field only off discharges can be found. An intermediary zone between the two above mentioned regions yields both on and off discharges. Fields where the pure on and pure off patterns of discharge were reversed were also located. Kuffler (1953), in confirmation of Hartline (1940), also points out:

... 'off' areas may suppress the discharge from 'on' areas, or visa versa. It is assumed that specific areas give rise to predominantly inhibitory or excitatory pathways to a given ganglion cell. (p. 67)

The reader is directed to Granit (1955) for an extensive survey of the literature in the area of on and off relationships in the retina.

An attempt has been made by Granit (1955) to relate on and off responses to the basic differences between rods and cones. He reports that the off response is very small in the electro-retinogram (ERG) of the guinea pig whose retina is composed mainly of rods while the predominantly cone eye of the horned toad and snake the off response is very evident. In the frog and the arthropod Limulus where the rod-cone ratio is nearly equal, large on and off effects are evident. The implication is that the off response can be associated primarily with the cones and on responses should be thought of as a product of rod activity.

Howarth (1961) recorded human ERG's in response to onset and offset of light under conditions of light and dark adaptation. He found that in each condition of adaptation, the off response was shown to resemble an inverted on response. However, he also
found that the off response could be obtained only from a strongly light-adapted eye, one where the test flash intensity was above 16,000 millilamberts (mL) or where the adapting field intensity was 160 mL or above.

DeValois, Jacobs, and Jones (1962) and Jacobs (1965, 1966) have shown some differences to light increment and decrement in the electrical response of the lateral geniculate nucleus (LGN) of the monkey. They found two types of cells which show opposite changes in discharge frequency in response to similar changes in stimulus intensity. Some fibers respond with increased firing rates to increases in intensity and decreased rates to decreases in intensity. Other fibers show decreased firing rates in response to intensity increases and visa versa. The magnitude of these response changes is directly related to the magnitude of intensity changes in the stimulus. A study by DeValois, Abramov, and Jacobs (1966), in which the response patterns of LGN cells to colored light were analyzed, has shown that there are several different functional types of cells located in that structure. These cells belong to one of two general categories, opponent cells and non-opponent cells. Opponent cells respond with an increased firing rate to some parts of the spectrum and a decreased rate to other parts of the spectrum. Non-opponent cells respond to all wave lengths with either an increased or decreased firing rate. It is the conclusion of the authors that the opponent cells transmit information about stimulus color (hue) while the non-opponent cells carry information relating to the luminance (brightness) of the stimulus.
It would appear, then, that the detection of stimulus intensity changes is based upon differences in neural patterning that arises in the retina and are carried as differences up to the cortex.

Psychophysical Considerations

Before going into a discussion of some of the psychophysical principles related to the present study, let us examine three of the basic methods of stimulus presentation that have typically been employed in vision research.

One method is to present (onset), or to extinguish (offset), a stimulus light to which S must respond in some manner. In this type of presentation, the stimulus is "on" or "off" for a sufficient duration for S to complete, or at least initiate, his motor response. Since this duration is long, S must respond to only one transient state, such as when the light goes from zero intensity to the testing intensity in the onset condition, and visa versa in the offset condition.

A second method often used is to present S with "light" and "dark" stimulus "flashes." This is similar to the first method with the exception that the "flash" is usually of such short duration that it is completed before S starts to respond. Under this condition, then, S is actually responding to two transient periods with each presentation of the stimulus. For a "light" flash there would be a transient when the stimulus went from zero intensity to the testing intensity, a given duration at this intensity, and then a transient at the stimulus offset as the
intensity returned to zero. Obviously, the reverse would hold true for a "dark" flash. As was mentioned before, since these two transients are so close to one another in time, S might actually be responding to a combination of them rather than to either one separately.

The third method of presentation resembles the first method described. With this method, S is presented with some prevailing stimulus intensity and at some point this intensity is either increased or decreased to a new intensity. As in the first method, S makes his response to only one transient and the stimulus usually remains at this new intensity long enough for S to complete, or initiate, his response before returning to the prevailing intensity. The present study made use of this particular method of stimulus presentation.

