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FILE 998565

IMAGE AND CUE ENHANCEMENT THROUGH THE USE OF MOVING OR FLICKERING PRESENTATIONS

An Annotated Bibliography

Prepared by

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[redacted]

[redacted]

15 August 1963

CONTENTS

PART I
RESEARCH PERFORMED AND IN PROGRESS

INTRODUCTION

STAT [redacted] is convinced of the need for further research in the application of apparent movement, real movement, and flicker to improve the performance of visual detection systems. This conviction is a product of three factors. The first is [redacted] recent success in applying apparent movement to markedly improve the performance of optical rangefinders. The second is the positive results of preproposal investigations done at [redacted] in 1957-1958 regarding the value of apparent movement in the comparison viewing of aerial surveillance imagery, recently corroborated by work done at the [redacted] STAT The third is information obtained from the literature and from preliminary investigations in the ongoing company-funded flicker research program. A review of each of these activities will serve to illustrate the bases of this conviction.

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SSD FLICKER RANGEFINDER STUDIES

Two flicker rangefinder studies have been performed under contract by the [redacted] STAT [redacted] assisted by the Human Factors Unit. (See references No. 25B, 52B, 90, and 91 in the bibliography.) The contracting agency for both was the US Army's Frankford Arsenal. In the first study, a 1-meter-base-length T-57 coincidence rangefinder was converted to a flicker rangefinder by means of a relatively simple system of external reciprocating shutters. By alternately presenting the view from each end of the rangefinder the shutters produced an apparent movement of all out-of-range objects instead of noncoincidence. ("Flicker rangefinder" is a misnomer in that the essential ranging cue is an apparent target movement.) In comparison testing, very marked reductions in variable ranging error were obtained with the flicker system.

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In the follow-on study, a 2-meter-base-length M17C coincidence rangefinder was modified in a more sophisticated manner and a more rigorous testing program was carried out. By using an internal reciprocating mirror to both produce apparent movement and to perform the function of combining the images in the eyepiece, the light-loss inherent in chopping light was approximately counterbalanced by the removal of the combining prism with its inherent 50 percent light-loss for each image. (This was in contrast to the shutter system used in the T-57 studies, where these losses were additive.) Comparison tests of the modified rangefinder (officially designated the XM-21) and an unmodified M17C were conducted.

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An analysis of variance of the test data showed that the modified rangefinder provided a very highly significant ($p < 0.001$) overall reduction in variable error of over two-to-one. For certain combinations of the independent variables this reduction was as high as five-to-one. These results are especially interesting in view of the fact that time and budget limitations caused mechanical design considerations to weight very heavily in determining the parameters of apparent movement incorporated in the rangefinder. In particular, the pulse shape and blank-time interval (=zero) were somewhat arbitrary and could not be varied at all. They are remarkable when considered in conjunction with the very slight improvements in performance that would be expected as a result of any presently conceivable refinements in the optical design of the system. In human engineering terms, it seems reasonable to state that redesigning the man-machine interface to take greater advantage of the eye's response characteristics resulted in a far greater improvement in system performance than could reasonably be expected from either improved training or system redesign.

Discussion of Results

Beyond their implications for the design of optical rangefinders, the results of these studies are taken to indicate that apparent movement should be considered for all applications where the task is one of visually detecting near-threshold differences in images. The results are believed to be directly related to the results of studies such as those demonstrating the superiority of the apparent-movement cue in detecting changes in aerial surveillance imagery, and those demonstrating the superior conspicuity of apparently moving or flashing lights. (See references No. 24, 47 and 89.) The frequencies used or found optimal in both of these kinds of studies are very close to those used in the rangefinder studies. (Also see reference No. 119.)

It is interesting to note that in both the XM-21 study and the [redacted] studies the apparent- STAT
movement cue was found to provide much greater accuracy but to require additional time. It is believed that this extra time required may be an artifact arising from the extra accuracy provided - ie, the time required to respond to additional discrepancies which are not detectable with the static presentation. (See references No. 24 and 91.)

A subjective phenomenon which occurred during the second rangefinder study is considered to have very important implications in addition to the above. The comparison tests were run in winter. On days when the near-twilight of the late afternoon was accompanied by smog, all subjects spontaneously reported that the far (2600 meter) target was completely invisible through the unmodified rangefinder, whereas they were able to detect and to range upon the same target through the flicker rangefinder. This effect, also apparent to the test conductors, was definite and consistent. It did not appear to be specifically related to the target movement, but appeared to be the result of a very marked increase in the whole-field brightness and in the contrast of each of the two alternating views. This suggested the possibility of using flicker and/or apparent movement to improve the visual detection of marginal intensity and marginal contrast targets.

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In view of the frequencies used (3, 4 and 5 cps) this phenomenon might have been the result of an actual contrast or brightness enhancement. Contrast enhancement through movement and intermittent illumination has recently been demonstrated by the work of Bittini, Ercoles, Fiorentini, Ronchi and Di Francia (see references No. 20 and 37). Brightness enhancement of marginal intensity targets through intermittent stimulation was demonstrated in 1951 by Bartley (see reference No. 10). In each case the frequency range in which maximum enhancements were obtained was very close to the above.

"Enhancement" properly refers only to an increase in contrast, brightness, visibility, or conspicuity beyond that of a static or steady presentation in spite of any light-loss caused by the off-time in light interruption. Whether or not brightness and contrast enhancements were obtained in this sense, it should be noted that such a lowering of the threshold of visibility of a low-contrast, low-intensity target also could be explained on the basis of the double-duty performed by the XM-21's sliding mirror, and the greater efficiency of intermittent visual stimulation demonstrated by Senders in 1948, and again by Nachmias in 1958 (see references 87 and 109).

Senders and Nachmias (except for very brief 250-msec presentations of the grating) both found that the intensity of the on-period of an intermittent light required for the resolution of an acuity grating has to be increased by much less than the increase required by Talbot's law to equate the brightness of an intermittent light with that of a steady light. (Talbot's law states that the intensity of the on-period must be raised by the amount necessary to make the mean intensity of the combined on- and off-period equal to that of the steady light.) This discrepancy between what is predicted necessary for equal brightness and what is actually needed for the resolution of an acuity grating was found by Senders to be greatest at the lowest frequency she investigated, 4 cps, and to increase as pulse-to-cycle fraction (PCF) decreases. Senders concluded and Nachmias demonstrated that brightness enhancement is not responsible for the effect.

The meaning of the statement that intermittent light is more efficient than steady light for resolution is most clearly demonstrated by the equal acuity contour shown in figure 1 of reference No. 109. The intensity of the steady light required for resolution of the grating is indicated by the common value of all curves at PCF = 1.00. It can be seen that the intensity of the on-period of intermittent light at PCF's of 0.50 and above had to be increased very little or not at all to match the resolution provided by the steady light - in spite of the fact that the light was off as much as half the time.

The phenomenon observed in the XM-21 study and these subsequently discovered studies indicating that a light can be interrupted up to half the time without degrading resolution led to the following observation: The threshold of visibility through a given optical system can be lowered whenever an intermittent presentation can be used to perform an essential system function, if the alternate ways of performing the function entail considerable light-loss. The improvement in visibility will be a function of the light-loss of the alternate methods.

In the XM-21 rangefinder, this was accomplished by using the sliding mirror to produce apparent-movement as well as to perform the combining prism's function of presenting the image from each end of the rangefinder in the eyepiece. Though there was no off-period (blank time interval) between alternating images, the light at any given receptor was flickering at the frequency of alternation due to the difference between the two images. Thus the sliding mirror system may have provided a resolution for each image approaching that which would have been obtained if it were somehow physically possible to transmit all of the light from both views continuously.

It should be noted that the XM-21 may have provided a slight increase in the actual amount of light transmitted, in that the light-loss due to all causes in the combining prism (ie, reflection and absorption) may have been slightly greater than the light-loss due to all causes in the sliding mirror system (ie, reflection, absorption, and off-time). However, it appears very unlikely that any increase due to this factor could have been sufficient to account for the marked improvement in visibility observed.

The fact that Senders found intermittent light to be more efficient for resolution even at fusion frequencies has suggested that sliding mirrors may be superior to combining prisms even for those applications where a static combination or superimposition of images is desired.

To further illustrate the generality of application of the above observation, the use of alternate binocular presentation (see reference No. 56) in rear projection stereo viewers represents another case in which an intermittent presentation might be used to improve the performance of a man-machine viewing system. Obtaining sufficient screen brightness has been a continuing problem with this type of viewer. By using alternate binocular presentation to perform the essential function of channeling each member of a stereo pair into the appropriate eye, picture quality superior to that provided by polarization or the lenticular screen should be obtained since both of these methods entail considerable light loss ($\simeq$ 50 percent for each member for polarization). As in other applications it is possible that actual brightness and contrast enhancements could be obtained through appropriate design in addition to this improvement.

A somewhat different way in which the relative invariance of resolution under chopped light might be utilized would be in real-time, low-light-level television viewing systems such as those under study for use in military vehicles. Here time-dependent image orthicon camera tubes and storage tubes could make valuable use of display off-periods to develop stronger and more stable images.

STAT [redacted] PREPROPOSAL STUDIES ON FLICKER COMPARISON VIEWING

In the winter of 1957-1958, preproposal investigations were conducted by [redacted] STAT
STAT personnel [redacted]) into the use of apparent-movement in the comparison viewing of surveillance imagery. Though these tests were not rigorously controlled or quantified,

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it was concluded that apparent movement, with the proper combination of frequency and blank-time interval, was definitely superior to superimposition or side-by-side comparison for detecting changes in imagery. It was also concluded that image registration was much less of a problem than would be expected, even when different types of imagery were being compared, such as aerial maps versus aerial photographs. Both of these conclusions appear to have been corroborated by the available information on the [redacted] studies (see references No. 23 and 24).

CURRENT [redacted] FLICKER RESEARCH

At the conclusion of the rangefinder studies, it was decided that the potential applications of apparent movement and flicker warranted a company-funded program of literature research and further experimentation. The stated objectives of this program, now nearing completion, were:

(1) To identify additional applications for the use of intermittent visual stimulation to improve the performance of viewing systems.

(2) To increase [redacted] understanding and control of the various factors involved in maximizing the performance of viewing systems through intermittent visual stimulation.

The stated technical objectives of the program were:

(1) To perform an open-ended survey of the literature relevant to the above program objectives.

(2) To develop an experimental viewing system suitable for a wide variety of researches on the application of intermittent visual stimulation.

(3) To perform experimentation based on previous experience and the information obtained in the literature research.

(4) To document the results in an annotated bibliography of the most relevant reports obtained during the literature survey, and in a final report on the experiments performed.

The progress to date in the current program can be summarized as follows:

(1) Literature Survey - Several hundred reports were obtained and evaluated. Bibliography cards were prepared for the reports judged sufficiently relevant and these were coordinate-indexed. The present report is the end product of the literature survey.

(2) Experimental Viewing System - An experimental viewing system has been developed which provides a wide variety of monocular, binocular and alternate-binocular flicker and apparent-movement presentations. The system is capable of simulating all of the tasks thus far identified which might benefit from the use of intermittent visual stimulation. The basic system consists of a combining prism for each eye which can superimpose or alternately present two back-lighted 35-mm slides. Shutters between each of the four slides and their respective light-sources are designed to provide independently variable frequency, pulse-to-cycle fraction, and pulse shape over a fairly wide range.

(3) Experimentation - In informal experiments performed in connection with the construction of experimental devices, observers concurred that both brightness and contrast enhancements were evident when aerial photographs were presented intermittently.

Formal experiments using ground and aerial photographs of both real targets and model vehicles have now been completed. The effects of various types of intermittent presentations on operator performance in simulated comparison viewers, stereo viewers, rangefinders, night binoculars, and space sextants were investigated. Analysis of the experimental results is now in progress and a final report on the experiments performed will be completed at the end of August.

PART II
ANNOTATED BIBLIOGRAPHY

INTRODUCTION

The present bibliography represents the end-product of technical objective (1) of the ongoing experimental flicker program described in Part I. It consists primarily of references which were actually obtained and studied during the literature survey. In a few cases, papers read at meetings have been included on the basis of a published abstract.

A great variety of military and nonmilitary bibliographies, lists of organizational publications, and indices were examined to identify reports of apparent relevance to the program objectives. The five Tufts University human engineering bibliographies* and the yearly indices of the Journal of the Optical Society of America were found to be particularly rich sources of relevant reports.

The bibliography is made up of two general types of references:

(1) Reports demonstrating, suggesting, or providing information directly relevant to image or cue enhancement through intermittent or dynamic visual presentations

(2) Reports containing no information directly relevant to such enhancement but providing research leads or other useful information for performing research in this area.

Examples of reports in this latter category are those investigating the effects of highly relevant independent variables such as frequency and PCF on relatively irrelevant dependent variables such

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* Human Engineering Bibliography 1955-1956 ONR Report ACR 24 Office of Naval Research 1957 OTS Report PB 131507

Human Engineering Bibliography 1956-1957 ONR Report ACR 32 Office of Naval Research 1958 (AD 205 931) OTS Report PB 131507S

Human Engineering Bibliography 1957-1958 ONR Report ACR 43 Office of Naval Research 1959 (AD 235 970) OTS Report PB 161125

Human Engineering Bibliography 1958-1959 ONR Report ACR 55 Office of Naval Research 1960 (AD 258 705) OTS Report PB 171109

Human Engineering Bibliography 1959-1960 ONR Report ACR 69 Office of Naval Research 1961 (AD 274 945) as CFF, and those providing information on advanced research methodology, analytic techniques, apparati, or particularly suggestive theoretical considerations.

In general, the first type of report has been annotated much more extensively than the second type. In many cases an original summary of the report was written. In other cases the author's abstract or summary was used and then augmented to stress certain features of the data or to provide a clearer picture of the results obtained. In most cases the graphs or tables of the report which were judged to best summarize or typify the results obtained have been included as a part of the annotation. Comments regarding applications suggested by the report and comments relating the report to one or more of the other references have often been provided. Unchanged or slightly edited phrases, sentences and paragraphs without quotation marks were often used in addition to the author's abstract and are hereby acknowledged.

Most of the annotations for the second type of report are unchanged or slightly edited author's abstracts or summaries, or short summaries provided by the present writer.

To facilitate comparison of reports it is suggested that all reported values of light-dark ratio or on-off ratio (L/D) be converted to pulse-to-cycle fraction or duty cycle (L/L+D). To facilitate comparison of reports investigating the effects of frequency, it is suggested that all reported values of cycles per minute or revolutions per minute be converted to cycles per second.

COORDINATE INDEX

The coordinate index consists of six classes of descriptors:

(1) Applications
(2) Types of enhancements
(3) Types of presentations
(4) Independent variables
(5) Dependent variables
(6) Methodology, analytic techniques, apparati, and theory.

A brief example will serve to illustrate how the index can be used to identify references on fairly specific topics. If information is desired on the combined effects of frequency and PCF on brightness enhancement, consult the two independent variable descriptors of frequency and PCF, the enhancement descriptor of brightness enhancement, and note those reference numbers which appear under all three descriptors. The most important references under each descriptor are indicated by *.

1. Reports demonstrating, suggesting, or providing information particularly relevant to specific applications of dynamic or intermittent visual presentations.

(a) Reduction of variable error in rangefinding.

Part I*, 24, 25B*, 52B*, 89, 90*, 91*, 98, 119*.

(b) Reduction of percent of undetected changes in the comparison viewing of time-separated surveillance imagery; facilitation of the comparison viewing of surveillance imagery from different types of sensors.

Part I*, 23*, 24*, 50*, 56*, 89, 90, 91, 92*.

(c) Increasing the conspicuity of external and internal warning and signal lights in aircraft and automobiles.

Part I, 24, 29, 34, 37*, 39, 44, 45, 46, 47*, 89*, 90, 91, 97.

(d) Increasing the visibility of marginal intensity or marginal contrast targets in military reconnaissance. (Night and twilight vision).

Part I*, 8*, 10*, 17*, 20*, 37*, 47, 70*, 83, 87*, 88, 89, 91*, 109*, 110*, 114.

(e) Increasing the brightness and possibly contrast of projection-type stereo surveillance-imagery viewers.

Part I*, 56*, 87, 98, 109.

(f) Increasing the conspicuity of target movements in radar surveillance.

24, 54*, 89, 90, 91.

(g) Reduction of headlight and floodlight glare while maintaining an equivalent level of illumination.

36*, 87, 109.

(h) Improving the quality of low light-level television displays.

Part I*, 87, 109.

(i) Maintaining dark adaptation while providing sufficient illumination to read instruments in night flying.

1, 87, 89, 109.

(j) Increasing the accuracy of aerial bombing.

No reports obtained. See references under 2.(a) and 2.(b).

The MA-2 bombing system developed by IBM for the B-47 bomber consisted of alternately presenting real-time 360° PPI radar displays of the target area with photographs of previous displays of the same type on which pre-selected targets were circled or otherwise marked. The display was adjusted (which changed the flight-path) until there was no apparent movement of the target and/or nearby landmarks. While some bombardiers were mistrustful of the new method and were reluctant to use it, the bombing scores of those who did use it increased markedly.

This system or a very similar system has reportedly also been used in navigation for taking checkpoint fixes, etc. An optical analogue of this system would alternately present a terrain map or aerial photograph with a real-time view through a telescope.

This application has suggested to [redacted] the possible application of apparent movement to real-time airborne or relayed-to-ground comparison viewing for target change detection. STAT

(k) Increasing the conspicuity of deviations from proper configuration in the visual inspection of miniaturized printed circuits. (Quality control).

No reports obtained. See references under 2.(b).

STAT [redacted] has constructed a simple apparent-movement machine for this purpose called the "Blink Area Correlator" which reportedly works very well. This STAT application has suggested to [redacted] the possible application of apparent-movement to detect minimal temperature changes in infrared displays of electronic assemblies, which may be useful for monitoring and troubleshooting of electronic equipment. (See reference No. 92).

(1) Increasing the conspicuity of minimal star movement in time-separated telescopic photographs in astronomy.

No reports obtained. See references under 2.(b).

The device called the blink-microscope has reportedly been used for many decades to improve the detectability of star movements.

This application has suggested to [redacted] the possible application of apparent movement to detect minimal changes in living organisms and cultures and in inorganic substances in microscopy. STAT

(m) Increasing the detectability of fake manuscripts, original editions, paintings, and coins.

No reports obtained. See references under 2.(b).

The Folger Shakespearean Library in Washington D. C. has for several years used an apparent movement machine called the "Hinman Blink Comparator", after its designer. When authenticated and suspect items are presented alternately, differences are translated into apparent-movement or flicker. The device is reportedly very superior to other methods for the purpose of detecting copies from originals. An [redacted] employee once took part in an informal investigation of the device's suitability for aerial photo comparison. While the results of the investigation were inconclusive, it was noted that it was sometimes possible to confuse shadow changes with vehicle changes in the comparison of time-separated photos of parking lots. STAT

(n) Producing adverse effects in enemy personnel. (Use of flicker as a battlefield weapon.)

2, 5, 6, 38, 50, 118.

(o) Use of critical fusion frequency (CFF), critical stereofusion frequency (CSF), and eye movements as indicators of physiological stress, alertness and bodily condition.

2, 5, 38, 56, 84, 111, 118.

2. Reports demonstrating, suggesting, or providing information particularly relevant to specific types of enhancements and increased light efficiency obtainable with dynamic and intermittent visual presentations.

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(a) Contrast enhancement.

20, 25B, 37, 70, 83, 91.

(b) Greater efficiency of intermittent illumination for acuity.

Part I, 25B, 48, 49, 87, 88, 91, 98, 109, 110.

(c) Brighness enhancement.

4, 8, 9, 10, 11, 12, 13, 17, 25B, 39, 48, 49, 87, 88, 91, 97, 105, 106, 109, 110, 114.

(d) Conspicuity enhancement.

23, 24, 25B, 29, 31, 34, 37, 44, 45, 46, 47, 50, 52B, 54, 56, 72, 89, 90, 91, 92, 119.

3. Reports providing information on specific types of dynamic and intermittent visual presentations.

(a) Apparent-movement

7, 23, 24, 25B, 44, 50, 51, 52B, 54, 56, 86, 89, 90, 91, 92, 107, 119.

(b) Alternate presentation (intra-eye).

50.

(c) Alternate binocular presentation (inter-eye).

56, 92, 93, 98, 112.

(d) Induced real movement.

20, 70, 119.

(e) Eye-movement; stabilized retinal image (indicated by_____).

20, <u>33</u>, <u>37</u>, 56, <u>58</u>, <u>69</u>, 70, <u>71</u>, <u>78</u>, <u>83</u>, <u>87</u>, <u>99</u>, <u>100</u>, <u>101</u>, 107, <u>116</u>.

(f) Flashing or flickering lights or homogeneous light-reflecting surfaces.

1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 21, 25A, 27, 28, 29, 31, 32, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 52, 53, 55, 57, 59, 61, 62, 63, 64, 65, 66, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 89, 93, 94, 95, 96, 97, 102, 103, 104, 105, 106, 108, 111, 113, 114, 115, 118.

(g) Intermittent illumination of a target or patterned surface.

20, 36, 37, 48, 49, 87, 88, 91 (see note), 109, 110, 112.

Note: all of the studies under descriptors 3.(a), 3.(b), and 3.(c) except 44, 54, 89, 93, and 112 involved intermittent illumination of a target, or patterned surface as an inherent feature of the presentation used.

4. Reports providing information on the effects of independent variables relevant to image and cue enhancement by means of dynamic or intermittent visual presentations.

(a) Frequency, pulse rate, flicker rate, rate of intermittence (cps, cpm; rps, rpm).

2, 4, 8, 10, 13, 17, 20, 21, 23, 24, 25, 27, 29, 34, 35, 37, 40, 42, 43, 47, 48, 49, 50, 51, 53, 55, 56, 57, 58, 59, 61, 62, 63, 64, 65, 66, 69, 70, 71, 73, 75, 76, 77, 81, 82, 84, 87, 88, 90, 91, 95, 96, 97, (98), 100, 101, 104, 106, 108, 109, 110, 114, 115, 118, 119.

(b) Movement amplitude.

20, 37, 51, 55, 56, 58, 69, 70, 71, 75, 76, 100, 101, 119.

(c) Light-dark ratio (LDR), on-off ratio, bright dark ratio, L/D; pulse-to-cycle fraction (PCF), light-time fraction (LTF), duty-cycle, duty ratio, L/L+D.

1, 8, 14, 15, 16, 17, 18, 27, 28, 29, 31, 34, 35, 39, 42, 43, 47, 48, 49, 62, 66, 73, 77, 81, 84, 87, 88, 95, 96, 97, 109, 110, 114, 118.

(d) Miscellaneous independent variables specific to the perception of apparent movement.

(1) blank time interval.

51, 86.

(2) separation between stimulus objects

51, 86.

(3) target similarity

51.

(4) direction

7, 51.

(e) Pulse duration.

16, 31, 39, 47, 77, 95, 118.

(f) Pulse shape, waveform, derivative of luminance with respect to time, temporal gradient.

20, 21, 35, 37, 40, 50, 62, 66, 96, 100, 104, 105.

(g) Complex stimulus trains.

(1) alternating durations

27, 28, 42, 43, 66, 73, 75, 76.

(2) two-component flicker, phase relationships

25A, 75, 76, 82.

(3) glissando

118.

(h) Exposure time, total duration of stimulation, total time of variation.

1, 4, 13, 18, 21, 31, 33, 49, 58, 69, 71, 77, 87, 88, 99, 100, 119.

(i) Luminance; illuminance; luminosity; intensity.

2, 4, 5, 6, 7, 8, 9, 10, 13, 14, 21, 35, 37, 41, 42, 51, 52, 55, 57, 59, 62, 63, 64, 65, 66, 72, 75, 81, 82, 83, 84, 86, 89, 90, 91, 93, 95, 96, 102, 103, 108, 112, 113, 114, 115, 118, 119.

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(j) Contralateral luminance, inducing luminance, simultaneous brightness contrast.

8, 17, 79, 80, 84, 102, 103.

(k) Entoptic light, stray light, scattered light.