Let us now consider some studies that have investigated threshold differences between "onset" and "offset," between "light" and "dark" flashes, and between stimulus increment and decrement using the methods of stimulus presentation outlined above. The results of these studies have sometimes been in conflict with one another. No attempt will be made in the present discussion to reconcile these studies. The point should be made, however, that since the experimental conditions varied from study to study, they are not directly comparable, and so without detailed analysis, not attempted here, the bases for these conflicts are not evident.

In 1914, Gildemeister (after Sticht, 1965) measured the absolute threshold of "dark" flashes in the fovea. He did
this by "blocking" light of various intensities (absolute values not given) with a pendulum and determining the least duration of this "blocking" that could be detected as a darkening of the stimulus 50% of the time. (No mention was made by Sticht as to the psychophysical method used to determine this figure nor was any comment made of any fixation arrangements as such although it is probable that the stimuli themselves served as fixation points.) Gildemeister found that as the intensity of his stimulus increased, the minimum detectable time of "blocking" notably decreased. He also found, while holding intensity constant and increasing the size of the stimulus through a range of 14° to 62° of visual angle, that the duration thresholds of the "dark" flashes decreased as the area of the stimulus increased.

A study conducted in 1914 by Rutenberg (after Sticht, 1965) investigated the thresholds of "light" and "dark" flashes to foveal stimuli of 56° of visual angle for three different durations: 6, 10, and 30 msec. (Again, no mention is made by Sticht of any fixation apparatus and, again, it is probably that the stimuli also served as fixation points.) It was found that threshold intensities of both "light" and "dark" flashes decreased as flash duration increased. However, these relationships were not linear with respect to one another. In comparing the products of intensity (I) and time (t) for both types of flashes, it was found that the relationship It = c (Bloch's Law) held for the "light" flashes but not for the "dark" flashes. In the latter case, greater changes
in intensity were required before threshold values were reached for a given duration. The data apparently suggest, then, a difference in mechanisms used to detect "light" and "dark" flashes.

In a study more directly related to the present investigation, Steinman (1944) required subjects to judge the magnitude of stimulus intensity changes presented to them along a seven-point rating scale, the larger numbers representing greater apparent magnitudes of change. Subjects viewed a ground glass stimulus field one inch in diameter from a distance of about two feet. No fixation point was provided other than the stimulus field itself. However, it is probable that if field were viewed directly, the image fell on at least some parts of the fovea. The prevailing intensity of the stimulus field was 4.5 footcandles (fc) and subjects were asked to rate the magnitudes of intensity increments and decrements in the field ranging from 0.4 to 2.0 fc. The results revealed, in all cases, that for objectively equal intensity changes, decrements in intensity were rated as being of greater magnitudes than corresponding intensity increments. In other words, the data clearly show that decrements produce a stronger sensory effect than corresponding equal increments and seem to suggest that perhaps the threshold for seeing decrements is smaller than for seeing increments.

Blackwell (1946) in a study involving a methodology somewhat different from that employed in the studies already discussed, determined contrast thresholds for the human eye. He presented
his subjects with a white field that subtended an angle of 10° at the eyes and required them to locate "positive" contrast points (points brighter than the background) and "negative" contrast points (points darker than the background). These points were located on an eight-point circle around the center of the test field. The radius of this circle was 3°, the center of which was marked by a small red dot. Size of the points were varied, in visual angle subtended, between 121.6 and 3.60 minutes of arc. Brightness of the field was varied between zero and 100 footlamberts (fL) while five different magnitudes were used for the test points, related approximately as the numbers 1.0, 0.75, 0.55, 0.37, and 0.24. At the sound of a buzzer, it was the subjects' task to search the field, locate the contrast point, and position a pointer on a recording device in front of him to correspond to the position on the circle he thought he detected the contrast point. The results show that in most cases, the thresholds for "negative" stimuli and "positive" stimuli are approximately the same. However, with larger contrast points and low adaptation brightness, the thresholds for the "negative" stimuli are about 20% lower than thresholds for the "positive" stimuli. Because Blackwell used free search methods and presented his stimuli binocularly, with long durations, his results are not directly comparable with the results of the studies mentioned above. The significant finding to be noted, however, is this difference between stimuli "decreasing" and stimuli "increasing."
A final study to be mentioned in this connection was conducted by Herrick (1956). He measured the minimal amount of luminance which had to be added to or subtracted from a prevailing luminance to be detected as a change in brightness. This determination was made with circular field of "white" light 1° in diameter centrally fixated. When S had been light adapted to the prevailing luminance, the experimenter would sound a buzzer. When S felt that his fixation was at its optimum he would throw a switch which would either turn on or extinguish a helium tube for a given duration. Durations ranged from 0.0035 to 2.013 sec. so that in reality, some of the durations were "positive" and "negative" flashes while others were discrete increments and decrements. A wide range of adapting luminances were used. Results of this study are inconclusive. For one subject, Herrick reports that for data for four durations, the thresholds for increments and decrements are equal. For his other subject, he reports that at the higher luminances, the thresholds for the increments appear to be a bit higher than thresholds for decrements. These differences are very slight, however.

In summary, Rutenberg (1914) found higher thresholds for "dark" flashes than for "light" flashes, the data of Herrick (1956) are inconclusive while the findings of Steinman (1944) and Blackwell (1946) seem to suggest that thresholds are lower for intensity decrements than they are for intensity increments. With these results in mind, let us now turn to some behavioral considerations, using reaction time as a measure.
Behavioral Considerations

Attempts to investigate the problem under consideration using some behavioral measure, mostly reaction time (RT), have been many and varied. The findings of some early researchers are in conflict with the reports of later workers in the field.

Among the early workers was Wells (1913). He measured the effect upon RT of brief "light" and "dark" flashes, and of the onset and extinction of stimuli of 1.0 sec, in duration. His stimulus, a white plaster disk, was presented binocularly and formed a retinal image .4 mm in diameter. The intensity of the stimulus was said to be equal to that of a 3½ candlepower lamp viewed at a distance of 142.5 cm. By use of a pendulum, the stimulus could either be presented to or occluded from S for periods ranging from .01 to 1.0 sec. No fixation point was provided but Wells states that the stimulus was large enough to stimulate the entire fovea and probably some areas outside the fovea as well. No differences in RT were found in this study in response to onset ("light" flashes) and offset ("dark" flashes). Similar results were obtained by Woodrow (1915) in response to onset and extinction of dim and bright test stimuli.

Jenkins (1926) obtained results conflicting with the data of Wells (1913) and Woodrow (1915). He presented a small (3° of visual angle) test flash of 510 millimicrons (green; wave band about twenty wave lengths wide) to the fovea and found that RT was faster to the offset of the stimulus than to its onset. He concluded,
however, that the longer RT's to onset may have been caused by improper fixation on the part of S. In the offset condition the stimulus light also served as a fixation point while in the onset condition S was surrounded by complete darkness and unable to attend properly. Jenkins advanced the point that RT to onset and offset could probably be shown to be approximately equal by providing S with a fixation point in the onset condition.

In 1927, Pieron (after Sticht, 1965) attempted to eliminate the fixation problem mentioned by Jenkins (1926) by providing his Ss with a dim red foveal fixation point. He found that RT to stimulus extinction was faster than RT to onset when the intensity of the stimulus was near threshold. He also found that the differences between RT to extinction and to onset tended to diminish as stimulus intensity increased.

Varying the approach somewhat, Steinman (1944) presented her Ss with a test field of 4.5 footcandles in brightness and measured RT in response to increments and decrements in the intensity of that stimulus. The stimulus field was a circle of ground glass one inch in diameter located about two feet away from the subject. No other fixation device was employed other than the test field which was viewed directly. At four second intervals, the test field would be illuminated by a constant intensity for two seconds. The intensity was either increased or decreased for a period of 1 sec, (over a wide range of magnitudes) and S would react to this change. She found that as the magnitude of
the change (in either direction) increased, RT decreased. It was also established that RT was faster in all cases to intensity decrements than to intensity increments. However, these differences in RT were reduced as the magnitude of change increased. On the basis of this finding, Steinmam predicted that all differences in RT to intensity increments and decrements would disappear when the magnitude of the changes became large enough. This prediction was confirmed by Rains (1961) in investigating the extreme case of change, from no intensity to very bright intensity and visa versa. Using a large foveal test field of $12^\circ 44'$ at an intensity of 344 mL he found no differences in RT to the onset and cessation of the test field.