3, 11, 12, 102, 103. 114.

(l) Contrast, edge gradient, presence of contours.

7, 8, 37, 45, 46, 47, 48, 59, 65, 90, 91, 101, 103, 104, 112.

(m) Shape of light or target.

89, 90, 91.

(n) Size or area.

8, 10, 32, 41, 57, 59, 69, 72, 79, 80, 81, 93, 102, 109, 114, 119.

(o) Color.

8, 9, 20, 21, 32, 37, 42, 52A, 55, 64, 65, 75, 82, 104, 109, 113, 118.

(p) Visual noise, distractors.

23, 24.

(q) Retinal region stimulated, cone vision versus red vision.

3, 8, 20, 21, 29, 37, 40, 44, 53, 64, 89, 104, 105, 108 109.

(r) Dark adaptation, light adaptation, artificial pupil.

3, 8, 11, 17, 31, 38, 59, 61, 62, 63, 64, 65, 66, 79, 80, 93, 102, 114.

(1) chromatic adaptation

65.

(s) Binocular versus monocular vision.

79, 93, 112.

(t) Abnormal vision.

(1) age

84.

(2) color blindness

32, 64, 65.

(3) hemeralopia

40.

(u) Individual differences.

34, 38, 91.

5. Reports providing information on dependent variables relevant to dynamic or intermittent visual presentations.

(a) Contrast perception, contrast thresholds; perception of Mach bands; acuity; brightness discrimination, perception of spatial gradients.

3, 20, 21, 25B, 33, 37, 40, 48, 49, 58, 69, 70, 71, 83, 87, 88, 91, 98, 99, 100, 105, 109, 110, 116, 119.

(b) Readability, word recognition.

48, 110, 116.

(c) Brightness, brightness thresholds, brightness increment thresholds.

4, 8, 9, 10, 11, 12, 13, 17, 25A, 25B, 32, 35, 37, 39, 40, 46, 48, 49, 52, 59, 63, 72, 78, 83, 87, 88, 91, 95, 96, 97, 102, 105, 106, 109, 110.

(d) Conspicuity, attention getting quality (as measured by reaction time, percent of possible detections, variable error, etc.).

23, 24, 25B, 29, 31, 34, 37, 44, 45, 46, 47, 52B, 72, 89, 90, 91, 92, 97, 119.

(e) Stereoscopic effect, stereoscopic depth perception.

56, 98.

(f) Color perception; subjective color.

64, 65, 86.

(g) Critical flicker frequency (CFF), flicker fusion frequency (FFF).

3, 4, 5, 8, 14, 15, 16, 18, 27, 28, 32, 35, 37, 38, 41, 42, 43, 52, 53, 55, 62, 66, 72, 73, 77, 78, 79, 80, 81, 84, 86, 93, 95, 96, 102, 103, 104, 112, 113.

(1) number of flashes at fusion

18.

(2) critical luminance (luminance at fusion for a given frequency)

104.

(3) beat frequency, scanning frequency

53.

(4) Subjective flicker rate

43.

(h) Critical color fusion frequency (CCFF).

113.

(i) Luminance required to perceive flicker.

82.

(j) Sinusoidal flicker amplitude thresholds, amplitude sensitivity.

27, 35, 42, 55, 57, 59, 61, 62, 63, 64, 65, 66, 75, 76, 82, 106, 115, 119.

(k) Critical stereofusion frequency (CSF).

56, 92, 98.

(l) Perception of movement and apparent movement (bare occurrence versus conspicuity).

7, 51, 86, 92, 107, 119.

(m) Adaptation.

1, 8, 12, 13, 59, 89, 119.

(1) CFF adaptation (change in CFF as a result of stimulation)

4.

(n) Injurious effects of flicker.

2, 5, 6, 38, 50, 118.

(o) Electroretinographic response.

8, 21, 37, 40, 47, 52, 95, 104, 105.

(p) Electroencephalographic response, cortical response.

2, 4, 5, 8, 9, 63, 106.

6. Reports providing information on advanced methodology, analytic techniques, apparati, and theory.

(a) Methodology.

12, 25A, 27, 28, 32, 35, 56, 59, 61, 62, 63, 64, 65, 66*, 67, 68, 73, 75 76, 78, 79, 80, 82, 107, 115.

(b) Analytic techniques.

5, 39, 42, 55, 57, 59, 62*, 66*, 86, 94, 95, 96, 97, 115.

(c) Apparati.

19, 22, 30, 33, 52A, 85, 111, 117, 118, 119.

(d) Theory and general.

5, 7, 8, 26, 35, 40, 51, 53, 57, 59, 61, 63, 64, 65, 66*, 74, 78, 83, 86, 94, 95, 96, 100, 106, 107, 111.

REFERENCES

1. Adair, Eleanor R. Duration and Light-Dark Ratio of Intermittent Preadaptation as Factors Influencing Human Dark Adaptation. J. opt. Soc. Amer., 1953, 43, 22-27.

The influence of intermittent preadaptation upon subsequent dark adaptation was investigated for six preadaptation durations ranging from 30 seconds to 16 minutes. The rate of intermittence was one cycle/second and four ratios of light-to-dark (plus continuous light) were used. The preadaptation intensity was 1188 mL. The resulting dark adaptation curves show that an increase in the duration of intermittent preadaptation produces an elevation in initial threshold, a prolonging of dark adaptation, and a decrease in the rate at which dark adaptation proceeds. An increase in the light-time of the light-dark ratio will affect dark adaptation in a similar manner.

2. Alexander, H.S. & Chiles, W.D. Prolonged Intermittent Photic Stimulation. U.S. Armed Forces Medical Journal, 1960, 2, 1156-1161.

In order to investigate the resistance of the human operator to effects of intense, flashing lights for prolonged periods of time, 4 subjects were exposed to very bright intermittent photic stimulation at 5, 10, and 15 cycles per second for a period of 2 1/2 hours. None of the subjects suffered any adverse subjective or behavioral effects, although all became somewhat drowsy from time to time presumably as a result of the boring nature of the situation.

After about 1 hour of stimulation, all 4 subjects showed definite evidences of electroencephalographic responses to the lights.

The research is also reported in the following reference:

Alexander, H.S. & Chiles, W.D. An Exploratory Study of Prolonged Intermittent Photic Stimulation. WADC Technical Report 59-715. Wright Air Development Center, Wright-Patterson AFB, Ohio. 1959 (AD 233 854)

3. Alpern, M. & Spencer, R.W. Variation of Critical Flicker Frequency in the Nasal Visual Field. A.M.A. Arch. Ophthal, 1953, 50, 50-63.

Measurements of the critical flicker frequency in the center and along the horizontal meridian in the nasal part of the visual field made every 1 degree for two observers showed that if variations in the size of the entrance pupil were prevented from influencing the amount of retinal illuminance the critical flicker frequency was successively less with increase in peripheral angle. If variations in the size of the entrance pupil were permitted to influence the amount of retinal illuminance, on the other hand, the critical flicker frequency for the peripheral field was higher than that for the central visual field. The decrease of the critical flicker frequency with increase in peripheral angle was much less than the corresponding decrease in visual acuity and than the decrease predicted if the perception of peripheral flicker were merely a function of scattered light within the eye. The variation of central critical flicker frequency with size of entrance pupil could be predicted with reasonable accuracy if consideration was given to the variation of retinal illuminance and to the Stiles-Crawford effect. The critical flicker frequency for the blind spot was significantly lower than that for immediately adjacent functional portions of the visual field.

4. Alpern, Mathew & Sugiyama, Sadao. Photic Driving of the Critical Flicker Frequency. J. opt. Soc. Amer., 1961, 51, 1379-1385.

A light pulsing above the critical flicker frequency (CFF) significantly elevates, and one pulsing below CFF significantly, depresses, subsequent CFF measurements. The characteristics of these phenomena, their dependence upon the duration of fixation, the luminance of the measuring, and the adaptation lights, and the duration of the after effect are described in the present series of experiments. The effects are virtually as pronounced if the pulsing adaptation light is viewed with one eye and the measuring light with the other, as when both adapting and measuring lights are seen by the same eye. It is proposed that the driving is a direct consequence of a change in the frequency characteristics of the responses of cells in the visual system to photic stimulation. Measurements of the brightness of lights, pulsing at various rates immediately after viewing lights pulsing above and below the CFF, confirm certain predictions of this hypothesis.

5. Bach, L. M. N. ERDL - Tulane Symposium on Flicker, New Orleans. 1957. (AD 155-440).

The primary purpose of this symposium was to establish research leads which could assist in arriving at answers needed to such practical questions as whether or not flicker could interfere with the consciously directed tactics employed by the soldier in battle. However, the symposium provides a very valuable and extensive summary of basic and applied research on many aspects of flicker, with emphasis on the effects of flicker on human behavior and consciousness.

6. Bach, L. M. N. Effect of Flicker on Humans. Conference Report. 3d Annual Army Human Factors Engineering Conference. October, 1957. Quartermaster Research and Engineering Command, Natick, Massachusetts. (Abstract)

The present experiments were undertaken with the idea of trying to develop the use of a flickering light source which would provide a possible tactic in battlefield operations by causing some degree of interference with the cognitive functions of enemy troops.

The principal findings of this investigation are that flickering lights between 7 cps and 20 cps, but particularly at 9 cps, are effective in producing sensations relating to interference with consciousness. It is felt that such sensations are indicative of real, but ineffectual, interference with cognition by flickering light. To achieve objective and effective interference with consciousness by flickering lights or by any other suitable technique will probably require (a) a better knowledge of the basic physiological nature of consciousness and sleep and (b) possibly other, even radically different, techniques than flickering light alone.

7. Barlow, H. B. & Hill, R. M. Selective Sensitivity to Direction of Movement in Ganglion Cells of the Rabbit Retina. Science, 1963, 139, 412-414.

Among the ganglion cells in the rabbit's retina there is a class that responds to movement of a stimulus in one direction, and does not respond to movement in the opposite direction. The same directional selectivity holds over the whole receptive field of one such cell, but the selected direction differs in different cells. The discharge is almost uninfluenced by the intensity of the stimulus spot, and the response occurs for the same direction of movement when a black spot is substituted for a light spot.

The authors believe these observations exclude simple explanations of movement sensitivity in terms of pooled effects from "on" and "off" zones of the receptive field. Exploration with a stationary spot turned on and off, and noting the phase at which the discharge occurs, did not provide a sufficient basis for predicting the response to a moving spot. It is concluded that two synaptic layers can abstract direction of motion from the spatio-temporal pattern of light falling on the retina, and that the rabbit possesses such a system of directionally selective ganglion cells in its retina.

This research at least suggests the possibility of direction-specific movement and apparent-movement receptors in the human retina.

8. Bartley, S.H. The Psychophysiology of Vision. In S.S. Stevens (Ed.), Handbook of Experimental Psychology. New York: Wiley, 1951. Pp. 921-984.

This chapter of the handbook summarizes the state-of-knowledge regarding flicker, flicker fusion, and brightness enhancement as of 1951. Figure 58 of the report illustrates the salient features of the data collected on brightness enhancement up to that time.

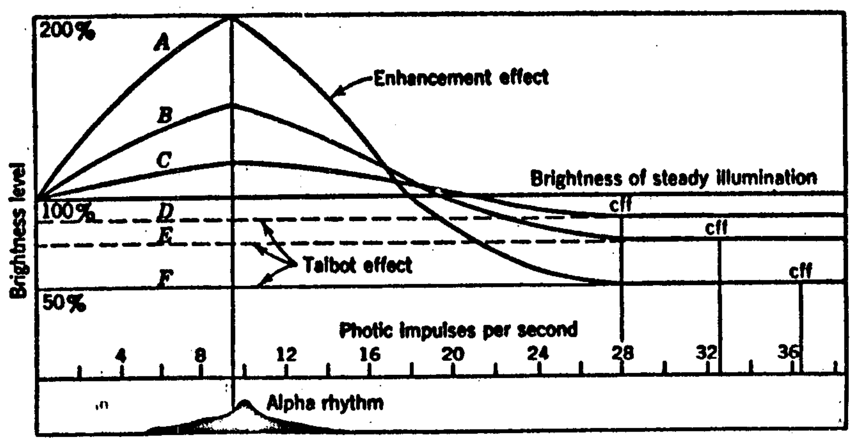

Figure 58. At some subfusional pulse frequencies the brightness of the pulses appears greater than the brightness of steady illumination of the same plysical intensity. This enhancement is maximum in the neighborhood of 10 pulses per second. The three curves represent three different LDR's. A = 1/1; B = 7/2; C = 8/1. D, E, and F are the Talbot brightnesses for these ratios. The Talbot brightness is the brightness predicted by Talbot's law: rapid intermittent stimuli produce a brightness equal to that produced by a steady stimulus having the same average intensity.
(Bartley, 1939.)

9. Bartley, S.H. Brightness Enhancement in Relation to Target Intensity. J. Psychol., 1951, 32, 57-62.

According to Talbot's law, when intermittent stimulation results in perceptual continuity, the resulting brightness of target surface is as though the stimulus has been uniformly distributed throughout the cycle. Thus if the stimulus period and the nonstimulus period are of equal length, the result is a brightness one-half as great as would be produced with the same stimulus continuously applied.

Brightness enhancement likewise bears a consistent relation to the ratio of the two parts of the stimulus cycle, and also depends upon the rate of intermittency. As pulse rate drops from c.f.f., brightness, which begins at the level designated by Talbot, begins slowly to rise. Whereas brightness begins as less than that produced by continuous stimulation it comes to be equal to it and then surpasses it. Previous studies have found brightness enhancement to be at a maximum at the rate of the alpha rhythm, i.e., in the neighborhood of 10 cps.

On the basis of psychophysical and neurophysiological evidence the author attributes brightness enhancement to cortical "driving" -- i.e. the intermittent stimulation setting up its own alpha waves in the cortex, but states that further investigation must continue to take into account the conditions that produce the various sizes of cortical response. Since no driving occurs with very weak stimulation, weak intermittent visual stimulation may fail to produce brightness enhancement. Likewise, in keeping with what is known about driving, monochromatic light may be somewhat more effective than white, and wave lengths toward the blue end of the spectrum may be most effective.

The results of this study are the first to bear on the question of whether weak stimulation results in brightness enhancement. The results are summarized in figure 1 of the report in which the graph for the author's observations are depicted. The same pattern of results was obtained in the data for each of the three observers; namely, that (a) at high intensity levels the intermittent stimulation was more effective than the continuous, (b) throughout a small intermediate range the two were substantially equivalent, and (c) at low levels of intensity the intermittent stimulation was less effective.

The straight diagonal line indicates where the curve should lie were intermittent and continuous light to be equally effective at all intensities, and the line parallel to it, in the upper righthand corner, shows where the curve would lie were intermittent stimulation twice as effective. It can be seen that the intermittent stimulation at the highest levels was approaching this double effectiveness. At the low levels the continuous illunination was about 14.0 times as effective as the intermittent. It is not certain whether the intermittent stimulation reached its minimum effectiveness or not. The levels used at the lower end of the intensity scale were not close enough to each other to indicate the true shape of the curve. It was concluded that weak stimulation does not produce brightness enhancement with the spatial arrangement of target used, although the same target manifests enhancement with intense light.

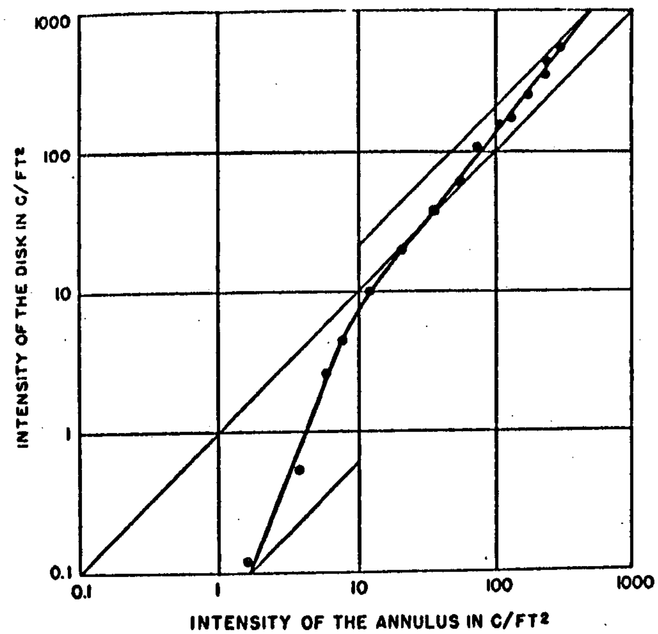

Figure 1. THE RELATION OF THE INTENSITY OF A STEADILY ILLUMINATED DISK TO AN INTERMITTENT RING (ANNULUS) IMMEDIATELY SURROUNDING IT (The entire test-object covered about six degrees of visual angle. No fixation point was used. Each point on the curve represents a mean of 10 readings for one observer.)

See reference No. 10 below, in which brightness enhancement of weak intermittent stimulation was found at lower frequencies.

10. Bartley, S.H. Intermittent Photic Stimulation at Marginal Intensity Levels. J. Psychol., 1951, 32, 217-223.

A previous study using only 10 cps apparently verified the idea that weak intermittent stimulation would produce little or no brightness enhancement since it fails to drive the cortex. (10 cps is the critical frequency region found to produce maximum brightness enhancement with strong intermittent stimulation, producing a brightness approximately double that of steady stimulation of equal physical intensity). This study investigated the effect of other frequencies and the effect of target area, using a pulse to cycle fraction (PCF) of .5. Definite brightness enhancement of marginal intensity stimuli was found with three of the four observers. The results are summarized in figure 2 of the report. The dotted line A shows the results generally found with higher intensity intermittent stimulation for comparison.

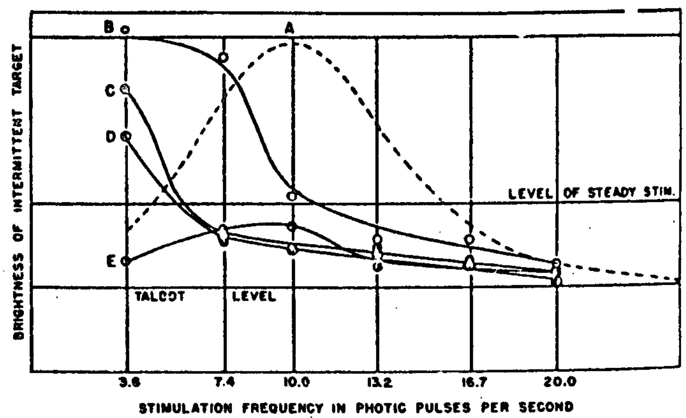

Figure 2. BRIGHTNESS ENHANCEMENT OBTAINED WITH FOUR OBSERVERS USING A REFERENCE TARGET AT A LEVEL OF 0.007 C/FT^2; EACH CURVE IS FOR A SINGLE OBSERVER, DRAWN FREELY THROUGH THE POINTS OBTAINED, EACH OF WHICH IS THE MEAN OF FROM 40 TO 80 READINGS

There was a statistically insignificant trend for the enhancement to be greater with smaller targets.

11. Bartley, S.H. Brightness Enhancement When Entopic Stray Light is Held Constant. J. Psychol., 1952, 33, 301-305.

The results indicate that less brightness enhancement occurs when otherwise fluctuating stray light is made uniform. The shift from the usual condition to the uniform condition represented a temporal redistribution of the same amount of light wherein more of it was applied between the intermittent pulses (in the "dark" period).

12. Bartley, S.H. Brightness Comparison When One Eye is Stimulated Intermittently and the Other Eye Steadily. J. Psychol., 1952 34, 165-167.

On the basis of the results it is concluded that intermittent stimulation is decidedly more effective when it falls upon an eye that is not stimulated between pulses by steady light from some other source. This corroborates the expectation of the neurophysiological theory. It must also be remembered that the absence of stray light in the area of the intermittent image reduces the amount of light adaptation that would otherwise be produced. For this non-neural reason, a better response would be expected than were the extra light adaptation (less dark adaptation) produced. Part of the difference in results under the two experimental conditions used may be due to this.

13. Bartley, S.H. Light Adaptation and Brightness Enhancement. Percept. mot. Skills, 1957, 7, 85-92.

The existence of four kinds of end-results found in dealing with intermittent stimulation was pointed out. Since all of these facts do not seem to be commonly regarded in connection with each other in the literature, their interrelations were discussed. Four facts stand out among the others. The first fact is that all targets of the kind used in brightness enhancement experiments produce some amount of light adaptation. The second is that the intermittent stimulation is, under some conditions, more effective than steady stimulation in producing brightness when duration of target presentation is other than brief. This may be determined by the difference in the amount, of light adaptation produced by the steady and intermittent targets, which if great would bias the comparison in favor of the intermittent. The third fact is that photic pulse rate is crucial in determining target effectiveness. And the fourth is that brightness enhancement is not produced by other than strong intensities of photic radiation. These last two facts point to the operation of the neural mechanism previously described by Bartley. Several ways of determining the relative effectiveness of steady and intermittent stimulation were described. The purpose of the discussion aside from the one just implied was to further the interest in and the study of brightness enhancement.

14. Bartley, S.H. Some Factors Influencing Critical Flicker Frequency. J. Psychol., 1958, 46, 107-115.

The present paper has stated one of the major unsolved questions stemming from the findings of various investigations on critical flicker frequency. Various workers obtained what looked to be contradictory results in relating pulse-to-cycle fraction ("light-dark ratio" in the intermittency cycle) to critical flicker frequency. It was shown in the paper that these diverse findings are, at least in part, a function of the level of target intensity used. Incident to the solution of this problem, it was deduced from the data curves that more than one pulse-to-cycle fraction for a given critical flicker frequency could be expected at some intensities. This was supported by references to certain findings in neurophysiology in regard to the conditions for emergence and inhibition of the off-discharge in the optic nerve.

15. Bartley, S.H. & Nelson, T.M. Equivalence of Various Pulse-To-Cycle Fractions in Producing Critical Flicker Frequency. J. opt. Soc. Amer., 1960, 50, 241-244.

An earlier investigation of the senior author suggested very strongly that various quite different PCF's (pulse-to-cycle fractions) were, under some conditions, equivalent in producing CFF. This was contrary to common expectation, and was not fully confirmed by the scant amount of data then obtained. The present study consisted of testing the earlier suggestions by the use of seven observers using one method, and two observers using a second method of collecting data. The CFF's for each of the following PCF's 1/30, 1/8, 1/4, 1/2, 3/4, 7/8, and 29/30, were obtained as the photic intensity was varied. In Part I, the range was from 1.28 c/ft^2 to 1164 c/ft^2. In Part II, the range was from 0.014 c/ft^2 to 1400 c/ft. The data produced families of curves, one curve for each PCF. Some pairs of these curves cross each other, the points of crossing indicating that, under those conditions, two PCF's were equivalent.

The results of this study are summarized below in figure 1 of the report.

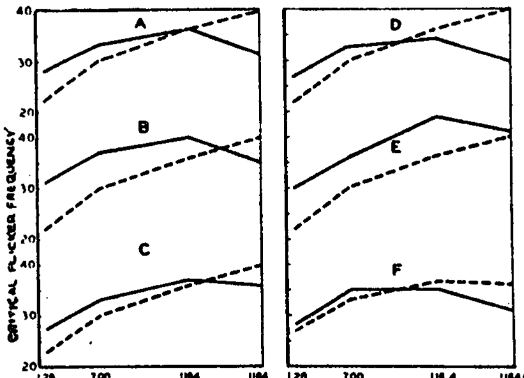

Figure 1. Pairs of curves which cross (means for 6 observers). In A-E, the solid curves are PCF = 1/30. In A, broken curve = PCF = 1/8; in B, PCF = 1/2; in C, PCF = 3/4; in D, PCF = 7/8; and in E, PCF = 1/4. In F, solid curve, PCF = 3/4, broken curve, PCF = 1/8.

16. Bartley, S.H. & Nelson, T.M. A Further Study of Pulse-to-Cycle Fraction and Critical Flicker Frequency. A Decisive Theoretical Test. J. opt. Soc. Amer., 1961, 51, 41-45.

Various curves relating CFF to log I cross each other when these curves represent different PCF's (pulse-to-cycle fractions). This was interpreted by Bartley to mean that PCF and conditions of flicker and fusion are not simply related, as has been generally taken for granted. He supposed that, whereas short pulses in a given repetitive cycle would produce flicker and longer pulses would produce fusion, still longer ones would reintroduce flicker, and finally the longest ones would produce fusion. An electronic fusion apparatus producing square waves and varying PCF from 0.02 to 0.98 was used to test this directly. PCF was varied over this range while CFF (and thus cycle length) and intensity were held constant. The supposition was readily confirmed. In addition, data were collected suggesting that the very shortest pulses would produce fusion rather than flicker at some intensity levels.

17. Bartley, S.H., Paczewitz, G. & Valsi, E. Brightness Enhancement and the Stimulus Cycle. J. Psychol., 1957, 43, 187-192.

The PCF, the pulse-to-cycle fraction of the intermittent stimulation was manipulated from 0.2 to 0.9 for two different photic pulse rates, 10.6 and 32 cycles per second. It was found that, according to expectations, shortening the pulse increased brightness enhancement, except for terminal conditions which were discussed. The results for these conditions do not seem to run counter to the expectations from what we know about the neurophysiology of the optic pathway including the interpretation known as the alternation of response theory. In fact, the present findings tend to corroborate the theory.

The results are summarized in figure 1 of the report.

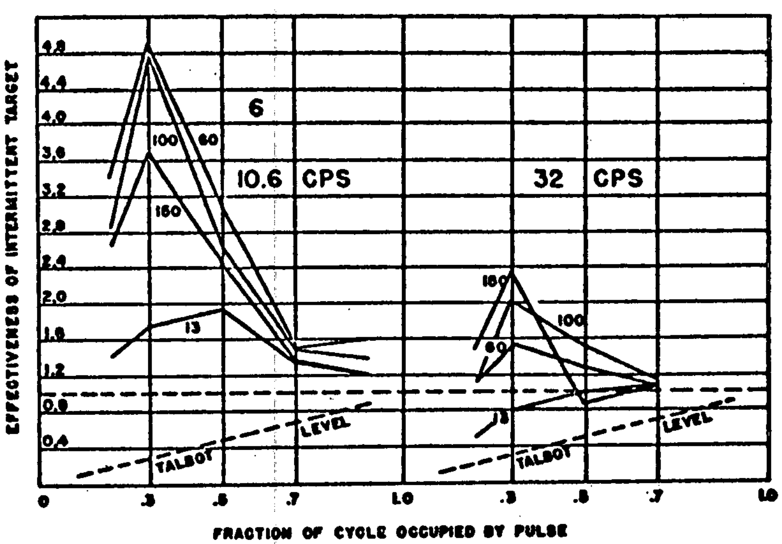

Figure 1. The relation of the effectiveness of intermittent stimulation to the fraction of the cycle occupied by the pulse. The horizontal line represents the effectiveness of steady stimulation of the same intensity as the intermittent.

The four curves for each frequency show the effect of four levels of constant luminosity in c/ft^2 of a steady ring surrounding the disk which was the intermittent part of the target.

See reference No. 114.

18. Battersby, W.S. & Jaffee, R. Temporal Factors Influencing the Perception of Visual Flicker. J. exp. Psychol., 1953, 46, 154-161.

A study of the temporal factors influencing CFF was performed. Using a "square" wave stimulator, an electronic interval timer, and a gas discharge tube, measures of CFF were taken from two Os when the over-all duration of exposure of the intermittent light was varied from 140 to 1000 msec. for each of three relative light percentages (light-dark ratios). For both Os, the plot of CFF vs. exposure time was a rising function of negatively accelerated slope. The magnitude of the slope of these functions varied with the percentage of the period occupied by light (in the order 50%, 20%, 80%). When the data were replotted in terms of number of light flashes at fusion vs. exposure time (as contrasted to frequency of flashes, or CFF, vs. exposure time), a linear curve for each light-dark ratio was found. These findings indicate that CFF, expressed in cps, varies systematically as exposure time is shortened, but that the number of flashes per unit time is relatively constant at fusion.

When the raw data obtained with each light-dark ratio were equated for total energy content, it was found that the longer the relative dark interval in an intermittent light cycle, the greater the ability of O to discriminate between successive flashes. These results are compatible with concepts of "excitation" and "recovery" in the visual system, but are equally predictable from either neural or photochemical theory. It is suggested that the relative merits of these theories can only be appraised in experiments where neural or photochemical factors are directly manipulated.

19. Berger, C., Mahneke, A. & Mortensen, O. Electronic Flicker Apparatus with Automatic Frequency Variation. J. opt. Soc. Amer., 1955, 45, 307-308.

An electronic apparatus is described which delivers light flashes with intensity, light-dark ratio, and frequency as independent variables. The flash rate is varied automatically, and is proportional to the voltage on the control grid of the charging pentode. The control voltage is taken from a highly isolated condenser through a cathode follower with very low grid current. When the condenser is charged or discharged by a constant current, the control voltage, and hence the frequency, will change proportionally with time. The rate of frequency change is determined by the magnitude of the current, and can be started or reversed either manually or by a saw-tooth voltage. This automatic and variable frequency variation makes it possible to keep the conditions more constant from measurement to measurement for each rate of frequency change, and to compare the effect of varying speed of frequency variation as well as of the duration of series of exposures (prethreshold exposure time) upon FFF (flicker fusion frequency) with significant precision. These factors are important for the standardization of FFF determinations.

20. Bittini, M., Ercoles, A.M., Fiorentini, A., Ronchi, L. & Di Francia, G.T. Enhanced Contrast of an Indefinitely Contoured Object by Movement or Intermittent Illumination. Atti Della Fondazione Giorgio Ronchi, 1960, XV, 62-84.

The research is divided into two parts. The first part is concerned with the effects of motion upon vision. The so-called Mach bands, which are responsible for a subjective sharpening of the vision of a blurred contour, have been found to become more conspicuous by a slow circular movement of the observed contour. The results for the dark band are very similar to those for the bright band. This shows that the effect of a time gradient of illumination on the retina is not only to increase brightness sensation but also to enhance inhibition. The results are discussed in terms of retinal inhibitory mechanisms. The second part of the research is concerned with some effects of intermittent illumination upon vision. The perception of contrast, in extrafoveal vision, at mesopic and scotopic levels, under steady illumination, is compared to the perception of contrast under pulsating illumination. Further, the effects produced by sequences of triangular and rectangular pulses respectively are compared. The peak luminance level is the same in every case. For pulsating illumination the light-dark ratio is equal to unity. At scotopic levels the sequence of rectangular pulses is found to be the least effective, while, at least in the range of luminances investigated, the sequence of triangular pulses is found to be as effective as the steady illumination. At mesopic levels, in a particular range of frequencies including fusion conditions, for green and blue light, a sequence of rectangular pulses allows a better perception of contrast than a steady illumination of equal peak level the sequence of saw-tooth stimuli seems to be of advantage for green light only, and in a very narrow range of frequencies in the neighborhood of fusion. The last result for green light is also found by comparing the effects of sequences of rectangular and triangular pulses of equal energy and different peak level, and varying the contrast. These findings are discussed in terms of retinal duality and the role played by psychological factors is also taken into account. An electrical parallel is suggested which might explain, at least partially, the observed effects.

The results of the first part of the study are summarized in figure 1.3 of the report. The test field contained three zones: a uniformly bright zone, a uniformly dark zone, and a zone between these two (zone b) in which luminance varied linearly from that of the bright zone to that of the dark zone. Therefore, in figure 1.3, the wider zone b, the less of a brightness gradient was required to see the Mach bands. The width of zone b is plotted as a function of frequency and angular amplitude (θ) of movement.

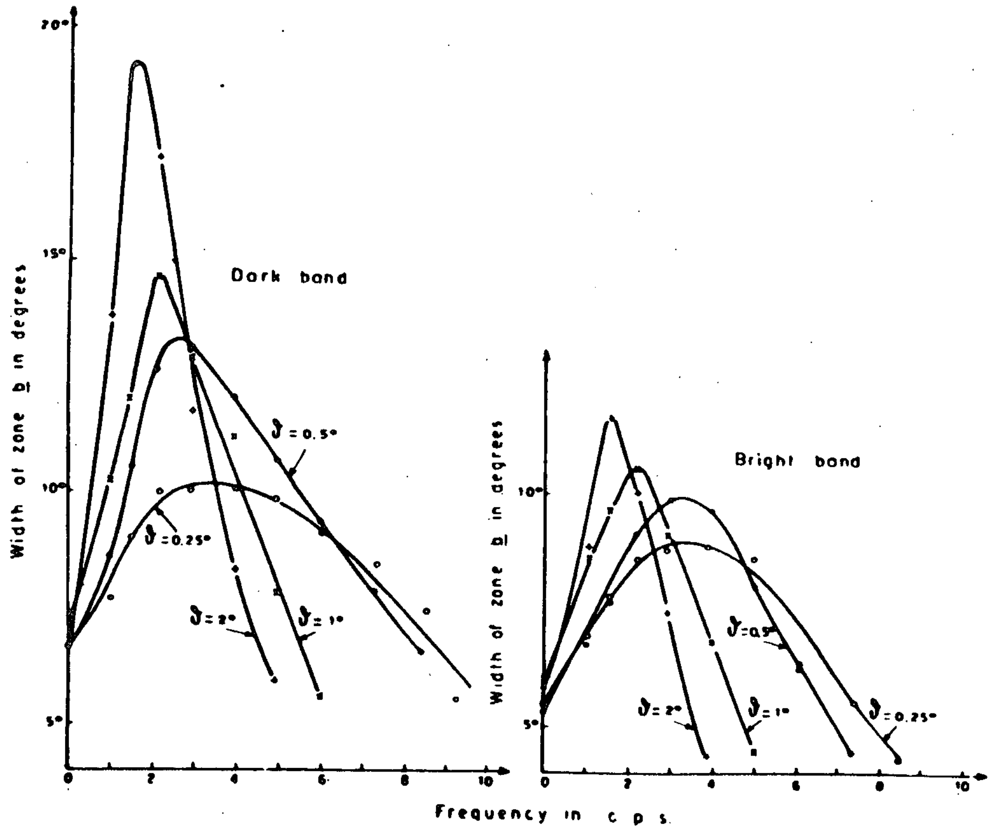

Figure 1.3

Some of the results obtained in the second part of the study are shown in figure 2.4(b) of the report. The visibility of a blurred vertical stripe as indicated by the percent of times that it was seen by the subject is plotted as a function of the luminance of the test field. The squares indicate the curve obtained with square-wave intermittent illumination of the stripe, the triangles the curves obtained with sawtooth illumination, and the circles the curve obtained with steady illumination. These curves were obtained with the observer viewing the test field through a green filter.

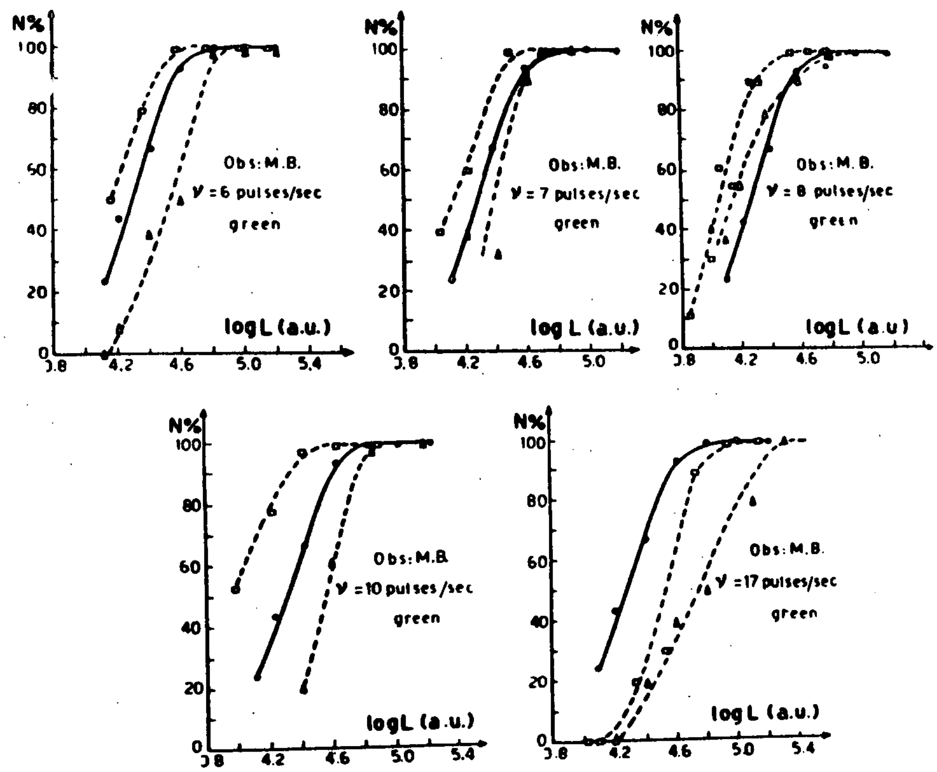

Figure 2.4(b)

21. Bittini, M. & Ronchi, L. On the Factors Which Influence the Human Scotopic Electroretinogram at Different Luminance Levels. Atti Della Fondazione Giorgio Ronchi, 1958, XIII, 318-323.

The authors investigate how factors such as the total time of variation of the luminance and the behavior of the time derivative of luminance influence the human scotopic electroretinogram. The first factor is found to influence the response to green (but not to blue) stimuli; the amount of the effect is noticeable at low levels and decreases when luminance is increased. The latter factor seems to be unimportant at any level for both colors. The results are discussed in terms of the cues for brightness discrimination furnished by the electroretinographic response. (See references No. 20 and 37).

22. Blackwell, H. R., Pritchard, B.S. & Ohmart, J.G. Automatic Apparatus for Stimulus Presentation and Recording in Visual Threshold Experiments. J. opt. Soc. Amer., 1954, 44, 322-326.

An apparatus is described which automatically controls the presentation of light stimuli and records subjects' responses in visual threshold experiments. The apparatus includes: (a) A tape reader which controls the magnitude and time of occurrence of light stimuli, in accordance with the location of holes in a programming tape, and (b) a punch recorder which makes a permanent record of the conditions of each light stimulus and of the responses made by each of four subjects. The accuracy of the stimulus-producing equipment is monitored. Electric counters tally the correct responses made by each subject for each magnitude of light stimulus.

23. The Boeing Company. Factors Affecting Change Discrimination. Paper read at Symposium on Human Factors Aspects of Photo Interpretation. Rome Air Development Center, Griffis Air Force Base, N.Y. November 1962.

The results to date of an ongoing human factors research program were described. The main research objectives were to: (1) determine the critical factors related to the imagery interpreter's ability to discriminate changes in the image situation; and (2) to develop an effective technique for change detection through optimal man-machine organization. The program has been in progress at the Seattle facility for two years.

The results of the study program were summarized as follows:

1. The most critical problem in future military photo interpretation tasks derives from the excessive work load confronting the interpreter. The average field Army will acquire 144,000 images of surveillance information every day. At current rates of processing it will require 48,000 man years to interpret one years collection of data.

2. Boeing elected to work on the problem of improving the interpreter's ability to detect change in the image situation, this being one of the more time consuming tasks and one which is not amenable to mechanization. The specific study objective was to explore three techniques of comparison viewing.

   a. positive negative overlay
   b. side-by-side simultaneous comparison
   c. superimposed alternate viewing of imagery (induced apparent motion)

3. In an experiment with photo interpreters with various levels of experience, it was found that apparent motion methods were far superior to the other viewing methods in terms of accuracy and rate of performance. It was also noted that inexperienced photo interpreters were as effective as experienced photo interpreters in identifying targets and detecting change. It was concluded that naive interpreters could be used for preliminary screening of imagery and that apparent motion techniques offer the best means for change detection.

24. The Boeing Company. Aerial Recon Steps Ahead. The Boeing Magazine. Feb. 1963.

This article summarizes the results of the Boeing studies on the use of apparent movement in photo comparison. Three methods of change detection were studied. The overlay method consisted of superimposing positive and negative time-separated negative photographs slightly off-register, and shining a light through them. Any difference could be seen as lines or shapes that did not coincide. The apparent movement method consisted of projecting time-separated photographs on a screen alternately at 1 1/2 cps, where any difference could be seen as a flicker swell or movement. The side-by-side method consisted of simply presenting time-separated photographs side-by-side for comparison.

The efficiency of 15 to 18 observers was compared, using each of the three methods. Each observer examined from 36 to 72 photos. The photos had from zero to six changes between each mated pair, though this was not known to observers. An observer's score was based on the number of errors made and on the time required to detect the changes.

Under the worst conditions of visual noise employed (e.g. detecting target changes on photos shot from camera angles differing by 58 degrees, where identical landscape appear very dissimilar) only 38 per cent of the changes were undetected using apparent movement, versus 75.7 per cent for side-by-side comparison and 87 per cent for the overlay method. The overlay method was found to be fastest, taking an average of 53 seconds, versus 60 seconds for apparent movement and 154 seconds for the side-by-side method. Using the side-by-side method, observers frequently gave up looking, assuming that remaining changes were almost impossible to find.

Under low visual noise conditions (clear photos, identical camera angles), omission errors were chopped to seven per cent. All experiments showed the apparent motion method to be relatively fast and from two to forty-three times as accurate as the other methods.

The importance of these studies is illustrated by a hypothetical but realistic case. If a field army were to index 144,000 photographs a day, 1,737 men would be needed to do the job in three hours by the side-by-side technique. This would give combat commanders the rest of the day for decisions and actions. Using apparent motion machines the same job could be done by 670 men.

Note: This research is also summarized in Lorant, M. Advanced Aerial Photo Comparing Techniques by the Aid of 'Visual Noise'. Brit. J. Photog. May, 1963. 436.

25A. Boynton, R. M., Sturr, J. F. & Ikeda, M. Study of Flicker by Increment Threshold Technique. J. opt. Soc. Amer., 1961, 51, 196-201.

Increment thresholds of a small test flash are measured with the flashes superposed upon a flickering background stimulus. Instrumentation is described that permits accurate temporal positioning of the test flash within the light-dark cycle of the background field, and allows rapid threshold measurements to be obtained for the test flash in any desired temporal position. It is found that the increment threshold rises with the light phase and falls with the dark and that this undulation in threshold (believed related to "on-responses" in the human visual system) persists even when the luminance of a 30-cps flickering background stimulus is made too low for the flicker to be perceptible. Other experiments are also described and interpreted.

25B. Briggs, S.J. & Carter, V.E. Application of Visual Flicker in Optical Rangefinders. Paper read at Annual Meeting of the Human Factors Society, New York. November 1962.

The purpose of this investigation was to apply certain psychological phenomena, i.e., apparent movement and brightness enhancement, to the development and design of a new concept in optical rangefinders -- a "flicker" rangefinder. The concept of a flicker rangefinder may best be described by comparison with a normal coincident rangefinder. In a coincident rangefinder, images from the right and left optics are combined and presented simultaneously to the viewer through a monocular eyepiece. In a flicker rangefinder, the two images are presented alternately at certain less-than-fusion frequencies to the viewer.

The first step of the study was to obtain two M-17C rangefinders and experimentally determine that they had equivalent ranging characteristics. One of the rangefinders was modified to incorporate flicker and became the "experimental" model. The remaining unmodified rangefinder became the "control".

The next step was to design an experiment which would compare the two rangefinders and, in addition, gather data relevant to the design of advanced flicker rangefinders. The first objective was met by a 4 x 3 x 5 (flicker rate x range x subject) mixed model factorial design plus certain individual comparisons. The second objective, to gain flicker rangefinder design information, was met by analyzing the flicker rangefinder data only. Thus, a second mixed model factorial design (3 x 3 x 5) was implicit in the basic design.

Flicker rate was assigned four levels, 0, 3, 4, and 5 cps designated F_0, F_3, F_4, F_5, respectively. The coincidence rangefinder data was designated F_0 (zero flicker). F_3, F_4, and F_5 data were obtained by operating the flicker rangefinder at different speeds. Range took 3 levels, 830, 1600, and 2600 meters, designated R_S, R_M, R_L respectively. Trucks were used as targets at the short and long ranges. A large tree served as a target at the middle range. The five subjects were Nortronics engineers between the ages of 24 and 39. All had normal far vision (corrected); two had some degree of color blindness.

There were two prerequisites for selecting the dependent variable. First, the criterion measurement units should permit comparisons between ranges. Second, the criterion should measure the variability of ranging estimates rather than their accuracy per se. That is, just as the quality of a rifle is determined by the size of the shot group (variable error) and not by the fact that the sights were misaligned (causing constant error), the quality of a rangefinder is determined by the variability of the range estimates and not by a constant error which can be corrected by equipment adjustment. The first prerequisite was met by expressing the variance in terms of an angular measurement which was independent of range. The angular unit chosen was one which is traditional in rangefinder measurement and is called "Unit of Observable Error" (U.O.E.). The second prerequisite was met by using the variance of seven observations made by each subject under each condition. Thus, while the analysis of variance was performed on only one score per cell, each cell entry was actually one variance estimate (in U.O.E.'s) based on seven observations. An analysis of variance of variances requires that the variance estimates be subjected to a logarithmic transformation. Once this transformation was made the statistical analysis was performed as usual.

The most important finding is the decrease of ranging variability using flicker. When averaged across all subjects and conditions, the variability of the flicker rangefinder (expressed in standard deviations) is reduced to less than half that of the coincident. Essentially, flicker doubled the "goodness" of the rangefinder. This effect is equivalent to doubling the rangefinder base length.

The range effect was not significant. The individual comparison, short (R_S) vs long (R_L) range where similar targets were used was a better test of range per se but this was also not significant. The comparison of the combined data ($R_S + R_L$) vs (R_M) was not significant indicating no difference found between the tree vs truck targets.

No individual differences were found between the five subjects. This appears a bit unusual in psychological experimentation; however, it must be remembered that the measured variable was a variance and that homogeneity of variance among subjects is not unusual.

The flicker frequency (F) by range (R) interactions were significant for both the combined data and the flicker data only. This latter significant interaction suggests the possibility of including an automatic control which would adjust the flicker frequency with changes in range. Individual comparisons made to identify the nature of the frequency-range relationship found the $F_{quadratic} \times R_{linear}$ interaction significant. A response surface fitted to this interaction data was difficult to defend logically. It is felt that further research is needed for confirmation. The flicker-frequency by subject comparison, using flicker data only, was significant. This finding suggests the need for a manual frequency control.

The range by subject interaction was significant, showing that certain subjects were relatively better at certain ranges. This finding has no apparent implication for equipment design.

It is felt that the usefulness of flicker is applicable to many systems where visual detection of small differences is required. We currently are investigating flicker's application to comparison aerial photographic viewers, to cathode ray tube displays, and to night binoculars. This latter area of application was prompted by a subjective observation made during the experiment. On one occasion, the target was not visible to the subjects when viewed through the coincident rangefinder yet was readily detectable with the flicker model - a finding which seems to substantiate a brightness enhancement effect using flicker.

See reference 91, the final report for the study summarized in this paper. Figures taken from the report are provided which illustrate the results.

26. Brink, Frank, Jr. Excitation and Conduction in the Neuron. In S.S. Stevens (Ed.), Handbook of Experimental Psychology. New York: Wiley, 1951. Pp. 50-93.

This chapter of the handbook summarizes the state-of-knowledge on neuron excitation and conduction as of 1951. Figure 25 of the handbook illustrates the supernormal excitability period of certain neurons, often hypothesized to be an important factor in explaining enhancements due to intermittent stimulation.

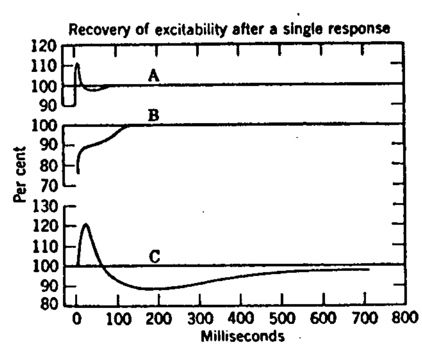

Figure 25. Excitability curves of A-, B-, and C-fibers. During the negative after-potential the fibers have supernormal excitability, and during the subsequent positive potential there is subnormal excitability. The sequence of changes in the C-fibers resembles those for the A-fibers except in duration. In keeping with the absence of negative after-potential, there is no supernormal period in the B-fibers. (Gasser, 1939.)