A final study worth mentioning in this connection was conducted by Pease and Sticht (1965). Using a small stimulus spot (20\' of visual angle), they systematically determined RTs for the foveal and periphery ($15^\circ$ in the temporal retina) to the onset and cessation of four different intensities: 3.140 mL; 31.4 mL; 0.314 mL; and 0.198 mL. They found that, in the periphery, RT to the onset of stimulation was faster than to the cessation, while in the fovea, although the differences are not statistically significant, there appears to some trend for the reverse to be true. It was also found, again in support of Steinman's (1944) prediction, that the differences in RT to onset and cessation of stimulation tended to decrease as function of increased stimulus intensity.
With all of the above considerations in mind, the hypothesis was advanced, for the present study, that perhaps the differences between RTs to stimulus onset and cessation and to increments and decrements in stimulus intensity are due to the fact that a given area of the retina is better constructed to detect a luminance increment rather than a decrement, or visa versa. Using the study of Pease and Sticht (1965) as a model, it was felt that perhaps RT was faster to stimulus onset in the periphery due to the peripheral retina being better equipped to detect onsets (and increments) of stimuli. Likewise, RT to offsets in the fovea may be faster than onsets because the fovea is better equipped to detect decrements.

The prediction was then advanced that if changes near the difference threshold were presented to the peripheral retina, and if the peripheral retina is indeed constructed so as to detect increments better than decrements, then a simple frequency count for seeing a large fixed number of increments and decrements should reveal that more increments were detected than decrements.
METHOD

Apparatus

Stimuli and fixation points were both presented to $S$ via an L-shaped visual discriminator. This device is a light-tight tunnel $2\frac{1}{2}'' \times 3\frac{1}{2}'' \times 30''$ and is shown in Figure 1. A Sylvania Glow Modulator tube (type R1131C), having a rise and decay time of 0.0001 sec., served as the stimulus source (A). The light from this lamp passed through a collimating lense (B) which had a 22 mm diameter and a focal length of 162 mm. Light intensity could be controlled at C by the use of Wratten neutral density filters. A field stop was inserted at D which provided $S$ with a small stimulus spot 1 mm in diameter which subtends an angle of 38° at the pupil of the eye. Continuing on from the field stop, the light passed through a beam splitter (E) and a converging lens (K) which had a diameter of 35 mm and a focal length of 90 mm. The light then converged at an artificial pupil (L) 3 mm in diameter.

The right arm of the discriminator provided $S$ with a foveal fixation display. A Mazda lamp, No. 313, was mounted at J. Light from this source passed through a collimating lens (H) which had a diameter of 35 mm and a 90 mm focal length and continued on through a red filter (Wratten No. 33) mounted at G. Intensity could also be controlled at this point by using appropriate Wratten neutral density filters. A field stop at F provided the
fixation display which consisted of five minute holes in a piece of over-exposed photographic film. These holes were made by pushing the point of a needle through the film and were arranged in the shape of a cross. The diameter of each hole was too small to measure, however, at its widest point, the fixation display was 1.5 mm across, subtending at the pupil of the eye, an angle of 57°. The optical arrangement was such that the stimulus spot and the center spot of the fixation pattern were at a level with one another and that the stimulus and fixation spots were at the same optical distance. A distance of 11°55′ of arc, at the eye, separated the center of the fixation display and the stimulus spot, the latter being projected onto the temporal retina. All Ss were provided with individual dental bite-plates, mounted at M, to help maintain constant fixation. Each S was able to position his bite-plate according to his own physical requirements. S sat in a 65″ x 24″ x 36″ light proof booth. At S's right hand, mounted on a 6″ wide shelf, was a Micro-Switch (Model L10). S responded by depressing this switch. A 1 mm downward movement of this switch was enough to close the switch circuit. Faster methods of responding could have been used but since reaction time in itself was not one of the variables under consideration in this study, they were not employed.