27. Brown, C. R. Symmetry of Fused Complex Visual Stimuli. II. Asymmetry of Duty Ratio. J. opt. Soc. Amer., 1959, 49, 1134. (Abstract)

In demonstrating the time symmetry of fused trains of complex light pulses, a duty ratio of 0.5 was used. A further type of symmetry demanded by the Fourier model concerns the use of complementary duty ratios. If pulse height and mean luminance are kept constant, the Fourier amplitude-frequency components of a stimulus with a given duty ratio are the same as the amplitude-frequency components of a stimulus with the complement of that duty ratio. Thus under the appropriate conditions a stimulus train with a duty ratio of 0.1 should yield the same fusion point as a stimulus train with a duty ratio of 0.9. The present experiment has used intermittent stimuli of two alternating durations, with duty ratios ranging from 0.05 to 0.95. Pulse height and mean luminance were kept constant by superimposing the stimulus signal on a carrier signal of adjustable luminance. The results show that the fusion points of stimulus trains of complementary duty ratios are in fact different; the amplitude-frequency components of the Fourier analysis do not determine when fusion will occur. By manipulating duty ratio, the shape of the fusion contour for intermittent photic stimuli of two alternating durations may be markedly changed.

28. Brown, Charles R. & Forsyth, D. M. Fusion Contour for Intermittent Photic Stimuli of Alternating Duration. Science, 1959, 129, 390-391.

It is generally thought that fusion of intermittent photic stimuli occurs when the duration between successive pulses of light is reduced to a certain value, this value being a function of the illumination and viewing conditions. The findings described in this report show that fusion is determined not only by the duration between successive stimuli but also by the temporal pattern of successive stimuli.

29. Brown, I.D. & Gibbs, C.B. Flashing Versus Steady Lights as Car Turning Signals: The Effects of Flash Frequency and Duration of Flash. A.P.U. 245/58, April 1958. Applied Psychology Research Unit, Medical Research Council, Cambridge, England.

(a) When "flashing" was the only cue for discrimination between light signals, flashes of short duration were found necessary to obtain quick motor responses. These findings refer to laboratory viewing conditions, when the signal appeared in an area subtended by ±1 1/2° of visual angle, i.e., within central vision. (b) A steady light was found more effective in immediate attention-getting than any of the flashing lights tested, when no discrimination between signals was required and the signals were spread over a field of view of ±6 1/2° horizontal visual angle and 20° above the line of sight. When signals were not seen immediately a flashing light was noticed more often than a steady light. The overall effect of these two factors was to equalize the attention-getting values of flashing and steady lights, when the criterion was the total number of signals seen in 3 seconds. This result was obtained under simulated daylight conditions on the road. The effects of frequency (1 to 3 cps) and on-off ratio (1/2 to 2/1) were not significant. Brightness contrast affected steady and flashing lights equally.

30. Buchmann-Olsen, B. & Rosenfalck, A. M. Spectral Energy Calibration of a Light Flash Source Used in Physiological Experiments. J. opt. Soc. Amer., 1957, 47, 30-34.

The Sylvania glow modulator tube has been used as a flash light source in physiological and psychological experiments. A set up is described for the study of color vision. Flash duration, intensity, and color were independently variable. The relative spectral concentration of irradiance was determined under different working conditions for three types of Sylvania glow modulator tubes, R_1: IB 59/R 1130 B (new type), R_2: IB 59/R 1130 B (old type), and R_3: R 1131. The variation in relative spectral distribution was no more than 2-3% when a tube was tested regularly both over short and long time intervals. The relative spectral concentration of irradiance varied uniformly as a function of peak current. It did not depend on mean current, i.e., the frequency and duration of the flashes could be varied without influence on the relative spectral concentration of irradiance as long as the peak current was kept constant. A method is described for the calibration of the total energy of the different colored light flashes from the glow modulator tube.

31. Clark, W.C. & Blackwell, H.R. Relations Between Visibility Thresholds for Single and Double Pulses. Project MICHIGAN Report No. 2144-343-T, U.S. Army Signal Corps, Contract No. DA-36-039 SC-52654, 1959.

The detectability of targets consisting of single light pulses of varying duration and of double light pulses of varying temporal separation was measured for seven observers. The data obtained verified the predictive adequacy of the temporal-contribution hypothesis, which postulates that each temporal element of a photic stimulus produces a pattern of neural activity spread out across time. This hypothesis uses double-pulse data to infer the function of the temporal-element contribution, which is then used to predict the relations between exposure duration and detection thresholds for single pulses.

Both double-pulse and single-pulse data showed a characteristic not accounted for by the temporal-contribution function. For double-pulse targets presented for more than 0.07 sec, detectability increased. However, this result was quantitatively predictable by probability summation. Double pulses separated by more than 0.07 sec. allowed an observer to detect the target by either of the two independent events represented by the two pulses. Thus, the neural activity aroused by the two pulses was broken by a cycling characteristic of the nervous system into a series of independent neural events suitable for probability summation.

The light-adapted eye was found to be superior to the dark-adapted eye in detecting pulse interruption, but inferior in temporally summating photic energy.

32. Collins, William E. Luminosity Functions of Normal, Deuteranomalous, and Deuteranopic Subjects as Determined by Absolute Threshold and CFF Measurements. J. opt. Soc. Amer., 1961, 51, 202-206.

Zegers' colorimeter, appropriately modified, was employed to determine the spectral sensitivity of one deuteranopic, two deuteranomalous, and two normal subjects. Absolute threshold data were collected using a 25-min field and CFF curves were determined for both 50-min and 100-min fields. The sensitivity relationships among the subjects differed markedly depending upon technique, flicker rate, and field size. The results seem to indicate that the flicker situation provides a kind of information different from that obtained when absolute thresholds or visual acuities are studied. Research directed toward the relationship between flicker and absolute threshold measures of spectral sensitivity may provide important new data bearing on theories of color vision and color defect.

33. Cornsweet, T.N. & Dwelley, D. Perfectly Stabilized Retinal Images. J. opt. Soc. Amer., 1962, 52, 598. (Abstract)

Objects whose retinal images are stationary with respect to the retina disappear as they are being viewed, but reappear off and on during continuous fixation. It has been argued that the reappearance results from (1) the action of the visual system itself vs (2) actual retinal-image movement due to apparatus artifacts (e.g., contact-lens slippage). Evidence is presented that contradicts the first interpretation and supports the second. An apparatus is described in which an observer may view a real image of his own retinal structure. The image is perfectly stabilized and requires no contact lens. In this apparatus, the viewed pattern disappears rapidly and never reappears unless movement is externally introduced. The relation of this stimulus condition to the viewing of Haidinger's Brushes, Maxwell's spot, and the retinal blood vessels by trans-scleral illumination is discussed.

34. Crumley, L.M. & Atkinson, W. Human Engineering Investigation of the Exterior Lighting of Naval Aircraft. Part 1 - A Study of the Effect of Flash Rate and On/Off Ratio on the Detectability of Flashing Lights. Report TED NAM EL 52003, Naval Air Materiel Center, Philadelphia, Pa., 1954 (AD 44207)

The effect on detection time of flash rate, on/off ratio and subject differences was investigated in a factorially designed experiment involving five flash rates (40, 60, 80, 100 and 120 flashes per minute), five on/off ratios (1/2, 1/1, 2/1, 3/1, 4/1), fifteen stimulus positions and five subjects.

The experiment was conducted in an experimental situation which simulated simultaneously flashing red and green wing-tip lights as they would appear to a pilot about two miles removed from a plane which was approaching him head-on.

Results of an analysis of variance performed on the averages of the fifteen times each flash rate X on/off ratio combination appeared for four subjects (one subject was dropped as atypical) indicated that flash rate was not a factor in the detection time but that there was significant subject X flash rate interaction; that subject was a significant factor and that on/off ratio was significant with ratios below 2/1 better than those above 2/1.

Recommendations are made for further studies to provide for better evaluation of the relationships; for selection of a flash rate for aircraft wing-tip lights based on factors other than those tested; and for use of on/off ratios below 2/1 if simultaneous flashing of wing-tip lights is used.

Note: The finding that flash rate had no significant effect may be a result of the fact that the range of frequencies investigated was extremely narrow (.67, 1.0, 1.33, 1.67, 2.0 cps.).

35. de Lange Dzn, H. Eye's Response at Flicker Fusion to Square-Wave Modulation of a Test Field Surrounded by a Large Steady Field of Equal Mean Luminance. J. opt. Soc. Amer., 1961, 51, 415-421.

With two electrical analogs of the brightness system it is shown that at a low luminance level (< 5 photons) and in the low-frequency region (< 2 cps), when under the special visual conditions no attenuation in the system occurs and with a symmetrical luminance variation such as a sinusoidal modulation or a square-wave modulation with a 1:1 on-off ratio, half the crest-to-trough value of the percentage variation at flicker fusion equals the internal threshold value r_o; but with an asymmetrical variation such as a square-wave modulation with a 1:3 on-off ratio, it is the crest value of the periodical percentage variation above the mean luminance level which at flicker fusion equals the internal threshold value r_o. At high luminance levels an over-shoot in the low-frequency region occurs with both forms of square-wave modulation in accordance with the shape of the attenuation characteristic (AC) of the system under the experimental circumstances. At the steep slope of the ACs for the whole luminance range in cone vision, half the crest-to-trough value of the Fourier fundamental percentage variation at the site of the threshold mechanism located anywhere in the system, equals the internal threshold value r_o at flicker fusion.

36. Denecke, H.J. Method and Apparatus for Eliminating the Dazzling Effect of Strong Sources of Light, Particularly for Automotive Vehicles. U.S. Patent No. 3,049,962. Filed Oct. 1, 1956. Publication Date Aug. 21, 1962.

The present invention relates to and has as its object a method and apparatus for eliminating the dazzling effect of strong sources of light, particularly in connection with vehicles.

In accordance with the invention, intermittent light flashes of high frequency alternately varying in intensity are produced. This type of light, without impairing the view or the necessary lighting and illuminating of the field of view in front of the source of light, avoids any dazzling effect, so that use thereof in vehicle operation, for example, eliminates dazzling while being entirely independent of whether or not a car coming from the opposite direction is provided with such a device. Devices utilizing the intermittent light flashes may be used for all purposes in which a long-beam light produces a dazzling effect, either in the cases of stationary sources of light or lights used on vehicles.

When a sensory organ is excited, an absolute refractory phase followed immediately by a relative refractory phase occur directly after the stimulus is given. If, for instance, a light stimulus falls within the relative refractory phase, then it will be perceived substantially weaker than it actually is, and, as a matter of fact, the weaker, the closer it falls in point of time to the absolute or unresponsive time range of the retina. All these considerations apply to the person looking at the source of light. On the other hand, this light stimulus is perceived in full intensity by an eye looking in the direction of the projection of the light, on which eye no refractory phase was produced. (See references 87 and 109).

37. Di Francia, G. T., Fiorentini, A., Ercoles, A. M., Radici, T., Rositani, L. R. & Bittini, M. Basic Research in the Field of Vision. (Final Report.) AFOSR Technical Report 59-14 Air Force Office of Scientific Research, 1958. (ASTIA No. AD 210473)

The general object of this research program was to investigate some specific effects of contrast and of interactions which arise as a result of variation in light stimuli with time. Three problem areas were selected for investigation.

In part I, the role of eye movements in vision was investigated as an extension of previous studies by the authors' and other researchers. Suppression of movement of retinal images was found to have detrimental effects on border contrast.

Part II investigated mutual binocular interaction. It was found that strong illumination of one eye depressed brightness sensation in the other eye when the latter was illuminated with lower intensity. This binocular inhibition seemed to be independent of the retinal location of the inhibiting stimulus, and to depend on the difference in intensity of illumination between the two eyes.

Part III was an investigation of the influence of time variation in luminance on fusion conditions and on electroretinal response. Some practical applications for night vision suggested by the results were pointed out. To increase the conspicuity of a light signal it was found necessary to not only use a flashing light but to minimize the ratio of the blue components of the light source to the other components. It was found that the visibility of images with diffused boundaries could be improved by illuminating the image with intermittent light near the fusion rate, when the pulse shape, the color of the light, and the luminance level were suitably selected.

The above finding with respect to the importance of minimizing the blue components of a flashing light may aid in further explaining disagreement in the literature with respect to the relative conspicuity of steady and flashing lights. (See references No. 44 and 46).

38. Dondero, A., Hofstaetter, P. R. & O'Conner, J. P. Critical Flicker Frequency in Light-and-Dark Adaptation. J. gen. Psychol. 58, 11-16.

The flicker thresholds of 78 male subjects were obtained in the two states of light-and/or dark-adaptation. In general CFF is higher in the former state than in the latter. Contrary to Hecht's derivation from his biochemical theory of vision this effect is not universal. It does not occur in subjects whose scores fall in the lowest quartile of Taylor's scale of manifest anxiety. The effect is most conspicuous in subjects who fall between the median and the 85th percentile of the Taylor scale.

An alternative interpretation of the adaptation effect in terms of the factors which produce drowsiness during the dark adaptation has been attempted.

The inter-individual variability of the flicker thresholds in the light-adapted state is significantly greater than that in the dark-adapted state. This seems to indicate the greater complexity of the task in the former state.

39. Douglas, Charles A. Computation of the Effective Intensity of Flashing Lights. Illum. Engng., 1957, 52, 641-646.

This report presents mathematical techniques for computing the effective intensity of flashing lights on the basis of the classical findings of Blondel and Rey.

40. Fiorentini, A. & Ronchi, L. Basic Research in the Field of Vision: On the Response of the Human Eye to Light Stimuli Presenting a Spatial or Temporal Gradient of Luminance. AFOSR-Technical Note-56-444, Air Force Office of Scientific Research, 1956.

The role of retinal mechanisms in the perception of spatial and temporal luminance gradients was investigated. In psychophysical studies of the foveal and extrafoveal response to spatial gradients, evidence was found which indicates that (1) a cone-related mechanism is responsible for the light and dark "Mach bands" seen respectively at the light and dark edges of a gradient between bright and dark uniform fields, as well as for the enhanced mean brightness of the area containing the gradient; and (2) a separate rod-related mechanism does not produce Mach bands but can also enhance the mean brightness of the gradient area. The first finding was corroborated by a study with a hemeralopic subject (having no rod vision) and the second finding was corroborated by an electroretinographic study of the extra-foveal response to temporal gradients of luminance. A very interesting result of the electroretinographic study was that slowly-rising or falling stimuli were found to be more effective than stimuli of any other waveform of equal energy. The waveforms B and B', which like C and C' contain only half of the energy of waveform A (see Figure 8 of the report, below), produced an electroretinographic response intermediate between that of C and C', and that of A.

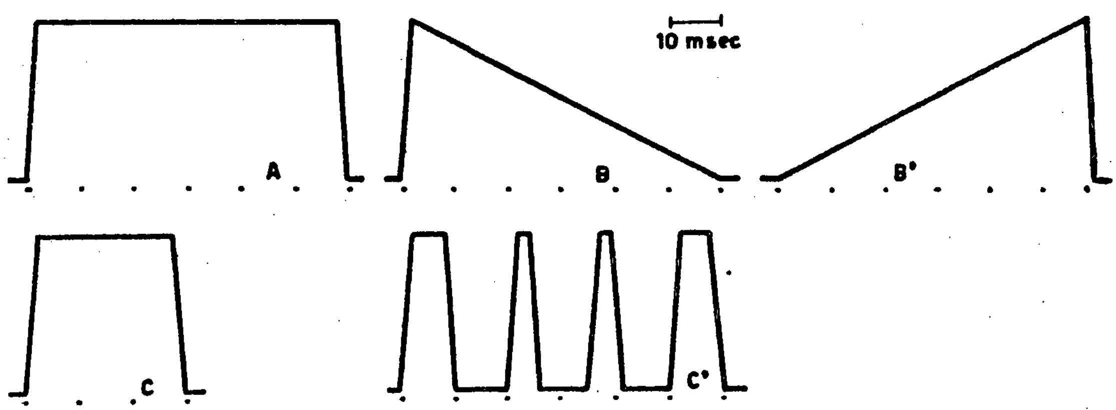

Figure 8.

41. Foley, P.J. Interrelationships of Background Area, Target Area, and Target Luminance in Their Effect on the Critical Flicker Frequency of the Human Fovea. J. opt. Soc. Amer., 1961, 51, 737-740.

An investigation was carried out to determine the effects of background area (A_B), target area (A_r) and target luminance (B_r) on the critical flicker frequency of the human fovea, and the interrelationships between these variables. CFF increases linearly with log A_B, log A_r and log B_r. Background area affects CFF much less than target area or target luminance. There are no interactions between the three variables. An index of spatial summation 0.57 was derived from the data and is compared with other indexes of spatial summation given for the human fovea.

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42. Forsyth, D. M. Use of a Fourier Model in Describing the Fusion of Complex Visual Stimuli. J. opt. Soc. Amer., 1960, 50, 337-341.

In 1922 Ives suggested that the fusion of intermittent light sources may be described by means of a Fourier analysis of the visual stimulus. De Lange has recently revived interest in this approach by plotting frequency response curves ("attenuation characteristics") which relate the amplitude and frequency of the Fourier fundamental of the stimulus at fusion. The resultant functions, while subject to displacement as a function of the intensity and wavelength of the test field, appear to be independent of waveform. One interesting property of this type of analysis is that the direction of analysis with respect to time is irrelevant. Given a train of pulses which consists of three periods of alternating duration, the train ABCABC ... has the same amplitude frequency components as the train CBACBA ... Further, if the three periods are square waves with on times equal to off times, these components remain the same when the on-off times within each period are reversed. The present paper demonstrates that such trains of pulses, having different temporal patterns but the same amplitude-frequency components according to Fourier, have equivalent fusion points.

43. Forsyth, D. M. & Brown, C. R. Flicker Contours for Intermittent Photic Stimuli of Alternating Duration. J. opt. Soc. Amer., 1959, 49, 760-763.

Flicker studies generally employ a train of light pulses consisting of a single period of stimulation repeated serially. In a recent study, fusion points were measured using trains of light pulses in which alternate periods were of different duration. Fusion points obtained with this type of stimulation are best described by a fusion contour which identifies those combinations of two periods which, when alternated serially, result in a transition point between flicker and fusion. In the present study, data have been obtained on three flicker contours each of which identifies those combinations of two periods which, when alternated serially, have the same apparent rate of flicker. A matching technique was used to measure the subjective rate of trains of light pulses. Data points were obtained from observers who matched the apparent rate of a variable stimulus (composed of two periods of alternating duration) to the apparent rate of a standard stimulus (composed of a single period repeated serially). Standard rates of 33.3, 28.6, and 25 cps were used. The fusion contour for each of the two observers in the experiment is also shown. The fusion and flicker contours are not dichotomous: as the frequency of the standard stimulus is increased, the flicker contours tend to resemble more closely the shape of the fusion contour. The contours illustrate the limiting values within which various combinations of two alternating periods may have the same apparent rate: (1) The sum of the durations of the two alternating periods must be greater than the duration of the period of the standard stimulus. (2) The sum of the durations of the two periods must be less than twice the duration of the period of the standard stimulus.

44. Gallup, H.F. & Hambacher, W.O. Human Engineering Investigations of the Interior Lighting of Naval Aircraft: Investigations into the Optimal Characteristics of Visual Light Indicator Systems. An Experimental Investigation of the Effects of Variation in Temporal Characteristics of Lights on Their Attention-Getting Value, with Reference to Master Warning and Caution Systems. Report No. NAMC-ACEL-298, Naval Air Materiel Center, Philadelphia, Pa., 1956 (AD 112767)

The need for more adequate warning and caution systems is discussed in terms of the greater probability of physical malfunction inherent in higher performance aircraft, with resulting increase in the probability of human errors. Suggestions for both a Master Warning System and a Master Caution System, incorporating check-off lists, are presented and their advantages over extant systems are expressed in terms of certain basic requirements of an optimal system.

In order to evaluate their possible usefulness in light indicator systems, the effectiveness of three types of lights (steady, flashing, and alternating) as attention gainers was studied in a factorially designed experiment. Nine subjects, engaged in the counting of randomly spaced dots of light appearing directly in front of them, were required to respond as quickly as possible to the stimulus lights, presented peripherally. These presentations were made randomly and the subjects' reaction times to the onset of the lights were recorded. The background of the stimuli was homogeneously dark.

The results of an analysis of variance performed on the data indicate that there are no significant differences in reaction time to the onset of the three types of lights used in this experiment, when these lights are presented peripherally at an angle of from 31° to 45°. This relationship holds despite the fact that the steady light provided a much greater total light flux to the eyes of the subjects than did the other two types of lights.

45. Gerathewohl, S.J. Conspicuity of Flashing and Steady Light Signals II. High Contrast. Project No. 21-24-014, Report No. 2. USAF School of Aviation Medicine, Randolph AFB, Texas. 1952. (ATI 152-956)

To investigate the conspicuity of steady light signals and intermittent light signals at contrast ratios higher than 1.00, multiple complex reaction experiments were conducted at contrast ratios of 1031.6, 138.9, 19.0, 18.3, and 6.6. It was found that, when the subject is not familiar with the test situation, steady light signals are more conspicuous than flashing light signals. On the basis of both the numerical results and the observation of subjects, it was concluded that the conspicuity of signals depends on physical, physiological, and psychological factors which determine the conspicuity thresholds for the two types of light. These findings indicate that for practical purposes the factors of brightness contrast, time, and attention must be considered. The time factor involved in the problem of conspicuity (duration and frequency of the flash) should be studied by further experimentation.

46. Gerathewohl, Siegfried J. Conspicuity of Steady and Flashing Light Signals: Variation of Contrast. J. opt. Soc. Amer., 1953, 43, 567-571.

In the past, two measures have been used to express the comparative effectiveness of steady and flashing light signals. These are comparative intensities (a) required for threshold; and (b) required for equal apparent brightness above threshold. The two measures agree in showing that the effectiveness of flashing signals is less than that of steady signals, when the intensity of the light phases of the flashing signal equals the intensity of the steady signal. The present study compares steady and flashing light signals with respect to conspicuity, defined as the speed of response to a signal above threshold. For large signal contrasts the conspicuity of steady and flashing signals is approximately equal. For small contrasts the conspicuity of flashing signals is considerably greater. These results suggest that flashing rather than steady signals be used for warning purposes.

47. Gerathewohl, S.J. Conspicuity of Flashing Light Signals: Effects of Variation Among Frequency, Duration, and Contrast of the Signals. J. opt. Soc. Amer., 1957, 47, 27-29.

This study investigates the conspicuity of flashing light signals of different frequencies, durations, and contrasts. The data show that at either high contrast or frequency, a change of the other factors does not produce a significant effect. At low contrast, however, conspicuity increases as flash frequency increases; and with low frequencies, conspicuity increases as brightness contrast increases.

A previous study showed that flashing lights were generally more conspicuous than steady signals at the same contrast when conspicuity was measured in terms of complex reaction time. By comparing flashing lights of different signal characteristics it was then demonstrated than an interaction exists between flash frequency, duration and brightness contrast. The effect of these factors was further investigated.