The remainder of the apparatus is shown in block diagram in Figure 2. The stimulus light was powered by a Heath Model W-PS-4 regulated power supply (A). Intensity changes were accomplished by the experimenter's (E) throwing a control switch (B) to one
FIGURE 1. VISUAL DISCRIMINATOR (APPARATUS DESCRIBED IN TEXT)
FIGURE 2. BLOCK DIAGRAM OF ELECTRICAL APPARATUS
of three positions. In the middle position, 30 milliampres (ma) of current produced an unfiltered intensity at the Maxwellian view of 141 millilamberts (mL). (This measurement, and all following measurements, were made with a Gamma Model 700 Log-Linear Photometer. These measurements are relative rather than absolute due to inherent problems in using a fiber optics probe to measure a Maxwellian view. See Appendix for a description of calibration procedure.) Since the measured luminance was much too great for the conditions postulated for this study, a Wratten neutral density filter of 3.0 log units was inserted into the system which reduced the apparent luminance at the Maxwellian view to 0.141 mL. When E threw the switch to either of the two extreme positions, the current was changed which in turn resulted in a corresponding increment or decrement of the luminance of the stimulus light. Each extreme position of the switch was wired to one channel of a Gebrands Model 2 PC event pen-recorder, located at E, so that whenever the switch was moved to either of these positions, a record of that movement was made on a moving strip of paper. The magnitude of intensity increments and decrements was controlled at C by two CRL potentiometers rated at 400 ohms and 5 watts. To insure that equal changes in current would produce equal luminance changes, measurements over a wide range of current values were taken. The results of these measurements can be seen in Figure 3. It will be noted that the relationship is approximately linear over the range used in this study. Thus, equal current changes above and below a given starting point (in this case, 30 ma.) will produce correspondingly approximately equal changes in luminance.
FIGURE 3. RELATIONSHIP BETWEEN CURRENT CHANGE AND LIGHT OUTPUT
Current changes were monitored at D by a Simpson Model 260 milliampere. Changes as small as 2.0 ma. could be measured by this instrument. Two Hunter Decade Interval times (F) controlled an audible click produced by a Potter and Brumfield Model K4/4DY electrical relay (G) located in the light-proof booth with S. This audible click was reproduced every six seconds and was also recorded on another channel of the pen-recorder. Whenever S detected a change in the luminance of the stimulus light, he responded by pushing the response key (H), which in turn operated a fourth channel of the pen-recorder. Power to operate the electric relay and the pen-recorder was provided by a 28-volt D.C. power supply (J) while power operating the fixation lamp came from a 16-volt battery (K). Apparent intensity at the Maxwellian view from the fixation lamp was 3.44 mL.

The nature of the control switch was such that all changes in intensity were instantaneous. That is to say, there was no time when the stimulus light would first extinguish and come back on at a different intensity. The duration of the transients in going to the new intensity was governed only by the physical limitations of the stimulus tube, in this case less than 0.0001 sec, according to the manufacturer.

Subjects

Subjects were four male undergraduates. Each subject spent fifteen hours practicing the discrimination tasks involved in this study prior to the actual test trials. All subjects were paid $1.00 per hour for their services.
Procedure

During an experimental session, S was randomly presented with three different luminances. His task was to decide just when \( E \) changed from one luminance to another. Each experimental session began with \( S \) dark adapting for thirty minutes by wearing Polaroid Dark Adapting Goggles. He then entered the reaction booth and was instructed to keep his fixation centered on the small red cross.

The balance of the instructions were as follows:

After each click that you hear, one of three things will happen. Either the stimulus spot will increase in intensity, or it will decrease in intensity, or it will remain at the same intensity. Whenever you detect a change, push the response key, but remember, push it only when you are certain that you have detected a change.

Each \( S \) was presented with three blocks of 50 trials each during an experimental session. Each trial was of six seconds duration, the time being bounded by a series of audible clicks. Any given click marked the end of a previous trial and the beginning of the next trial. During the experimental session, one-half of the trials were "catch" trials in that no changes in intensity were presented to \( S \). The remainder of the trials were equally divided between increases and decreases in illumination. Changes were presented randomly, with the exception that it was impossible, because of the nature of the control switch, to go from the highest intensity to the lowest intensity, or visa versa. A stop had to be made at the intermediate intensity first. Whenever a change occurred, it came randomly anywhere between one to three seconds after the click to avoid precise anticipation on the part of \( S \). A three minute rest period separated the blocks of trials.
In the present study, since there were three intensities, bright (I), medium (II), and dim (III), four different types of changes were possible, two being increments and two being decrements. There could be an increase from the medium intensity to the bright intensity (type A), there could be a decrease from the bright to the medium intensity (type B), there could be another decrease from the medium to the dim intensity (type B'), or there could be another increase from the dim to the medium intensity (type A'). These designations of intensities and changes will be used throughout the balance of this paper.

As was mentioned above, the difference threshold of each S was employed in this study. This threshold was determined by a modified Method of Limits. Three out of the four subjects reported, during their first session in the experimental booth and throughout the entire study, that when the intensity of the stimulus spot was reduced by Δ, the subjective effect was much greater than when the intensity was increased. (It should again be pointed out that, objectively, all changes for a given S were equal.) The fourth subject reported, with the same consistency, the opposite effect: increases were much more noticeable than decreases. Thresholds were set for the first three Ss by finding the minimal decrease that could be detected 50% of the time. For the fourth S the threshold was set at the minimal increase that could be detected 50% of the time. Once the difference threshold had been found, be it decrease or increase, that value also served as the magnitude of the
opposite change. Table I shows a summary of the necessary current changes and corresponding intensity changes required by each S. It will be noted that for S KB all changes were 2 ma in magnitude while changes for Ss TJ and GW were 4 ma in magnitude. S GS required magnitudes of 6 ma for his changes.

Once values had been established, S was subjected to 15 hours of intensive training in an effort to minimize his false report rate. Training procedure was as follows: If E presented a change to S and it was not reported, E said nothing. However, if E did not present a change and S reported one, or if E presented a change in one direction and S reported a change in the opposite direction, E verbally corrected S by telling him the nature of his mistake. (Adapted from Blackwell, 1953, p. 177, ff). In this manner it was hoped that S would raise his criterion for what he considered to be a change, thereby reducing his false response rate. After 15 hours of training, all Ss had false response rate of less than 1% of the total responses in a given session.
<table>
<thead>
<tr>
<th>S</th>
<th>Intensity</th>
<th>Milliammeter Reading</th>
<th>Apparent Light Output (Millilamberts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KB</td>
<td>I</td>
<td>28</td>
<td>.125</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>30</td>
<td>.141</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>32</td>
<td>.158</td>
</tr>
<tr>
<td>TJ</td>
<td>I</td>
<td>26</td>
<td>.111</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>30</td>
<td>.141</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>34</td>
<td>.174</td>
</tr>
<tr>
<td>GS</td>
<td>I</td>
<td>24</td>
<td>.098</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>30</td>
<td>.141</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>36</td>
<td>.187</td>
</tr>
<tr>
<td>GW</td>
<td>I</td>
<td>26</td>
<td>.111</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>30</td>
<td>.141</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>34</td>
<td>.174</td>
</tr>
</tbody>
</table>
RESULTS

The design of this study was such that a series of Chi Square tests could be performed on the data. The main difference for which we tested was in the ability on the part of S to detect increases and/or decreases in stimulus intensity. Of secondary interest were any differences in detecting one type of increase (or decrease) as opposed to the other type of increase (or decrease).

The results for three out of the four subjects in this study are directly opposite to what was predicted. The fourth subject follows predictions. Table II gives a summary of the frequency of each type of change seen, as compared with the number of times it was presented, for each S, along with the computed results of the several Chi Square tests involved. It should be noted that all the computed Chi Squares are highly significant (P < .001). Table II shows that three Ss, KB, TJ, and GS, detected significantly more decreases than increases in intensity while S GW detected many more increases than decreases in intensity. Figure 4 shows the percentages of the total increases and decreases seen for each S and clearly indicate the differences presented above. In these graphs, both types of increases and both types of decreases have been combined for the sake of clarity. It should be noted that for Ss KB, TJ, and GS, the percentage of decreases seen is near 50%
**TABLE II**

Summary of Total Changes Seen

Total Changes Presented for All Subjects

<table>
<thead>
<tr>
<th>Increases</th>
<th>Decreases</th>
<th>Chi Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>Type A</td>
<td>Type A'</td>
</tr>
<tr>
<td>KF</td>
<td>80/258</td>
<td>78/260</td>
</tr>
<tr>
<td>TJ</td>
<td>75/226</td>
<td>36/215</td>
</tr>
<tr>
<td>GS</td>
<td>29/242</td>
<td>21/230</td>
</tr>
<tr>
<td>GW</td>
<td>130/258</td>
<td>132/233</td>
</tr>
</tbody>
</table>

** P < .001

while the percentage of increases seen ranges from 32% to 25%, to 12% respectively. For S GS, who shows the opposite effect, the percentage of increases seen is near 50% while the percentage of decreases seen approaches 30%.