The results of the main experiment are shown in Table 1 of the report, which also shows the results of a preliminary experiment. The top and bottom entries in each row of the first column show the brightness contrast used in the main and preliminary studies respectively. The bottom entry in each row for columns 1, 2, and 5 is the mean for the two top entries. The fractions across the top of the table are the flash durations in seconds. In the preliminary study on-off ratio was 1/1 and flash duration was allowed to vary with frequency (as shown by the fact that flash

Table 1. MEAN RESPONSE TIME BY VARIOUS FLASH FREQUENCIES, FLASH DURATIONS, AND BRIGHTNESS CONTRASTS.[a]

	Frequency and duration								
	0.33 per sec		1 per sec			2 per sec	3 per sec		4 per sec
Contrast	1/10	2/10	1/10	2/10	1/2	1/4	1/10	2/10	1/8
0.16	2152	1567	1175	890			918	947	
0.19[b]	(1860)		(1033)		1024[b]	970[b]	(933)		946[b]
0.95	1732	1550	976	882			790	762	
1.00[b]	(1641)		(929)		876[b]	871[b]	(776)		872[b]
11.16	1164	1078	896	894			791	858	
74.20[b]	(1121)		(895)		826[b]	802[b]	(825)		830[b]

[a]Times are given in milliseconds.
[b]Preliminary experiment

duration is inversely proportional to flash frequency). In the main study the same two flash durations were used for each frequency and on-off ratio was allowed to vary with frequency. The values obtained with these two very different methods agree surprisingly well.

An examination of Table 1 shows that the response time decreases with increasing contrast, decreases with increasing flash frequency, and decreases with increasing flash duration. This effect is most pronounced with low contrast, low-frequency signals; but it is not very consistent. At either high contrast or high frequency, a change of the other variable does not produce a great change in response time.

An analysis of variance showed a highly significant main effect of contrast largely attributable to the signals with lowest frequency, a highly significant main effect of frequency which was strongest at lowest brightness contrast, and a significant interaction between contrast and frequency. The p value for the third main effect of duration was only .07 and all other interactions were statistically insignificant.

The results of this study are in general agreement with the previous study. The authors hypothesize that the faster flashes investigated were more conspicuous due to the sequential build-up and loss of light causing repeated alterations of the adaptational state of the eye. Thus the specific stimulus is the change in eye illumination rather than illumination per se, one change as the light comes on and the other as it goes off. The more often the changes occur the greater the probability of detections.

It is noted that long flashes were best at the lower frequencies investigated and short flashes were best at the faster frequencies. (See Table 1.) Though the statistical significance of the effect of duration was marginal, the work of Crumley and Atkinson is cited (see reference No. 34) in which only very low brightness contrast was used. In this study shorter flashes were also detected faster than longer flashes. The rather surprising finding that signals made up of short flashes are under some conditions responded to faster than signals made up of long flashes is discussed with respect to its deviation from the classical formulations of Blondel and Rey and others. The finding was compared to those of electroretinographic studies which found that the b-wave amplitude of the partially adapted eye was maximal for long flashes at high intensity and was maximal for short flashes at low intensity. It is suggested that response time may not be a simple function of stimulus intensity, but also of the time after the onset of the signal when the retina is maximally stimulated; i.e. when the b-wave reaches its maximum amplitude. It is pointed out however, that the deviation of these and Crumley and Atkinson's results from those of classical experiments could be due to the greater complexity of the required response, and that the effect of flash duration is far from clarified.

The results are taken to indicate that, under the conditions tested so far, the most conspicuous signal is one flashing three times per second when it is at least twice as bright as its background.

48. Gerathewohl, S.J. & Taylor, W.F. Effect of Intermittent Light on the Readability of Printed Matter under Conditions of Decreasing Contrast. J. exp. Psychol., 1953, 46, 278-282.

The utilization of the Bartley effect for the improvement of readability under conditions of low contrast was investigated. A reading chart with gradually decreasing brightness contrast was read under steady and flicker conditions with four different light-drak ratios and two flicker frequencies (9 and 15 cps). The number of lines read was accepted as index of readability and, in a more general way, as index of visibility under low $\Delta L/L$ conditions.

It was found that the effect of flicker was to lower the number of lines read, especially at low illumination levels. (This result is in close agreement with the effect that would be predicted by Talbot's law.) The authors point out that the brightness enhancement found by other studies is subjective and must not necessarily be construed as identical with an increased sensitivity for the detection of visual stimuli. They conclude that it seems doubtful that flicker can be used for the improvement of visibility under conditions of low contrast.

The results are summarized in Table 1 of the report. The effects of aperture size, flicker frequency and equality of lighting were statistically significant, as were all of the interaction effects except that between frequency and equality of lighting. Aperture size in degrees/360° = PCF. To equate steady light with intermittent, the rotating sector was run in front of the steady light at 50 cps, well above fusion.

Table 1. MEAN NUMBER OF LINES READ UNDER FLICKERING AND STEADY LIGHT, BY APERTURE SIZE OF ROTATING SECTOR (LDR) AND FLICKER FREQUENCY*

Flicker Level	Aperture Size of Rotating Sector (LDR)							
	90°		180°		270°		345°	
	Mean	σ_m	Mean	σ_m	Mean	σ_m	Mean	σ_m
9 cps	15.5	.8	20.6	.8	21.2	.8	22.1	.6
15 cps	19.8	.7	20.3	.5	22.2	.5	21.2	.6
Steady, with rotating sector**	18.5	.8	19.4	.8	22.6	.6	21.7	.6
Steady, without rotating sector**	Mean = 23.2 σ_m = .3							

* Based on 52 observations except Row 4 where the mean is based on 208 observations.
** With rotating sector the amount of light is the same as in the two flicker cases. Without rotating sector the amount of light is greater than in any other case.

See reference No. 110 in which these data are reinterpreted and it is concluded that they actually provide an additional demonstration of the greater efficiency of intermittent light.

49. Gibbins, K. The Effect of Overall Duration on Acuity Threshold and Brightness Matching Tasks. J. opt. Soc. Amer., 1961, 51, 457-58.

Nachmias probably accepted his results at their face value as they appeared (or at least, as the long-train acuity data did) to confirm Senders' findings of reduced energy requirement for acuity with small LTF. (See references No. 48, 87, 109, and 110).

However, recent work in this laboratory has tended to throw doubt on the universality of Senders' findings and in the writer's opinion these cannot be regarded as adequate support. The reason Nachmias' ingenious and plausible correction has hidden rather than clarified his data would, it seems, lie in his assumption of rectilinearity of the relation of log I to log t over too large a range of durations.

The weight of the evidence such as that given by Graham and Cook, and Niven and Brown, that the effect of duration on acuity thresholds is basically similar to its effect on other discrimination thresholds, remains unchanged.

Dr. Nachmias would appear, in the writer's opinion, to have shown the similarity of acuity and brightness-matching tasks, rather than their fundamental difference.

See reference No. 88 for the specific arguments set forth in this reference and for Nachmias' rebuttal to these.

50. Glick, J. M., Berkowitz, B., Bashe, R. & Eckstein, B. V. Integrated Sensor Interpretation Techniques (U). RADC Technical Note-59-139, Rome Air Development Center, 1959. (AD 306567) CONFIDENTIAL

This report discussed the general techniques for the integration of displays from two or more reconnaissance sensors (e.g., aerial photography, radar and infrared) which were to be investigated in this program. These techniques were side-by-side display and superimposition, where the masking effect of superimposition is modified by alternating (flickering), fading, color filtering, and/or level slicing the presentations. The methods to be used to evaluate the techniques are also discussed. (U)

The authors state that physiological and human engineering studies have demonstrated that flicker near the CFF tends to be irritating to the subject. Also, a study on relatively low frequency flicker (4, 8, and 12 cps) revealed that the time required to respond to images decreased with decreasing flicker rate. (U)

In the initial laboratory tests run on the INSITE equipment, it was found that high flicker rates were uncomfortable to all viewers and tended to distract from the subject matter rather than to heighten attention and increase information return. Lower frequency flicker, or alternation was not investigated. (INSITE equipment can achieve alternation periods from as low as one second to more than three minutes.) Fade, which is alternation employing a trapezoidal rather than a rectangular wave form, is stated to have potential as an integration technique both on the evidence of the laboratory work and the literature. Several rates were to be experimented with for cross-fade (where both presentations are faded in opposing phases) and for the combination of one continuous presentation with one fading presentation. (U)

(See subsequent INSITE reports, not obtained in time for inclusion in this bibliography.)

51. Graham, C.H. Visual Perception. In S.S. Stevens (Ed.), Handbook of Experimental Psychology. New York: Wiley, 1951. Pp. 868-920.

This chapter of the handbook summarizes the state-of-knowledge on the perception of movement and apparent movement as of 1951.

52A. Granda, A.M. Electrical Responses of the Human Eye to Colored Flickering Light. J. opt. Soc. Amer., 1961, 51, 648-654.

The electrical flicker responses of the eye to stimulation at various wavelengths and luminances were recorded by means of a frequency analyzer in a manner suggested by Granit and Wirth. This instrument employs a tuned circuit to "lock in" on the stimulating frequency of the light flashes. Its tuning characteristics allow it to reject frequencies other than the one to which it is tuned, thus improving the signal-to-noise ratio. The results obtained were plotted against stimulus luminance, and criterion responses were used to plot spectral sensitivity points as a basis for comparison with the standard I.C.I. photopic sensitivity curve. The results point to the electrical responses of the eye as being more sensitive in the blue and red regions of the visible spectrum than their counterpart in psychophysical data. Various discrepancies and their possible sources are discussed. The use of the frequency analyzer in further electroretinographic research is evaluated, particularly with problems that depend on some frequency characteristic of the response.

52B. Hammond, D.L. Flicker - An Improved Ranging Method. Paper read at the annual meeting of the Infantry and General Purpose Fire Control Section of the American Ordnance Association. Fort Ord, California, April 1962.

Flicker, a new method of optical ranging in a 100 year old art, has been under development for the last four years by Nortronics Division of Northrop Corporation. In this method of ranging, the target appears to flicker back and forth or shimmer laterally until the target is correctly ranged. Using this method, ranging accuracies as measured by the reciprocal of variable error have been doubled under average viewing conditions. In cases of obscure low-light-level targets, accuracies have been improved as much as five times.

The triangulation measurement of an unknown distance by calibrating the parallax angle from a single instrument of a fixed optical base length was first patented by Adie in England in 1860, according to Glazebrook's Dictionary of Applied Physics (MacMillan Co., 1950).

The basis for the high precision of the coincidence rangefinder is related to the vernier acuity of the eye, which refers to the eye's ability to judge the coincidence or alignment of 2 lines at an angle 5 times smaller than the eye's ability to resolve or distinguish 2 parallel lines. Devices in common usage for many years which apply vernier acuity are machinists' vernier calipers and the vernier scales on surveyer's theodolites.

A brief survey of the literature on intermittent visual stimulation indicates that there are at least three possible explanations of the enhancement in ranging repeatability which is obtained through the use of flicker. Briefly these are, (1) the "attention-getting" quality of a moving, versus a static, visual stimulus; (2) the "brightness enhancement" effect, which refers to the fact that, at optimum flicker rates, a flickering visual stimulus of a given light intensity will appear as much as twice as bright as a steady stimulus of the same intensity; and (3) the physiological fact that an intermittent stimulus, by allowing sensory neurons to recuperate after stimulation, actually reduces the stimulus threshold so that a less intense stimulus is needed to trigger the neoron than is needed when the stimulus is constant. (Though separated here for purposes of description, this effect is not really separate from (2) and in fact is one of the possible explanations of the brightness enhancement effect.)

Two flicker ranging studies have been completed at Nortronics. In the first study, using translating flicker shutters placed in front of the rangefinder entrance windows, a remarkable increase in ranging accuracy of the one-yard base length T-57 Rangefinder was obtained. The study found an accuracy improvement with both real and photographically simulated well-defined targets and obscure, poorly-defined targets. It also demonstrated the adaptability of closed circuit TV to flicker ranging. (The percent improvement in ranging accuracy provided by flicker was especially high for the degraded image of the television display.) As much as a 5 to 1 accuracy improvement was obtained with poorly-defined, obscure targets. Ranging accuracies with good viewing conditions were twice those of the conventional method.

The second flicker study involved the modification of the larger 2-meter (79 inch) base-length M17C coincidence type rangefinder being installed in the M-60 and M-48 Tank Series. A more sophisticated flicker-producing system which doubled the illumination of the intermittent image pulses over that of the T-57 was developed. An extremely precise vertically sliding mirror replaced the beam-splitter prism located directly in front of the rangefinder eyepiece. By alternately permitting light pulses from each end of the rangefinder to enter the eyepiece, the mirror not only produces flicker, but also doubles the intensity of an equivalent shutter-flicker pulse.

A more rigorous human factors test plan was designed for the comparison of the mirror-flicker rangefinder versus the unmodified rangefinder using camouflaged real targets. The results showed a statistically significant increase in ranging accuracy of 2 to 1 over the unmodified rangefinder. Although low light-level, obscure targets were not specifically studied in the second program, it is assumed that results similar to those of the first study would have been obtained.

(A short pilot study using the T-57 shutter system adapted to the unmodified M17C had failed to show an accuracy improvement with flicker for all targets. It was hypothesized that this was due to the fact that the adaptation did not provide a fixed reticle against which to judge movement, since the literature indicates that movement detection is greatly improved when a fixed reference is available in the field of view. A vertical hairline reticle like that present in the T-57 flicker system was therefore incorporated in the modified M17C, which was always placed close to the target being ranged upon in the final study).

The results of the two studies at Nortronics, leads us to believe that a discovery of very important practical significance has been made. For example, under conditions of average visibility a flicker rangefinder of 1/2 the base length would have accuracies equal to that of conventional models and under conditions of poor visibility, it would be as much as 2.5 times more accurate.

Further flicker studies are planned at Nortronics. One is in the field of fire-control system applications such as the Nortronics DAGGAR System - Direct Artillery Ground to Ground Aiming and Ranging. This will use a flicker rangefinder of 1/2 the base length of current models and will investigate low-light-level TV viewing capability.

A Human Factors study will involve a more comprehensive search of the massive quantity of published flicker research, along with psychological experimentation at the Nortronics Human Factors Laboratory.

In conclusion, it can be seen that a radical improvement is in the making for the optical rangefinder which in turn can directly benefit American fire power capabilities.

53. Hovnanian, H.P. Scanning Mechanisms Hypothesis of Vision. J. opt. Soc. Amer., 1960, 50, 921.

On the basis of repeated observations of an extrafoveal 3-5 cps flicker of propeller blades flickering at approximately 60 cps, the author concludes that there is a possible beat frequency between the propeller produced frequency and a hitherto undetermined retinal scanning frequency. To explain such an observed low flicker frequency from a high flicker-frequency source it is concluded that some regions of the retina might have specific scanning frequencies. CFF refers only to the minimum stimulus-decay time permitting us to discern moving objects. On the other hand, scanning frequency, SF, refers to the time intervals at which sensitivity recovery is exercised by the seeing mechanism, independent of decay time and the flicker frequency of the light source. Thus, SF is the frequency of accepting and rejecting (or the rate of "switching" on and off) of the rods of the retina.

54. HRB-Singer, Inc. Display Problems in Aerospace Surveillance Systems. Part I. A Survey of Display Hardware and Analysis of Relevant Psychological Variables. AFESD-TR-61-33, Air Force Electronic Systems Division, June 1961.

This report mentions the use of apparent movement created by successive, time-compressed P.P.I. presentations to increase the detectability of target movements in radar surveillance.

55. Hyman, A. Formulation to Account for CFF Findings. J. opt. Soc. Amer., 1960, 50, 507-508.

CFF findings have been previously related to the amplitude of the first periodic component in the Fourier series describing the waveform of the stimulus. The present formulation develops a new rationale for such a mathematical model. It utilizes a modification of Hecht's photochemical theory and postulates a stochastic process, the process of random flights, for the transfer of excitation within the visual receptor. The formulation further assumes that spatial summation in the visual mechanism depends on the relative magnitude of the periodic portion of the waveform, if mean luminance is kept constant; and that CFF is a resultant response which originates from individual mechanisms differing in sensitivity to luminance level, spectral energy distribution, and relative magnitude of the periodic portion of the waveform. Curves describing CFF data, if obtained for a 52' foveal target viewed against a dark background, are not "smooth." Instead they show regions where the slope changes rapidly or even abruptly. Also, the curves for CFF vs luminance obtained for different hues, in general, cannot be superimposed by translation of the coordinate axes. The present formulation attempts to account for such findings.

56. Hyman, A. Potential Uses of Alternate Binocular Presentation in Studies of Vision and as an Indicator of Physiological Stress. WADD TR 60-302, Wright Air Development Division, 1960.

This report invites study of two phenomena. One is stereofusion resulting from alternate stimulation of the two eyes with disparate displays. The other is response latency of eye movements resulting from periodic ocular occlusion. The usefulness of such investigations, particularly for the development of simple indices reflecting the presence of physiological stress, is discussed. Indicators of physiological stress are needed for evaluating protective devices and procedures which are to be used by personnel flying in future high performance aircraft and spacecraft. Also discussed is the contribution which may be provided to vision theory by an investigation of the phenomenon of sterofusion from alternate binocular presentation. An exploratory examination of this phenomenon uncovered an interesting finding. The critical stereofusion frequency (CSF) was found to be approximately 11 cps (frequency of alternation). Below approximately 7 cps, the stimulus appeared to jump back and forth laterally, but between approximately 7 cps and CSF, two stationary stimuli were perceived to be displaced laterally, even though a single target displaced in depth was perceived above CSF. The author notes that CSF may be superior to CFF as an index of central nervous system excitability, since it appears to be primarily a cortical response.

The report mentions that alternate binocular presentation was used to publicly display 3-dimensional movies in New York in 1922. A sectored disk (episcotister) attached to the arm of each seat was synchronized with the alternate presentation of the member of each stereo pair on the screen, so that each eye saw only the picture intended for it.

This has suggested the possibility of using alternate binocular presentation to increase the screen brightness and picture quality of rear-projection stereo surveillance-imagery viewers. By taking advantage of the greater efficiency of intermittent light, the light loss inherent in the alternate methods of channeling the appropriate picture to each eye (polarization, the lenticular screen, color filtering) could be effectively eliminated. Such a viewer would automatically possess two types of apparent-movement change detection capability: (1) the apparent movement or flicker resulting from the failure of changes in alternately presented time-separated stereo imagery to sterofuse; (2) the apparent movement or flicker resulting from the failure of changes in alternately presented time-separated non-stereo imagery to superimpose (shuttering not required).

57. Jones, R. C. Sinusoidal Flicker Perception and the Quantum Efficiency of Photopic Vision. J. opt. Soc. Amer., 1956, 46, 379. (Abstract)

A few measurements have been made to determine how strongly one must modulate (sinusoidally) the intensity of a source of light in order that a human observer may perceive the modulation as flicker. A source of light was arranged so that its luminance could be modulated sinusoidally at rates between 1 and 100 cps. Curves will be presented showing the threshold value of the modulation index as a function of the frequency. The threshold value of the modulation index tends to have a minimum value around 10 cps for sources with luminances of 1.5 and 150 foot-lamberts and with angular diameters of 1° and 10°. Such measurements permit the determination of the quantum efficiency of the eye at any desired luminance level. The method differs significantly from that used by Rose.

58. Keesey, U. Tulunay & Riggs, Lorrin A. Visibility of Mach Bands with Imposed Motions of the Retinal Image. J. opt. Soc. Amer., 1962, 52, 719-720.

The present study confirms the value of low-frequency, high amplitude (3 cps greater than 1.3 mm of arc) motions of the retinal image for the maintenance of seeing.

It appears that the mechanism responsible for contrast effects, such as Mach bands and detection of fine detail, is mainly a spatial one dependent on the differential responding of adjacent units to the retinal-illuminance pattern. However, a time variance in the illuminance seems to be necessary to sustain this initial responding. A possible retinal basis for these effects can be found in the spatial interaction that has been described for the frog, cat, and Limulus eyes. It has been shown that simultaneously illuminated regions exert an inhibitory action upon each other. The fiber-response pattern can be modulated by varying the illuminance differential on the interacting elements or by varying the spatial separation of the illuminated areas. The resulting response is such that differences in illuminance of the adjacent parts of the retina are maximally effective, especially at the critical border where a large change in illuminance is found to occur over a few receptors. Ratliff et al. have suggested that the observation of vivid Mach bands may depend on such an inhibitory mechanism in the human retina. The present data indicate that the initial response pattern set by the mutually interacting elements is not affected by small motions of the retinal image. Perhaps this is because the differentiation pattern of a border is such that these motions do not yield a sufficiently large change in light falling on any given group of receptors. Significant effects have been produced only by motions that are large by comparison with the typical width of a diffraction pattern, (about 1 min of arc). Slow oscillations of this magnitude serve to restimulate the underlying receptors and so maintain vision. Rapid oscillations, however, do not produce separate responses and their temporally fused effect is to stimulate the retina with a blurred spatial pattern that fades out even more readily than a stationary one.

59. Kelly, D. H. Effects of Sharp Edges in a Flickering Field. J. opt. Soc. Amer., 1959, 49, 730-732.

In view of the well-known transient "overshooting" behavior of the human visual system in the time domain (e.g., Broca-Sulzer phenomenon, rapid adaptation, brightness enhancement) confirmed by psychophysical threshold measurements and neurophysiological recordings, the visual frequency response curves recently published by deLange seem to require further explanation. A system with this kind of transient response must be a differentiator, and hence its amplitude sensitivity should increase steeply with frequency, at least over a considerable low-frequency range. This conclusion cannot be avoided by appealing to the well-known nonlinearity of the visual system, since thresholds are obtained with very small amplitudes in the pertinent frequency band.

Recent measurement by deLange show this rising characteristic at low frequencies to a slightly greater extent than his earlier frequency response curves, but are still disappointingly "flat" compared to the expected behavior of individual receptor cells. In the course of an experimental program of engineering systems analysis applied to the visual process, the author has had occasion to compare frequency response curves obtained with various spatial patterns, and has been led to conclude that this disappointing behavior at low frequencies is an artifact resulting from the use of the traditional sharp-edged, 2° photometer field.

On the basis of a comparative analysis of experiments performed by the author and those performed by deLange Dzn, the author concludes not only sinusoidal flicker thresholds, but also other measurements of human visual properties appear to be confounded by the artifacts discussed. As a result of this "edge-enhancement" behavior of the retina, the observer responds chiefly to the edge gradient, while the experimenter often controls only the large area luminances.

60. This reference was dropped since its content is identical to that of a much more accessible reference cited.

61. Kelly, D.H. Visual Responses to Time-Dependent Stimuli. I. Amplitude Sensitivity Measurements. J. opt. Soc. Amer., 1961, 51, 422-429.

With sinusoidal modulation of the radiance of the stimulus as a function of time, amplitude thresholds are measured instead of the repetition-rate thresholds usually obtained in flicker-fusion experiments. Controlling the modulation amplitude independently of the time-average radiance provides an additional degree of freedom, so that the observer's adaptation level can be held constant while his amplitude sensitivity is measured as a function of the modulation frequency. With an "edgeless" flickering field, these amplitude sensitivity curves show a broad peak of maximum visual response, in the region from 10 to 20 cps at high photopic levels. Such classic relationships as the Ferry-Porter, Talbot-Plateau, and Weber-Fechner laws are derivable from the present results, as descriptions of the behavior of certain parts of the amplitude sensitivity curves as functions of adaptation level.

62. Kelly, D. H. Flicker Fusion and Harmonic Analysis. J. opt. Soc. Amer., 1961, 51, 917-918.

Bartley and others have often discussed the visual effects of varying the PCF or "pulse-to-cycle fraction" (i.e., the relative on-time or duty cycle) of the rectangular waveform used in traditional flicker-fusion experiments. Recently, Bartley and Nelson measured the CFF (i.e., the high-frequency flicker threshold) as a function of the PCF, using several observers at four different intensity levels (but without an artificial pupil). The purpose of the present note is to show that the form of this function can be understood in a very simple manner. The observed relation between the PCF and the CFF is readily explained (i.e., could have been predicted) by analyzing these rectangular waveforms into their fundamental frequency components. This analysis of the stimulus permits the results to be deduced from the visual response to sinusoidal waveforms, as measured by the writer and others.

The author has shown that the high-frequency threshold for sinusoidal stimuli depends only on the absolute amplitude as expressed by the product mB, where m equals the relative amplitude (dimensionless) or percent of modulation and B is the average retinal illuminance overtime (adaptation level). This is true over almost the entire photopic range of retinal illuminance amplitudes.