Table III shows a comparison of the ability to see the two different types of intensity increases used in this study. It can be seen from the table that only one S, TJ, exhibited any differences in the ability to see a type A increase (changing from the medium intensity to the bright intensity) as opposed to seeing a type A' increase (changing from the dim intensity to the medium intensity). Subject TJ saw significantly more type A increases than type A' increases (Chi Square = 15.12, P < .001).

Table IV shows a comparison of the ability to see the two different types of intensity decreases used in the study. Subjects TJ and GS saw significantly more type B' decreases (changes from the medium intensity to the dim intensity) than type B decreases (changes
FIGURE 4. PERCENTAGE OF CHANGES SEEN FOR SUBJECTS - KB, TJ, GS, AND GW
from the bright intensity to the medium intensity). The effect for S TJ is represented by a Chi Square of 6.05 ($p \leq 0.02$) while the Chi Square of 51.69 ($p \leq 0.001$) represents a highly significant difference between the number of decreases seen for S GS.

TABLE III

Statistical Comparisons Between Two Types of Increase
(Based on: Number Seen/Number Presented)

<table>
<thead>
<tr>
<th>Type of Change</th>
<th>Type A</th>
<th>Type A²</th>
<th>Chi Square</th>
<th>Level of Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>KB</td>
<td>80/258</td>
<td>78/260</td>
<td>0.035</td>
<td>NS</td>
</tr>
<tr>
<td>TJ</td>
<td>75/226</td>
<td>36/215</td>
<td>15.12</td>
<td>$P \leq 0.001$</td>
</tr>
<tr>
<td>GS</td>
<td>29/242</td>
<td>21/230</td>
<td>0.810</td>
<td>NS</td>
</tr>
<tr>
<td>GW</td>
<td>130/258</td>
<td>132/233</td>
<td>2.08</td>
<td>NS</td>
</tr>
</tbody>
</table>

TABLE IV

Statistical Comparisons Between Two Types of Decreases
(Based on: Number Seen/Number Detected)

<table>
<thead>
<tr>
<th>Type of Change</th>
<th>Type B</th>
<th>Type B²</th>
<th>Chi Square</th>
<th>Level of Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>KB</td>
<td>141/258</td>
<td>136/260</td>
<td>0.279</td>
<td>NS</td>
</tr>
<tr>
<td>TJ</td>
<td>91/226</td>
<td>112/215</td>
<td>6.05</td>
<td>$P \leq 0.02$</td>
</tr>
<tr>
<td>GS</td>
<td>76/242</td>
<td>150/230</td>
<td>51.69</td>
<td>$P \leq 0.001$</td>
</tr>
<tr>
<td>GW</td>
<td>72/258</td>
<td>72/233</td>
<td>0.641</td>
<td>NS</td>
</tr>
</tbody>
</table>
The main objective of this study was to investigate the ability of the peripheral retina to detect increments and decrements in stimulus intensity. The prediction was made that frequency of seeing counts would reveal that more increments in stimulus intensity had been detected than comparable decrements. The data collected show that only one subject followed predictions. The other three subjects saw a great many more decrements than increments.

Even though the obtained results were in disparity with the predictions, the data does allow for some speculation as to what might have happened.

One explanation of the results can be based on detection theory. Let us consider a general two-state threshold theory of detection as advanced by Nachmias (1966). According to this hypothesis two internal states occur when a person is faced with a detection situation: A D-state when some fixed threshold, or criterion, is expected and a D̅-state when it is not. Let us assume that the stimulus increments in the present study produce a D-state and D̅-state with a given criterion and that the stimulus decrements produce a separate D-state and D̅-state with its own, and different, criterion. This does not seem too unreasonable when we remember that three subjects reported objectively equal
increments and decrements as producing sensory effects where the decrements were subjectively larger than the increments. The remaining subject reported the opposite effect. Another argument for this point is that the increments and decrements are, after all, qualitatively different. It seems logical to assume that if S does adopt two different criteria for the two types of changes, he is likely to liberalize his responses to the change that produces the stronger sensory effect and be conservative in his responses to the other type of change. In fact, he may "see" just as many increments as decrements, but if his criterion for increments is more stringent than his criterion for decrements, he is less likely to report an increment as seen. Obviously, the reverse holds true as well. This would explain why the three Ss who reported that decrements were "larger" than increments tended to see more decrements and why the S who reported increments as producing the stronger sensory effect tended to report more increments as seen.