Demonstrating that curves similar to those obtained by Bartley and Nelson could have been deduced from the known amplitude thresholds for sinusoidal stimuli, the author concludes that the main features of their PCF data (which were regarded as a decisive test of a neurophysiological hypothesis) are primarily artifacts of the stimulus waveform chosen for the experiment. It is further concluded that neurophysiological models should be tested with the simplest periodic stimuli available, and that experiments with non-sinusoidal periodic stimuli should be designed on the basis of a preliminary harmonic analysis of the waveforms used. See references No. 14, 16, and 66.

63. Kelly, D. H. Visual Responses to Time-Dependent Stimuli. II. Single-Channel Model of the Photopic Visual System. J. opt. Soc. Amer., 1961, 51, 747-754.

A relatively simple model of the first two links in the visual receptor system is proposed in order to explain the data reported in Part I on amplitude sensitivity to sinusoidally flickering stimuli at photopic adaptation levels of white light (see reference No. 61). The model consists of a linear filtering stage followed by a nonlinear pulse-encoding stage. The first stage is regarded as essentially "noiseless" at photopic levels; amplitude thresholds are treated as thesholds for the transmission of variable intervals between pulses. With the aid of the model, suprathreshold responses can be inferred from the measured threshold behavior.

In this way, responses comparable with various other psychophysical, neural, and electroretinographic data are predicted; the resulting agreement is considered fairly good in view of the persimony of the proposed model.

64. Kelly, D. H. Visual Responses to Time-Dependent Stimuli. III. Individual Variations. J. opt. Soc. Amer., 1962, 52, 89-95.

Eight normal and two dichromatic observers are tested for amplitude sensitivity to sinusoidally flickering white light at various photopic adaptation levels. The mean response curve of the color-normal observers is in good agreement with the theoretical model of the visual system proposed in Part II. In addition, certain individual curves show three smaller peaks of sensitivity in the frequency ranges of 4-7, 10-15, and 20-30 cps. Their stability with varying adaptation level indicates that these subpeaks occur in the initial, photoreactive state of the system, according to the proposed model. Thus they may be associated with the linear mechanism of color discrimination. Abnormal amplitude-sensitivity curves obtained with one deuteranope and one protanope lend further weight to this hypothesis. See reference No. 63.

65. Kelly, D. H. Visual Responses to Time-Dependent Stimuli. IV. Effects of Chromatic Adaptation. J. opt. Soc. Amer., 1962, 52, 940-947.

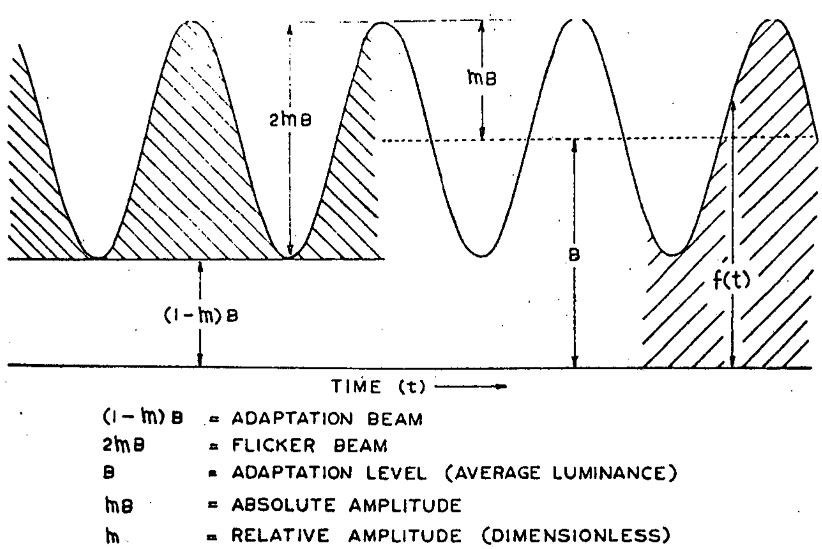
At photopic levels, the amplitude-frequency response curve of the retina assumes a wide variety of shapes when the color of the flickering component of the stimulus is not the same as that of the steady component. Apparently, the photoreaction rates and neural time constants of the various color subchannels differ in the same order as their spectral sensitivities, so that low-frequency sensitivity is enhanced when the adapting wavelength is longer than the flickering wavelength, and high-frequency sensitivity is enhanced when the adapting wavelength is shorter than the flickering wavelength. Chromatically adapted responses to white flicker show that the low-frequency band (4-7 cps) is controlled by the blue-sensitive channel; the middle-frequency band (10-15 cps), by the green-sensitive channel; and the high-frequency band (20-30 cps), by the red-sensitive channel. The results also depend on the spatial pattern of the stimulus; a sharp-edged field obscrues the "red" peak and enhances the "blue" peak, even in the absence of blue light. These phenomena cannot be detected with traditional flicker-fusion stimuli, since they do not occur at the CFF. See reference No. 64.

66. Kelly, D. H. New Stimuli in Vision. Paper presented at 6th Congress of the International Commission for Optics, Munich, August 19-26, 1962.

This paper is concerned with the systematic design of stimuli for visual research. Several investigators have recently adopted some form of "harmonically pure" stimulus for studying various properties of the visual system. In particular, sinusoidal waveforms have been used to investigate time-dependent responses, and sinusoidal patterns to study space-dependent responses. Some current data on the spatial frequency response and the temporal frequency response of the visual process are reviewed, and an attempt is then made to apply the same methodology to the measurement of spatio-temporal interaction. In spite of much current interest in the subject, a simple, precise definition of what is meant by spatio-temporal interaction has been lacking; a virtue of the systematic methodology is that it provides one.

The author cites the trend in visual research towards the application of techniques of measurement and analysis which have proven to be important in the design and testing of electronic, photographic, and optical information processing systems.

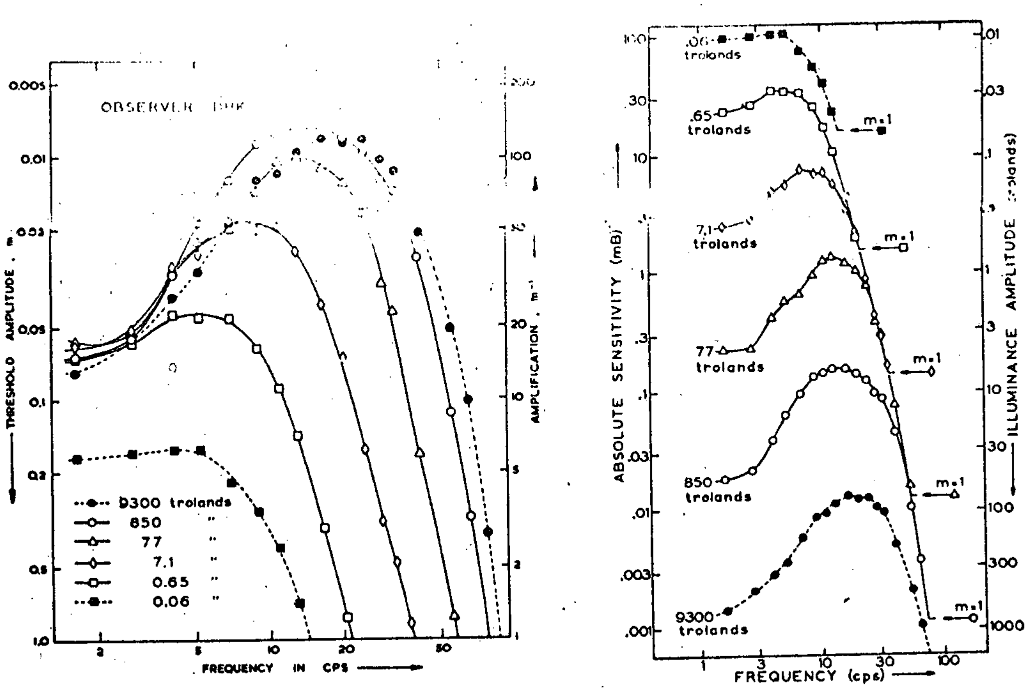
The author points out the advantages of using sinusoidal variations of luminance as a function of time or space superimposed on a steadily illuminated background. Sine waves are the simplest possible signal in that any other variation can be synthesized only from the appropriate sine waves. Superimposing the variation on a steady background holds the adaptation level (defined as the "dc component" or widefield average) constant while the threshold variable is measured as a function of some other parameter. Slide 1 used in the presentation illustrates the parameters of the temporal sine wave stimulus.



Slide 1. Parameters of the temporal sine-wave stimulus

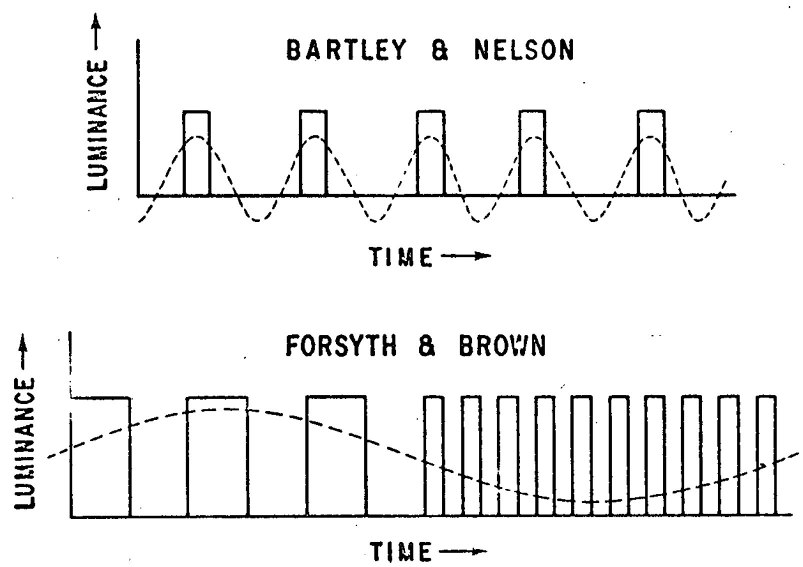
The threshold amplitude-frequency curves obtained by four different experimenters who used flickering fields of different sizes are compared. The comparison indicates an unexpected trend for sensitivity to decrease as field size increases. The curves are similar in that they all show a peak sensitivity between 8 and 18 cps. This peak, indicating that the retina acts as a bandpass filter rather than a low-pass filter, was never discovered by the older method of using the CFF as the threshold variable. Thus it is not only convenient but actually necessary to use the amplitude threshold as the dependent variable in order to obtain a single valued function. Even the high-frequency cut-off (closely related to the CFF) can be determined more accurately using amplitude thresholds, since in this region a small change in frequency produces a large change in amplitude.

In contrast to the CFF, the high-frequency cut-off is the asymptote of a complete response function obtained at a constant known level of retinal illuminance. Being a more fundamental measurement, it provides more interesting information. Both the author and deLange have found that for a fixed modulation ratio, e.g., 100%, the cut-off frequency depends on the adaptation level or average retinal illuminance. (See the left hand figure of Slide 5 of the presentation.) Multiplying these modulation threshold functions by the adaptation levels at which they were measured gives the absolute amplitude threshold in illuminance units. Then the high-frequency cut-off is found to depend only on this absolute amplitude of the sinusoidal component of the stimulus and not on the steady component; i.e., when plotted in terms of absolute units, these different curves all fit together into a single high-frequency cut-off curve, regardless of adaptation level. (See the right-hand figure in Slide 5.)



Slide 5. Comparison of relative (modulation) amplitude sensitivities with absolute amplitude sensitivities to the (65°) Ganzfeld stimulus

This makes it simple to predict the results of CFF experiments in which effective pupil diameter is properly controlled, even where the stimulus is much more complicated than the traditional square wave such as the rectangular waveform with varying pulse-to-cycle fractions studied by Bartley, and the complex pulse trains studied by Forsyth and Brown. (See Slide 6 of the presentation.) If the stimulus waveform is known in absolute units of retinal illuminance, we have only to calculate the amplitude of the first Fourier component, as shown by the dotted line, look up this absolute amplitude on the high-frequency cut-off curve, and read off the CFF.



Slide 6. Periodic stimuli and sinusoidal equivalent stimuli of two classic CFF experiments

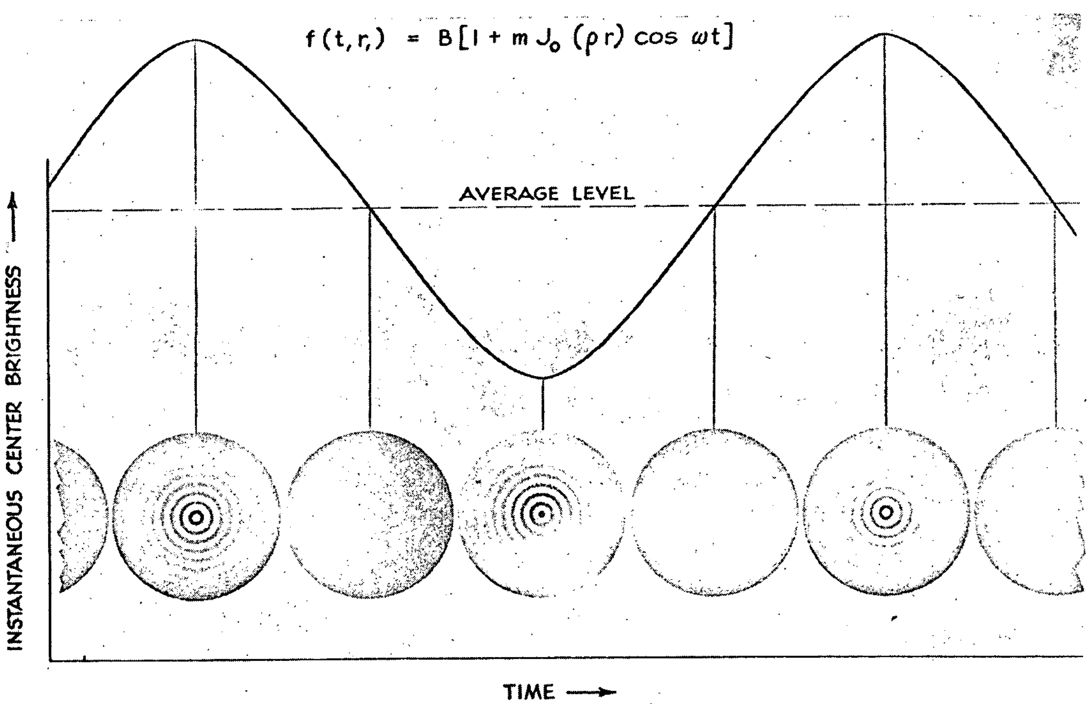
The author believes that equally good threshold predictions for complex spatial patterns may eventually be made from appropriate sine wave measurements in the space domain, in spite of such additional complicating factors as the spatial inhomogeneity of the retina.

The spatial amplitude sensitivity curves obtained from four experimenters are examined. The spatial response curves all show a peak of maximum sensitivity between 1 and 3 cycles per degree of visual angle with spatial high-frequency cut-off less than half as steep as the temporal one. Thus the eye apparently acts as a bandpass filter in the space domain as well.

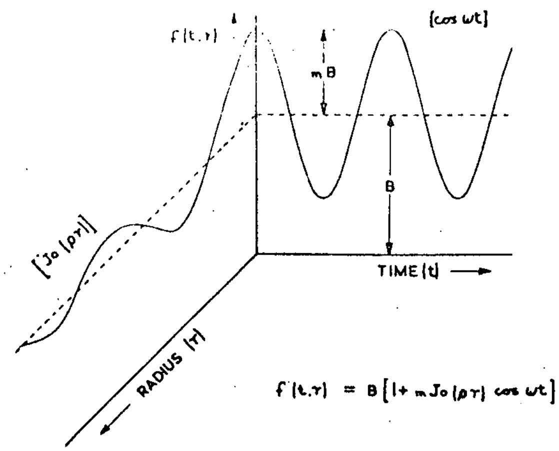
To explain the fact that the spatial frequency response appears to be a smoothed version of the temporal frequency response, it has been theorized that involuntary eye movements convert spatial frequencies of the stimulus into corresponding temporal frequencies of the individual receptors. Dividing the temporal frequency of maximum sensitivity by the spatial frequency of maximum sensitivity indeed gives a linear scanning speed of 5 to 10 degrees per second which is in good agreement with the measured velocity of the eye's "flick" movements. However, electrophysiological evidence obtained with the immobilized eye indicates that retinal interconnections are also important in the spatial response. (The author illustrates how this argument might be reversed using the spatial frequency response to explain some of the differences found between temporal response curves).

The author illustrates how both types of experiments will be combined, i.e., the investigation of the spatial response at each temporal frequency and vice versa. It is pointed out that the temporal response has been studied only at low spatial frequencies, and that the spatial response has been studied only at low temporal frequencies. The author believes that exploring the spatio-temporal interaction over a broad range of spatial and temporal frequencies will provide the key to the relation between thse two types of data and perhaps also to induction, Mach bands, the phi phenomenon, and other forms of spatio-temporal interaction.

The characteristics of the required three dimensional stimulus proposed by the author are described and illustrated. Slides 11 and 12 of the presentation illustrate the appearance and the parameters of the proposed stimulus.



Slide 11. Elementary spatio-temporal stimulus



Slide 12. Alternative graphic method of representing the elementary spatio-temporal stimulus

Note: If difficulties are met in obtaining a copy of this paper, it may be possible to obtain a copy from the author at the Research Optics Department of the Itek Corporation, Lexington 73, Massachussets.

67. Kolers, P.A. A Multi-Field Electronic Tachistoscope. WADC Technical Note 58-349, Wright Air Development Center, Wright-Patterson Air Force Base, 1958. (AD 208 320)

A multi-field electronic tachistoscope is described which has variable duration, sequence, and intensity controls. In addition, the device may be cycled automatically, or be made to run through a single cycle manually. Each viewing field can be illuminated for durations ranging from 1 msec. to 3 sec. during automatic operation. The upper limit of the exposure duration may be increased to any desired value greater than 3 sec. by means of a manually operated switch. Other provisions are described which control intensity of the illuminated or transilluminated stimulus materials.

68. Kolers, P.A. Multi-Field Electronic Apparatus for Studies of Visual Perception. Technical Documentary Report No. MRL-TDR-62-33, Aerospace Medical Division, Wright-Patterson Air Force Base, 1962.

An apparatus is described that precisely controls intensity, duration, and order of firing of gas-discharge lamps. It can be used to illuminate visual stimulus objects for either long or short exposures, and in different viewing modes. Various methods of reducing the onset variability usually encountered with gas-discharge lamps are also described. Although designed primarily for the study of contour formation and visual masking, the apparatus can be used wherever a controlled sequence of separate stimulus presentations is required, as in studies of apparent movement, critical flicker frequencies, and time-dependent series.

69. Krauskopf, J. Effect of Retinal Image Motion on Contrast Thesholds for Maintained Vision. J. opt. Soc. Amer., 1957, 47, 740-744.

Contrast thresholds for maintained vision were determined under varying conditions of retinal image motion. The "stopped image" technique was used to eliminate normal image motion. Controlled motion at various frequencies and amplitudes was introduced by rotating one of the mirrors in the optical system. Low-frequency vibrations (1, 2, and 5 cps) of the retinal image were found to be beneficial to maintained vision while high-frequency vibrations (10, 20, and 50 cps) were found to be detrimental to maintained vision when compared to vision in the absence of normal retinal image motion.

The type of results obtained are illustrated by figure 3.

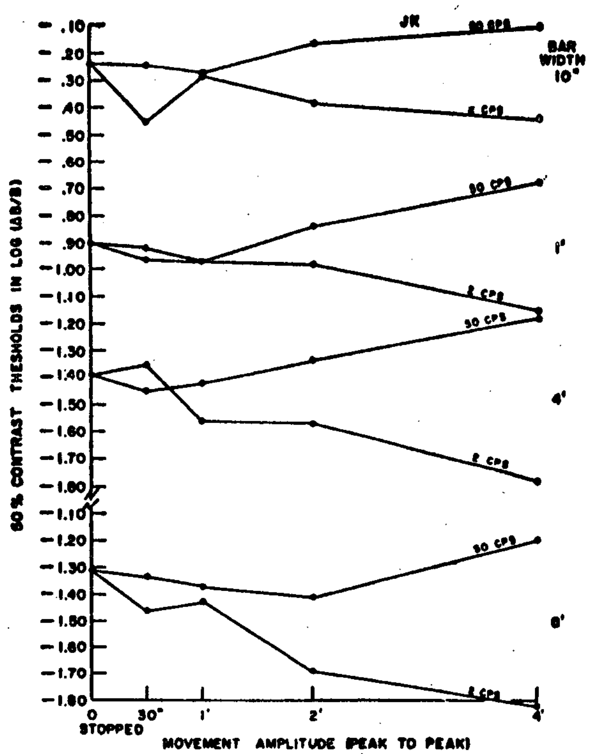


Figure 3. 50% contrast thresholds as a function of amplitude of vibration at 2 and 50 cps for four bar widths. Experiment II. Four determinations per point.

70. Krauskopf, J. Effect of Target Oscillation on Contrast Resolution. J. opt. Soc. Amer., 1962, 52, 1306.

This report mentions some recent experiments by other authors which provide strong contradictory evidence for "dynamic" theories of visual acuity which hold that eye movements contribute positively to acuity. Recent research by the author is reported however, which indicates that low frequency motions decrease contrast thresholds while high-frequency motions increase them. Since most theoretical treatments of acuity treat it as a special case of contrast detection, it is concluded that judgement of dynamic theories should be suspended until experiments comparable to those reported are performed with acuity targets.

The results of the author's experiments are summarized in figures 1 and 2 of the report.

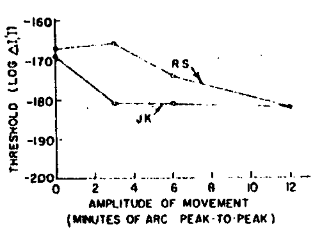


Figure 1. Contrast thresholds as a function of oscillation amplitude. Frequency -- 4 cps.

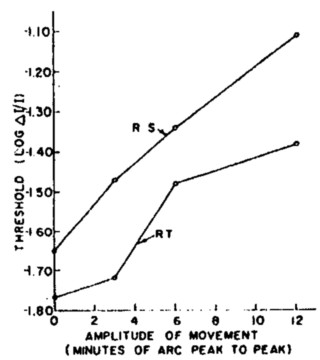


Figure 2. Contrast thresholds as a function of oscillation amplitude. Frequency -- 32 cps.

71. Krauskopf. J. & Kalla, R. The Effects of Retinal Image Motion on Contrast Thresholds. Report No. 221, Army Medical Research Lab., 1956. (AD 83003)

Contrast thesholds for continuous seeing were determined under varying conditions of retinal image motion. The "stopped image" technique was used to eliminate normal retinal image motion. Controlled motion at various frequencies and amplitudes was introduced by means of a rotatable mirror in the optical system. Low frequency vibrations (1, 2 and 5 cps) of the retinal image were found to be beneficial to maintained vision while high frequency vibrations (10, 20 and 50 cps) were found to be detrimental to maintained vision when compared to vision in the absence of normal retinal image motion.

72. Landahl, H. D. On the Interpretation of the Effect of Area on the Critical Flicker Frequency. Bull. Math. Biophysics, 1957, 19, 157-162.

The effects of area and intensity on the critical flicker frequency, threshold, and reaction time are considered in terms of neural net theory. An attempt is made to develop a mechanism which can account for the phenomena associated with the empirically observed laws of Ricco, Granit, Talbot, and Ferry-Porter as well as observations on reaction time and threshold. A simple model gives results which are substantially in agreement with observation except for a few apparent discrepancies. Experimental procedures are suggested which can determine whether these are apparent or real.

73. Landahl, H. D. Note on the Fusion Frequency for Stimuli of Alternating Duration. Bull Math. Biophysics, 1959, 21, 283-287. AFOSR TN 59-374 (AD No. 213-856)

The case of alternating stimulus patterns of moderately high intensity is considered in terms of the model previously discussed (Landahl, 1957). If both of the alternating patterns have the same light-dark ration, then the relation between the period of the longer and the period of the shorter pattern at the critical flicker frequency is independent of the light-dark ratio, and is given by a dimensionless expression which is roughly in agreement with data in which the light-dark ratio is one (C. R. Brown and D. M. Forsyth, 1959). See references No. 72 and 28.

74. Landis, C. An Annotated Bibliography of Flicker Fusion Phenomena. Covering the Period 1740-1952. Armed Forces - National Research Council, Ann Arbor, 1953 (AD 121-183).

This bibliography contains hundreds of references on flicker fusion as well as a number of references on related phenomena such as brightness enhancement for the period indicated.

75. Levinson, J. Fusion of Two-Component Flicker. J. opt. Soc. Amer., 1960, 50, 21. (Abstract)

The technique of combining two sinusoidal modulations of an otherwise steady luminance has been applied to flicker-fusion threshold measurements at lower intensities and with other colors than previously reported. In brief, the technique consists, first, in finding the foveal flicker-fusion threshold amplitude for the sinusoidal modulation of a light source about its average luminance at each of two frequencies, one twice the other. Second, the two modulations are applied together, i. e., their amplitudes are summed. The resulting waveform depends upon their relative phase of the two components. It is found necessary to reduce the combined amplitudes for flicker-fusion. The required reduction depends markedly upon the relative phase of the two components. This phase-dependence is displayed graphically by plotting the fractions of the original amplitude required for threshold against the relative phase. Qualitatively, the characteristics of the dependence of flicker sensitivity upon the relative phase of the two components remain similar to those previously reported. Quantitative differences arise, however. At low intensities, phase sensitivity decreases, and the phase difference for minimum sensitivity changes with frequency in the opposite direction from that previously observed at high intensity. When red light is used, the flicker sensitivity is found to depend less upon relative phase than with white light; green light, on the other hand, leads to very little change in phase dependence.

76. Levenson, J. Two Aspects of the Perception of Flicker. J. opt. Soc. Amer., 1962, 52, 1327. (Abstract)

First, a brief review is presented of the relation between temporal integration, low-pass filter action, and harmonic analysis of visual stimuli. The upshot of this discussion is a simple prediction: For repetition rates above about 10 cps, most stimulus waveforms are equivalent to their fundamental harmonic component alone. This conclusion depends only upon the existence of an integrative process in the eye. No analytic property is assumed. While this topic is by no means new, its discussion appears called for in view of certain misconceptions which continue to appear in the literature. To show that for the given stimuli, the process of temporal integration is all that need be assumed, a demonstration experiment is presented illustrating the role of the fundamental harmonic of a waveform. The second topic deals with an exception to the above prediction. It is possible to compensate for the integrative action of the visual system by presenting a combination of flickers of 2 frequencies with amplitudes adjusted to apparent equality of flicker intensity. When one frequency is exactly double the other, the combined waveform, when set for fusion threshold, has been found to depend on phase, but rather weakly. Since this phase dependence is important as an indicator of nonlinearity in the visual system, another demonstration experiment is presented showing stronger phase dependence, using suprathreshold amplitudes.

77. Lichtenstein, M. and Boucher, R. Minimum Detectable Dark Interval Between Trains of Perceptually Fused Flashes. J. opt. Soc. Amer., 1960, 50, 461-466.

The minimum detectable dark interval between trains of perceptually fused flashes of light was investigated. The length of this minimum interval between such trains was an inverse function of both train duration and of pulse rate within the train. Trains longer than a critical duration of 70 or 80 msec did not further decrease the dark interval duration. Also, an $It = K$ law is approximated in that any constant amount of light energy in the fused trains, regardless of its time distribution within the critical duration, produces a constant value of minimum detectable dark time between trains. Results are discussed in relation to action of light quanta in the stimulus, neural summation, and neural latency changes, all of which, it is contended, jointly contribute to production of the psychophysical results of the experiment.

78. Lindsley, D.B. (Principal Investigator). Psychophysiology of Perception. Project Progress Report: US Army Contract No. DA-49-007-MD-722, 1962, (AD 281919).

This report describes several studies completed and in progress in the areas of perceptual blanking (perceptual interference of successively presented visual stimuli), stabilized retinal images versus eye movements, and flicker.

79. Lipkin, B.S. Monocular Flicker Discrimination as a Function of the Luminance and Area of Contralateral Steady Light. I. Luminance. J. opt. Soc. Amer., 1962, 52, 1287-1295.

It is hypothesized that a steady light in one eye will lower or inhibit the critical rate (CFF) of contralateral intermittent flashes of light in a manner consonant with the effect of an adapting field on the discrimination of single flashes. Luminances spanning a 6-log-unit range were variously combined in two 1.5° fields. Results indicate that there is an inhibitory effect which depends in part on relative luminances: except with very dim stimuli, an adapting light dimmer than a given flicker light reduces CFF somewhat; and CFF decreases progressively as adapting luminance increases. Viewed with bright adapting light, a moderately bright flicker field shows a 10-20% reduction in CFF and a dim flicker light (whose CFF is 8 cps or less) shows a 100% reduction in CFF. However, the data, when plotted in a Δ I/I format, show only partial similarity to curves of steady-field and single-flash luminance discrimination. Moreover, the upper limb in each of the family of binocular CFF-log I curves, in which adapting luminance is the parameter, parallels the monocular curve and may be fitted to a similar exponential equation.

80. Lipkin, B.S. Monocular Flicker Discrimination as a Function of the Luminance and Area of Contralateral Steady Light. II. Area J. opt. Soc. Amer., 1962, 52, 1296-1300.

The relation between field size and decrease in critical rate (CFF) of a flickering field stereoscopically superimposed on a contralateral steady image is reported. Two designs were used. In one, luminances spanning a 6-log-unit range were variously combined in fields which were both 1.5°, 3°, or 9° or in which the flickering field was the smaller image. The other design utilized the same luminance combinations but the flickering image was 6° and the adapting field was varied from 9° to 1.5°. Results indicate that if both fields are initially 1.5° then increasing the size of both fields or just the adapting field does not further decrease

CFF. But if the size of the flickering field is increased to 6°, CFF of the 1.5° central portion of the flicker field which appears superimposed on the 1.5° adapting field is markedly reduced, while the flickering annulus shows the threshold reduction expected with equal-sized 6° fields. The center of a fairly bright 6° flicker field viewed with an adapting field 4.5° or less and flashing at low frequencies appears steady. Several interpretations of the results (macular dominance, corresponding points, monocular cross-regional interaction) are discussed.

81. Lloyd, V.V. & Landis, C. Role of the Light-Dark Ratio as a Determinant of the Flicker-Fusion Threshold. J. opt. Soc. Amer., 1960, 50, 332-336.

An apparatus and procedure are described by which CFF-log I functions were obtained for a range of LDR values with two sizes of foveal area. When the data are plotted against log light-pulse brightness, i.e., uncompensated, the relative positions on the y axis of the sets of points corresponding to the different LDR's vary with brightness level. When the results are shown as a function of log brightness which has been compensated according to the Talbot-Plateau law, the higher the LDR, the lower the set of points on the y axis, irrespective of brightness level. The effect of an increase in area is to raise the position of a given set of points.

82. Luria, S.M. and Sperling, H.G. Phase Relations in Flicker Fusion. J. opt. Soc. Amer., 1962, 52, 1051-1057.

The luminance at which the flicker of a white test light was perceived was determined as a function of the phase angle between the light and pulsing white, green, yellow, red, and blue surround fields which were equated for brightness. It was found that the luminance thresholds for perceived flicker increased when the test light and the surround were in phase. The amount of increase varied as a function of the color of the surround, being a maximum for white, less for green, still less for yellow, and a minimum for red and blue. No differences in absolute threshold were found as a function of phase for 1-sec observation periods of the test flash. The results are discussed with reference to the differences in amplitude as a function of the surround wavelength as well as to submaxima found in the luminance functions.

83. Marimont, Rosalind B. Model for Visual Response to Contrast. J. opt. Soc. Amer., 1962, 52, 800-806.

A simple steady-state model is proposed to explain a well-known phenomenon of subjective brightness, namely that high illuminance greatly increases the apparent contrast of a scene. This effect is obtained in the model by making both the reference level and gain of the system depend on the average illumination. The numerical values of the system parameters evaluated from published data of Hurvich and

Jameson are in good agreement with those derived from independent experiments of S.S. Stevens. The basic model can be improved by modifications which make it show qualitatively the stabilized retinal image effect, and edge effects such as Mach bands. The physiological plausibility of the model is discussed briefly and no implausible requirements are found.

This study has suggested the possibility that brightness enhancements obtained with intermittent light, and increases in the effective light transmission of a system obtained by using intermittent light to perform some essential system function normally involving light loss, may in themselves produce increased contrast.

84. McFarland, R.A., Warren, A.B. & Karis, C. Alterations in Critical Flicker Frequency as a Function of Age and Light: Dark Ratio. J. exp. Psychol., 1958, 56, 529-538.

Binocular critical flicker frequencies (CFF's) were determined for 108 Os ranging in age from 13 to 89 years. The light pulses were in the form of square waves activating a glow modulator tube. The ratio of light-time/dark-time in the flicker cycle was varied systematically from 2/98 to 98/2. The uncompensated luminance procedure was used. The test field consisted of a circular test area of .6° subtense shown at the center of a circular 17° surround. Tests were made at surround luminances of 23.6 and .04 ml.

The major results were: (a) The relationship between CFF and age is linear and negative for all LDR levels under both conditions of surround luminance. (b) The decrement of CFF with age is a function of the light-time percentage of the flicker cycle. The differentiation between age groups is more pronounced at the lower light-time percentages. (c) The light-time percentage at which the maximum CFF occurs is a function of chronological age of 0. (d) The change of the surround luminance resulted in a shift of the position of the CFF-LDR curves, but the shape and slope of the curves were not altered.

On the basis of the results it was suggested that the use of lower levels of light-time in the flicker cycle, rather than the conventional 50:50 LDR, would enhance the sensitivity of CFF as an indicator measure.

85. McQuistan, Richmond B. On an Approximation to Sinusoidal Modulation. J. opt. Soc. Amer., 1958, 48, 63-66.

The distribution of modulation frequencies for radiation chopped by passing rectangular chopper teeth over a circular aperture has been determined. The ratio of aperture radius to tooth width that produces an amplitude of the fundamental equal to the amplitude obtained in the case of sinusoidally modulated radiation is calculated. The calculation reported here also establishes the ratio of aperture radius to tooth width that will result in an rms value of the incident radiation which is equal to that of sinusoidally modulated radiation.

86. Motokawa, K. & Ebe, M. The Physiological Mechanism of Apparent Movement. J. exp. Psychol., 1953, 45, 378-386.

The problem of apparent movement is not a special problem of perception. It is concerned with various psychological phenomena and should be studied in connection with these phenomena. Nothing conclusive on the mechanisms of apparent movement can be presented before our knowledge about related phenomena, such as subjective colors, fusion of flicker, etc., has been enriched by further investigations. Our experiments have revealed that these phenomena stand on a common physiological basis, namely retinal induction. Retinal induction is concerned with geometrical illusions in its static phase and with all the phenomena mentioned above in its dynamic phase.

Retinal induction caused by stroboscopic stimuli was measured by the method of electrostimulation. It is concluded that:

1. The retinal induction caused by a first stimulus is changed in character and magnitude by the action of a second stimulus successively delivered. This phenomenon is termed "conversion of retinal induction." The phenomenon of subjective color, caused by intermittent white light, may be attributed to conversion.

2. With an adequate interval between two stimuli, the induction lying in the field between the retinal areas exposed to the stimuli acquires the same quality as the induction at the site of stimulation, so that the two physically separate stimuli become fused as retinal processes. This phenomenon gives a physiological basis for the perception of fused optimal motion.

3. A gradient of retinal induction directed from the first stimulus to the second is established by conversion. The gradient is seen over a wide range of intervals and is independent of fusion processes. If it can be shown that a gradient associated with fusion corresponds to optimal movement, then it would be conceivable that a gradient devoid of fusion corresponds to the phi phenomenon.

4. The interval for optimal conversion decreases with increasing intensities of stimuli. The interval increases as the distance between two stimuli increases. These relations correspond to Korte's laws of apparent movement.

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87. Nachmias, J. Brightness and Visual Acuity with Intermittent Illumination. J. opt. Soc. Amer., 1958, 48, 726-730.

Data on perceived brightness and visual acuity were obtained under essentially identical conditions of steady and intermittent illumination, using long exposures (up to 45 sec) as well as brief ones (250 msec). Flicker frequencies down to 8 cps and light-time fraction to 0.083 were sampled. By taking into account the exact duration of the test exposures, a more general form of Talbot's law was derived, which fits all the brightness matches obtained. When this new equation is used as a yardstick, intermittent illumination turns out to be less efficient than steady illumination so far as visual acuity is concerned for brief exposures. For long exposures it is more efficient, as was previously reported by Senders.

Senders reported that interrupted light is more efficient than steady light so far as visual acuity is concerned. She found that acuity thresholds for a grating, expressed in terms of mean luminous energy, decrease with decreasing light-time fraction. A subsequent investigation by Gerathewohl and Taylor, in which contrast between printed letters and their background was the dependent variable, has been shown by Senders to confirm her major results. Since these findings conflict with expectations based on Talbot's law--which requires equal mean energy for equal brightness--Senders concluded that acuity is not simply a matter of brightness discrimination. (See references No. 48, 109, and 110).

No brightness matches were actually made in Sender's study. At frequencies above flicker fusion she assumed the validity of Talbot's law; at lower frequencies, she argued that since the Brucke effect (brightness enhancement) is maximal at 8 cps whereas the acuity improvement is not, the former cannot be responsible for the latter. However, neither Talbot's law nor the Brucke effect invariably hold, but depend on as yet incompletely investigated conditions. One of the purposes of the present investigation was therefore to obtain data on brightness and acuity under essentially identical conditions of intermittent illumination.

The threshold luminance for the resolution of a grating was determined as a function of light-time fraction by (1) the upward method of limits with continuous increase of of luminance, essentially as employed by Senders; (2) the staircase method, with exposures of 250 msec maximum duration; (3) the fluctuation method wherein 45 sec exposures of different constant luminances were presented and the total time per exposure during which the striations are visible was determined. In addition, the first two methods were used to match the apparent brightness of a flickering grating to that of a steadily illuminated grating.

The author found no brightness enhancement in the brightness matches made. He concludes, on the basis of Bartley's work, that this may be due to the low luminance levels employed, never over -0.80 log ml. Bartley's later work suggests that lower frequencies might have produced brightness enhancement at these levels. (See reference No. 10).

Figure 4 of the report shows the results obtained with the staircase method and the upward method of limits in relation to the equation expressing a more general form of Talbot's law developed by the author, which applies to both long and short exposures. The equal-acuity contours clearly diverge from each other and from the equal brightness contour. With the long exposures intermittent light seems to be more efficient for acuity than for brightness. With the short exposures the opposite is the case.

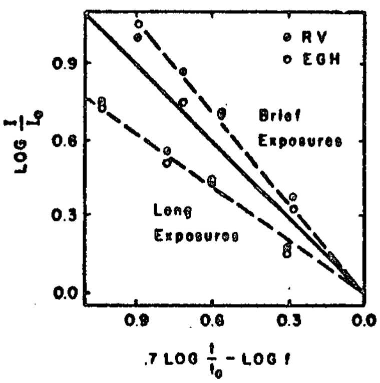

Figure 4. The relation between log relative luminance required for resolution of the grating and 0.7 log (t/t_0) - log f. Data from both observers obtained with the staircase method lie above the solid line; data obtained with the upward method of limits lie below the line.

Figure 5 of the report shows the results obtained with the fluctuation method. The relative mean energy required for all these visibility fractions clearly decreases with decreasing light time fractions, in agreement with the upward method of limits which also employs long exposures.

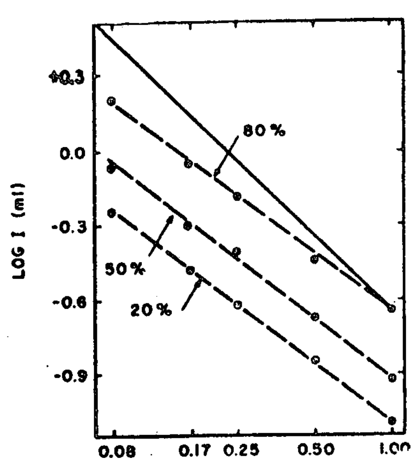

Figure 5. The relation between log luminance at which the striations are seen for different fractions of the exposure and log light-time fraction. The solid line is a plot of Talbots law. Data were obtained from observer RV with the fluctuation method.

The author concludes: It is difficult to conceive of a mechanism which can satisfactorily account for the behavior of acuity thresholds under conditions of intermittent illumination. No doubt, as Senders suggested, the fatigability of receptors and associated structures is involved in some manner. This possibility is strengthened by recent findings that visibility of a stabilized retinal image varies with flicker frequency, possibly even beyond fusion. Also suggestive is the fact that eye movements are beneficial with long exposures and detrimental with brief exposures, thus paralleling the effect of intermittent illumination presented in this paper. However, it would seem that any mechanism which predicts an improved acuity with flicker would also have to predict increased brightness, contrary to the findings of the present investigation. (See references No. 49 and 88).

88. Nachmias, J. Brightness and Acuity with Intermittent Illumination. J. opt. Soc. Amer., 1961, 51, 805.

Some years ago, on the basis of experiments in which brightness matches and acuity determinations were made with intermittent illumination, I offered these conclusions: (a) Decreasing the light-time fraction of intermittent illumination increases the luminance necessary for constant acuity and that for constant brightness, but not by the same amounts. (b) The direction of this difference depends on exposure duration. With brief trains of flashes, luminance for constant acuity increases more rapidly than that for constant brightness. With long trains of flashes, luminance for constant acuity increases more slowly than that for constant brightness. (c) When long trains of flashes are used, Talbot's law fits the brightness matches obtained even at the lowest flicker frequencies and smallest light-time fractions investigated. (d) When short trains of flashes are used, brightness matches are fitted by a more general form of Talbot's law which "corrects" light-time fractions by (1) defining exposure duration as extending from the beginning of the first flash to the end of the last and (2) taking into account the effect of exposure duration on apparent brightness.

Recently, Gibbins (see reference No. 49) has criticized these conclusions as not warranted by the data, which he feels lead more plausibly to the following conclusions: (a) Decreasing the light-time fraction increases the luminance necessary for constant brightness by the same amount as that for constant acuity. (b) This identical dependence of luminance on the light-time fraction is described by a function which is identical to Talbot's law at high flicker frequencies and light-time fractions, and which becomes less steep at low flicker frequencies and light-time fractions.

In rebuttal, I wish to put forward three arguments:

(1) Gibbins does not claim that his curves fit all of the data actually obtained by me better than, or as well as, do mine. Rather, he seeks to show that the discrepancies between his curve and those of my points which are remote from it can be accounted for in terms of either their standard error or assumed methodological artifacts. This sort of ad hoc analysis applied to certain points might be more convincing if data existed which showed that the assumed artifacts were actually present, or if the standard error of the "impugned" points were indeed much greater than that of the others. As regards the standard errors, data from the fluctuation method appearing in my paper, and variability data, unpublished but appearing in the dissertation on which the paper was based, indicate that they are roughly the same for all points.

(2) Gibbins points out that in taking account of the effect of exposure duration so as to derive a general form of Talbot's Law, I assumed "the equation of a line joining two points on a curve to be a sufficient approximation to the equation of the curve between the two points." If this were a poor approximation--even though the points in question differ by less than 0.3 log unit in the time dimension--it certainly would be true also that the type of general form of Talbot's law which I had in mind does not fit well the brightness matches obtained with brief trains of flashes. But this would invalidate only part (d) of my conclusions, not part (b) as well, as Gibbins seems to imply.

(3) Gibbins reports that recent work in his laboratory (as yet unpublished) throws "doubt on the universality of Senders' finding" of reduced energy requirement for acuity with decreasing light-time fraction. I also have such data. But the universality of Senders' finding is not in dispute, only its repeatability under comparable conditions. And that it is repeatable would seem to be indicated by the data which I have published, and others recently obtained but unpublished.

89. Noble, R. & Lazo, J. Investigations of the Optimal Characteristics of Visual Light Indicator Systems. J. aviat. Med., 1957, 28, 318-321.

This report summarizes the results of an extensive series of published investigations done at the USN Air Crew Equipment Laboratory on the temporal characteristics and shape of signal lights with respect to their attention-getting quality.

In an attempt to simulate the circumstances surrounding the pilot in an aircraft, the subjects in these experiments were assigned a tracking task, either in an experimental test set-up or in a mock-up of an F7U Cutlass Aircraft cockpit. The effects of three types of stimulus lights were investigated--steady, flashing, and alternating. The alternating light situation is that in which two lights, proximally placed, are flashed alternately at the same rate, thus giving the impression of a moving stimulus. It is pointed out that though the brightness of the different types of lights which were used was instantaneously identical, the total light emitted, and thus available for perception, was considerably greater in the instance of the steady light than in either the flashing or the alternating light situation.

The effect of the temporal characteristics of a light as an attention-getter was investigated when the light was within both a homogeneous and a heterogeneous environment and under both "day" and "night" conditions. (The reaction of subjects to caution and warning light indicators which appear in a heterogeneous background under both day and night conditions are the most applicable to the aircraft situation.) The results indicated that under day conditions, both flashing and alternating, or apparently moving, lights were significantly better attention-getters than was a steady light. In addition, the apparently moving light was significantly better than the flashing one. Under night conditions, again the superiority of the alternating, apparently moving light as an attention-getter was evidenced. These results were the same when the stimulus lights occurred within the visual field of the subjects and outside of the visual field, both against a heterogeneous background.

In attempting to equate the attention-getting qualities of these lights, it was found that, in order for a steady light to be as reliable an attention-getter as a flashing or an alternating light, under both day and night conditions, its brightness must be increased many times. In addition, it was also observed that if the onset of a steady light is missed, it does not gain attention under day conditions and only occasionally does so under night conditions. In the case of lights whose temporal characteristics vary, i.e., flashing or alternating lights, attention is always gained, even if the initial onset of these lights is missed; the alternating light stimulus is somewhat superior as an attention-getter, especially when the stimulus light is outside of the visual field.

In a separate study, the effects of varying the shape of signal lights was investigated. Four geometric shapes of the same area were used. The results showed that under both day and night conditions, in a high light contrast environment and in surroundings illuminated at light levels close to threshold, within the visual cone of the pilot, there were no differences in the attention-getting quality of the signal light which could be attributed to the varying shapes. Indications are that these results can be safely extrapolated to the regions outside of the visual field. It is noted that the lack of effect of the shape of a signal light on its attention-arresting characteristics may be utilized for a shape coding system to impart additional specific information to the pilot.

The authors conclude that the superiority of the indicator which has changing in-'nsity characteristics, i.e., the flashing and alternating light as opposed to the .eady light, has been shown positively in each of these experiments. On the basis of these results the use of steady light as an attention-getter is eliminated. In addition, there are a sufficient number of conditions where the alternating light has been shown to be significantly better than the flashing light in a similar instance. It is to be noted that alternating and flashing lights are not only a more effective and noticeable stimulus for the indication of "trouble" but can also serve, in contrast to a steady light of much higher brightness, as a means of maintaining the pilot's dark adaptation in the cockpit. The authors point out that, in spite of the significant and positive results derived from these experiments, the solution to the problem of the optimal characteristics of visual light indicators has only begun and that among other features, optimum flash rate, on-off ratio, and speed and direction of apparent movement of the alternating light remain to be investigated.

90. Nortronics Systems Support. Final Report. Rangefinder Modification Study. NSS Report No. 711A. U.S. Army Contract No. DA-04-495-502-ORD-3040. (Frankford Arsenal) 1960.

One of the objectives of this program was to evaluate the possible advantages of a "flicker" (apparent-movement) presentation versus the conventional superimposed presentation in a coincidence rangefinder.