An alternative explanation of the results, and one that is much more speculative, is more psychophysically oriented. It rests heavily on the conclusions of Granit (1955) and Howarth (1961). Granit concluded that the off response is primarily a product of the cones while the on response is a result of action of the rods. Howarth, as mentioned above, has shown that the off response of the human ERG resembles an inverted on response. He therefore suggests the concept of algebraic addition of the components of the human ERG. If this is indeed the case, then events perceived will depend upon the sheer numbers of on and/or off units stimulated.
Using the second formulation as a model, it is possible to assess the results of the present study. Let us assume that for three subjects, the stimulus spot fell in an area where off units outnumbered on units. When the stimulus decreased, more numbers of off units would respond than would on units when the stimulus intensity increased by an equal amount. It might then be possible that higher centers interpret these differences in responses as signaling different magnitudes of change, even though the magnitudes are really equal. The opposite idea would then hold true for the S who reported more increases seen than decreases. If this formulation were correct it would theoretically be possible to map the relative number of on and off units in the retina. If more increments were seen than decrements, the stimulus would be landing in an area with more on units than off. If the frequency counts yielded the opposite information it would be an area with a predominance of off units. If the frequency counts showed no difference, it is possible that the stimulus spot would be landing on relatively equal on and off units per unit area.

Although the first hypothesis is somewhat speculative, the principle of parsimony favors its adoption over the second hypothesis which is based on many assumptions that have yet to be concretely proved. Reasoning from the first hypothesis it is concluded that the reason some subjects differed from predictions and from each other was because of the phenomenon of certain types of changes being more pronounced in sensory effect. This led to the establishment of two different criteria of what is taken as being "seen" for the two different types of changes.
It is suggested that if further work be performed on this problem, resort be made to the psychophysics of detection theory. Psychophysics of this type permit a measure of sensitivity to change (the so-called $d'$ measure) and presumably are inherently free of any complications on account of the stringency of the reporting criteria used by subjects. Indeed, preliminary discussions in this laboratory point to a detailed methodology which may prove suitable for attacking the problem to which we have addressed ourselves in this report. At any rate, the inconclusive results reported herein require further investigation.
SUMMARY

"Frequency of seeing" counts were taken in response to luminance increments and decrements of a stimulus spot located 11°55' in the temporal retina of the right eye.

The results indicated that: (1) for three subjects, decrements produce stronger sensory effects than increments, thus, more decrements are reported as "seen," (2) for the remaining subject, increments produce the stronger sensory effect and more increments are reported as "seen."

Two hypotheses were advanced to explain these results. The first was based on detection theory. It says that subjects adopt a more stringent criterion for the change of stimulus intensity that produces the lesser sensory effect and a less stringent criterion for the stimulus change causing the greater sensory effect. The second hypothesis was based on certain physiological considerations and stated that the contrary effects between subjects was due to differences in the retinal mosaic, particularly the rod-cone ratio, at the place where the stimulus spot fell.

The former hypothesis was adopted over the latter, according to the principle of parsimony, as the probable reason for the inconclusive results obtained in this study.
APPENDIX

METHOD USED TO CALIBRATE LIGHT
The Gamma Model 700 Log-Linear Photometer has, as one of its attachments, a fiber optics probe. Using this particular attachment, calibrations of the stimulus lamp and fixation lamp were carried out using the following procedure.

A wooden adaptor to hold the fiber optics probe was constructed and mounted at the eye piece of the Visual Discriminator. After the Photometer had been calibrated to a standard light source, the fiber optics probe was inserted into the wooden adaptor. This assembly was centered in the Maxwellian view. In other words, the fiber optics probe took the place of the eye. Readings of the light output of the stimulus lamp were taken over a wide range of current values. A single reading was taken for the fixation lamp.

It should again be emphasized that readings obtained in the manner described above are relative rather than absolute. Problems inherent in the use of fiber optics preclude absolute measurements. However, for the purpose of this study, relative measurements were sufficient.
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