A T-57 one-meter baselength, monocular coincidence rangefinder was modified by an external system of motor-driven, horizontally reciprocating shutters. By alternately covering the end-housings of the rangefinder, the shutters produced a horizontally reciprocating apparent-movement for all out-of-range targets. The amplitude of the movement of a given real target was proportional to the ranging knob's deviation from the correct setting for that target. In the conventional presentation (without the shutters) two images are seen where the lateral separation between the images of a given target is proportional to the ranging knob's deviation from the correct setting for that target.

Comparison tests were run using the same rangefinder with and without the shutters operating. Tests were run using both photographs of targets and real targets. The dependent variable was variable ranging error as measured by probable error in units-of-error (U.O.E.s). The error in yards or meters per U.O.E. at a given range for a given rangefinder is calculated according to the formula

$$\frac{\text{error}}{\text{U.O.E.}} = \frac{(\text{least noticeable difference angle})\ (\text{true range}/1000)^2}{(\text{rangefinder magnification})\ (\text{rangefinder base length})}$$

where the least noticeable difference angle of the average unaided eye is assumed = 12 seconds = $5/82 \times 10^{-5}$ radians, and the true range and rangefinder base length are given in yards or meters.

The type of results obtained with real targets is illustrated by figure D-7 of the report. For each of three targets, readings were made at the frequencies shown in the normal way (looking in the eyepiece), and with a closed circuit television presentation of the view normally seen through the eyepiece.

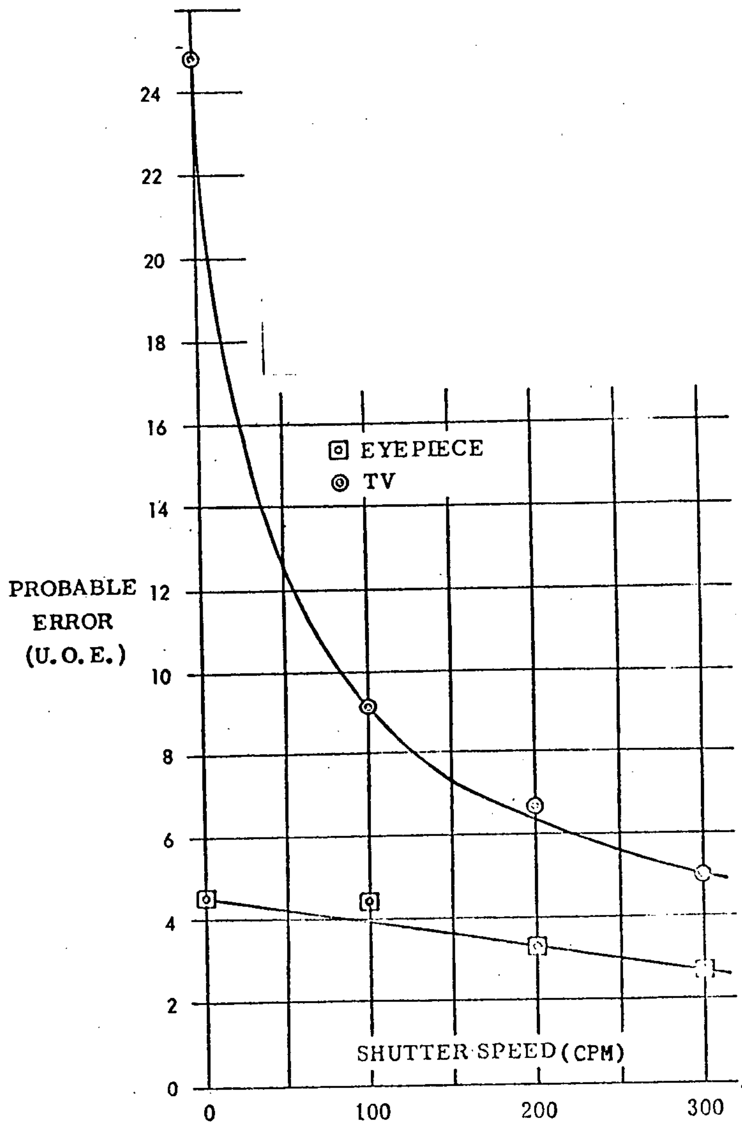

Figure D-7. CLEAR TARGET AT 1100 YARDS - STEEL STACK

The atmosphere was hazy when the eyepiece was used and clear when the television presentation was used. Figure D-7 is atypical in that the optimum frequency appears to be above 300 cpm (5 cps). This was hypothesized to be a function of the extremely long near-vertical edge of the smokestack which provided an unusual, While no tests of statistical significance were made, the magnitude of the differences between the results obtained with certain flicker frequencies (apparent movement) and those obtained with the conventional presentation were so large that statistical significance, at least for these differences, can be safely assumed. For both types of tests three observers made five readings each for each condition investigated. The results were graphed by drawing freehand curves through the means of the 15 readings for each condition. It should be noted that the graphs selected to illustrate the results are those which show the greatest improvements for flicker, but that improvements large enough to have marked practical significance were found for all targets.

The type of results obtained in the tests using identical photographs at each end housing of the rangefinder is illustrated by figure D-3. For each of five targets readings were made at 0 (conventional coincidence presentation) 100, 200, 300, and 400 cpm (1.67, 3.33, 5, and 6.67 cps) at two levels of intensity. (Photograph illumination was varied by changing the voltage supplied to standard 60-watt tungsten light bulb.) It must be noted that these tests were not really representative of the ranging task, in that everything in the photograph was effectively at the same range as the target ranged upon. Thus as the ranging knob was turned, the movement or separation of everything in the photograph was increased or reduced by the same amount. In spite of this the results are in general agreement with those obtained with real targets. Marked improvement was obtained with apparent movement. This improvement appeared to be even more pronounced for obscure and poorly illuminated targets. The optimum apparent-movement frequency appeared to be between approximately 100 and 300 cpm (1.67 and 5 cps) depending on the target used.

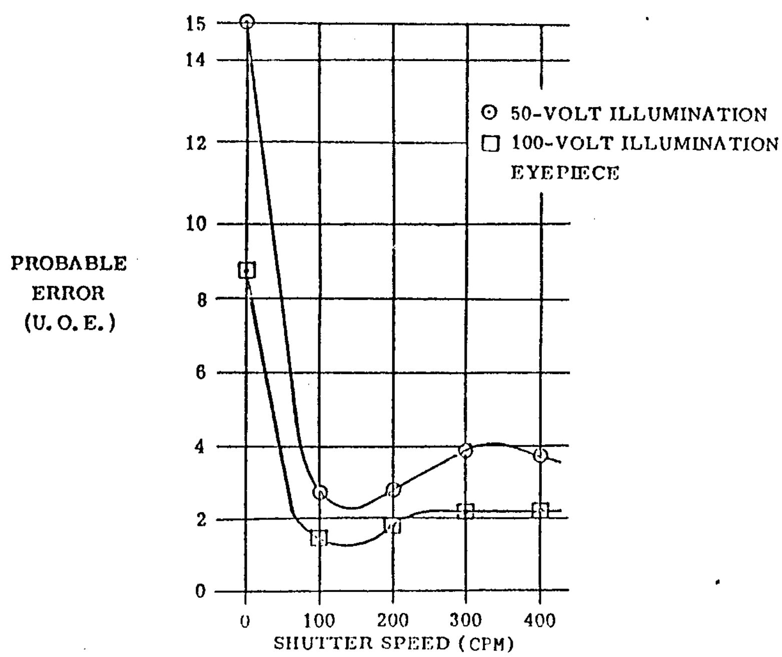

Figure D-3. OBSCURE TARGET AT 800 YARDS - TANK, SLIDE NO. 8

theoretically ideal ranging cue. The optimum frequency for the other targets ap-
ared to be between 100 and 200 cpm (1.67 and 3.33 cps). As in the tests using
otographs, flicker was found to provide relatively greater improvements with obscure targets and with the degraded target images of the television presentation.

It was concluded that flicker (apparent movement) provides a great improvement over conventional coincidence rangefinding, and that this improvement is greatest for the poorly defined targets which are the most difficult to range. It is also concluded that closed circuit television ranging is practical if flicker is also incorporated in the system. (See reference No. 91).

91. Nortronics Systems Support. Final Report. M17C Rangefinder Modification Study (XM-21 Flicker Rangefinder). NSS Report No. 2113. U.S. Army Contract No. DA-04-490-ORD-3306 (Frankford Arsenal) 1962.

The purpose of this study was to further investigate the use of "flicker" in rangefinding by incorporating a more sophisticated apparent-movement producing system in the M17C two meter base-length, monocular, coincidence rangefinder. (In this and in the previous report "flicker" is used to indicate that the light entering the rangefinder is interrupted, where the cue introduced was actually an apparent target movement.) By using an internal reciprocating mirror to both produce apparent-movement and to perform the function of presenting both images in the same eyepiece, the light-loss inherent in chopping light was approximately counterbalanced by the removal of the rangefinder's combining prism with its inherent 50% light-loss for each image. This was in contrast to the external shutter system used in the T-57 studies, where these losses were additive. (See reference No. 90).

Comparison tests of the modified rangefinder (officially designated the XM-21) and an unmodified M17C were conducted by mounting the two rangefinders piggyback. A 4 x 3 x 5 factorial experimental design was used, where the independent variables were apparent-movement frequency, range and subjects respectively. The targets were real camouflaged trucks parked at three ranges. The dependent variables were variable error as measured by probable error, and time required for ranging. (Plus or minus one probable error, $= .6745\sigma$, includes 50% of the range estimates.)

The results are summarized in figure 12 of the report. The three graphs are for the short, middle, and long range targets. (The lines drawn between data points are for illustration and do not represent curves fitted to the points). The mean probable error across subjects and the probable error for each of the five subjects is shown in percent of nominal range, in units-of-error, (See reference No. 90) and in meters. Thus the graph for the 2600 meter target shows that approximately 50 percent of subject number one's ranging estimates fell between ±4.2 U.O.E.s for 0 cps (conventional coincidence presentation) versus ±1.3 U.O.E.s for 3 cps apparent-movement indicating in this particular case, well over a three-to-one reduction in variable error through the use of apparent-movement.

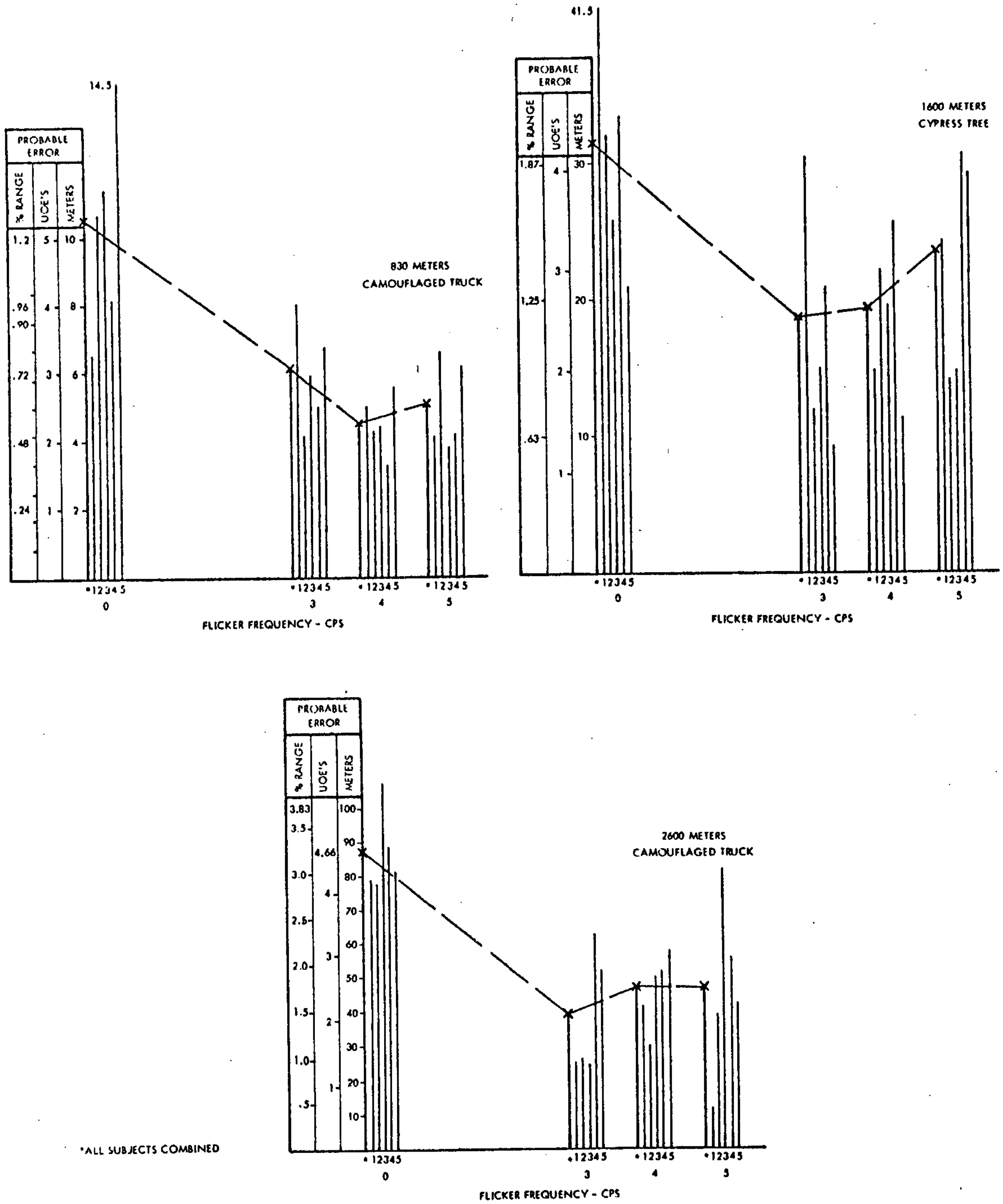

Figure 12. PLOTS OF PROBABLE ERROR

Since the dependent variable was variable error an analysis of variance technique was used in which the analysis is performed on the $\log_{10}$ of the variances for each condition. The difference obtained between coincidence ranging (0 cps) versus apparent movement (3, 4, and 5 cps combined) was found statistically significant beyond the .001 level. The differences between 3, 4 and 5 cps and the differences between ranges and subjects were not significant. Significant interactions were found for frequency x range, frequency x subject and range x subject. A mathematical surface fitted to the frequency x range interaction showed that only the frequency-quadratic x range-linear component of the interaction was significant.

Apparent movement ranging took longer. The mean ranging time for coincidence ranging was 22.4 seconds versus 22.8 seconds for apparent movement. This difference was statistically significant.

Figure 13 of the report provides a general comparison of the results obtained in this study with those of the previous study. The probable error in meters for all subjects combined is shown for the apparent movement frequencies and ranges investigated in each study. (The T-57 data is that obtained with real targets, using the eyepiece).

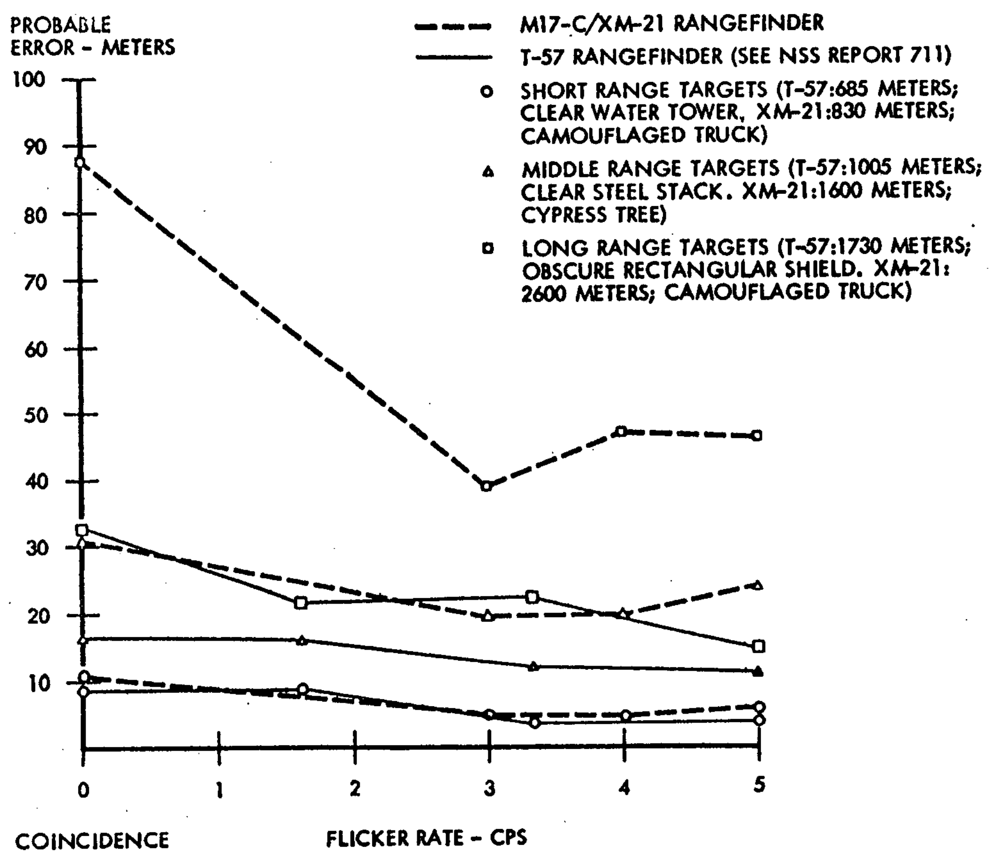

Figure 13. PROBABLE ERROR IN RANGING - FLICKER AND COINCIDENCE RANGEFINDERS

It is concluded that flicker ranging afforded an approximate two-to-one improvement in ranging repeatability (reduction in variable error). This improvement was much greater for particular combinations of frequency, range and subject. On the basis of a preliminary experiment, it is hypothesized that a fixed vertical reticle place near the apparently moving target is critical in apparent-movement ranging.

It is noted that during periods of very low visibility, the far target could be sighted and ranged upon with the apparent-movement rangefinder when it could not even be detected through the unmodified rangefinder. This suggests that apparent-movement might be used for the detection of low visibility targets in other than the range-finding situation. See references No. 25B and 52B.

92. Parker, D.C. & McDonald, M.A. Infrared-Strip-Map Stereoscopy (U). Project MICHIGAN Memorandum Number 2900-170-R, U.S. Army Signal Corps, 1960. (AD 318545) CONFIDENTIAL

Relevant contents classified. See pages 17, 20, 24 and 25.

93. Perrin, F.H. A Study in Binocular Flicker. J. opt. Soc. Amer., 1954, 44, 60-69.

If both eyes are subjected to flickering stimuli of equal luminance and frequency, the critical fusion frequency is usually somewhat higher when the stimuli are in the same phase than when they are in opposite phase. The difference in fusion frequency for the two cases is herein termed the Sherrington effect after its discoverer. Apparatus for measuring this effect is described in the present paper. It was found that, for a 2° visual field and dark surround, the Sherrington effect was proportional to the mean critical frequency for the two eyes as the field luminance was varied, being about 8 percent of it for the present observer. At constant field luminance, the effect approached zero as the field angle approached zero but was approximately constant for angles greater than 2° . The mean monocular fusion frequency for seven observers was below the simultaneous (in-phase) binocular frequency, and for a 0.25° field it was even below the alternate (out-of-phase) frequency; for three observers, it was below the alternate frequency for a 2° field. The present data appear to be inadequate to serve as a basis for deciding between alternative explanations of the phenomena.

94. Pieron, H. La Vision en Lumiere Intermittente. Monograph, Centre Nationale de la Recherche Scientifique, Paris, 1961.

Despite the voluminous literature pertaining to flicker and fusion phenomena, the subject is not well understood and has seldom been thoroughly elucidated from a theoretical viewpoint. In this monograph, the author brings together the data of a selected number of flicker studies. Often replotted and/or presented in tabular form, these are considered in relation to other psychophysical studies of relevance. All are then interpreted in the light of his theory, which is presented in detail along with supporting neurophysiological evidence.

95. Pieron, Henri. Nomenclature of Retinal Ganglion Cells. J. opt. Soc. Amer., 1961, 51, 458.

The nomenclature of the retinal ganglion cells with the corresponding cortical cells consists of three types: "on," "off," and "on-off." Of the latter two, one type is characterized by inhibitory responses to light and spikes upon its cessation, the other by bursts of spikes at the beginning and end of the light stimulus. The on cells are essentially of two different types. Some behave like on-off cells at the onset of stimulation but do not respond to cessation of the light. However, others, less numerous, respond continuously for the entire duration of the light stimulus. Their frequency of response decreases, but initially, at least, it is proportional to the logarithm of the light intensity. These are the cells which determine brightness perception, and it is the variation of this spike frequency during the intermittent stimulus cycle which determines flicker. At CFF (critical fusion frequency) no further modifications in spike frequency occur during the light-darkness cycle.

The cells of the first type, as well as the on-off and off cells, have already ceased to respond synchronously at lower frequencies.

It is to be regretted that the same designation is used for cells having a transitory response, favoring contrast perception, and for cells which play the major role in brightness perception.

The author believes that these should be named differently. They might be designated as "on-with" in order to emphasize that their response accompanies stimulation. Present-day neurophysiology neglects them too much.

96. Pieron, H. Neurophysiological Mechanisms of Critical Flicker Frequency and Harmonic Phenomena. J. opt. Soc. Amer., 1962, 52, 475.

Research and discussion continue on the role of harmonic phenomena in intermittent luminous stimulation for critical flicker frequency determination.

However, these discussions are and will continue to be futile because the process of physiologic excitation set off by the absorption of the photons follows in no way the stimulus modalities. Critical flicker frequency (CFF) is determined by the value of the critical time τ . During that time the effect engendered by the photochemical process is the same irrespective of the distribution in time of stimulating photons, increasing as the logarithm in their number. This effect, as is know consists of the slow excitatory potential and the activity of the on-with neurons whose :requency is proportional to this potential.

Within the limits of τ and for a given number of photons, the brightness is the same for all distributions of very brief flashes (Davy, 1952), as well as for all shapes of flashes: rectangular, triangular, circular (G. E. Lang, 1951). The critical time τ diminishes as a function of the logarithm of the luminosity (Graham and Kemp, 1938; Margaret Keller, 1941; Herrick, 1956; Biersdorf, 1958). This has led to the Ferry-Porter law for CFF. As soon as the time τ is surpassed, there are oscillations of the slow potential and of the frequency of optical messages producing the flicker. If the utilization time, allowing partial summation of the successive stimuli, is shorter than the interval between stimuli, the responses to the excitation become independent and the sensations are separated.

What is the effect on the period of the varion in the phase ratio when the mean number of photons is kept the same? This number determines the brightness at the moment of fusion in accordance with Talbot's law, which is correlated with the Bunsen-Roscoe law (valid for vision, like Bloch's law, in the limits of the critical time τ). In this case, a law established by Ives (1922) relates the CFF to the logarithm of the relative length of the stimulus interval, as has been unanimously verified (pieron, 1928; Cobb, 1934; Ross, 1938; Winchell and Simonson, 1951). However, when the luminance of stimulation is kept constant, the variation in the mean number of photons during the period acting in an inverse direction to Ives' law, explains, as the author has already shown, all results (Segal, 1920; Ross, 1943; Bartley, 1958-60) which indicate a maximum CFF for a ratio in the neighborhood of 50%.

All interpretations which introduce "off" effects in the retina are excluded because CFF occurs while "on" and "off" responses no longer respond (Grusser), being controlled by the frequency stability of the messages from "on-with" responses.

97. Projector, Theodore H. Effective Intensity of Flashing Lights. Illum. Engng., 1957, 52, 630-640.

The purpose of this article was to review existing psychophysical knowledge essential to the design and evaluation of flashing lights. Emphasis is placed on an examination of the adequacy of the classical formulations of Blondel and Rey in the light of more recent research.

98. Richards, Walter J. The Effect of Alternating Views of the Test Object on Vernier and Stereoscopic Acuities. J. exp. Psychol., 1951, 42, 376-383.

The pre ent study investigated (a) the effect of rate of alternation of stereoscopic and pseudoscopic views of the targets on the threshold for depth, and (b) the effect of rate of alt rnation of R and L views of the targets on the vernier threshold.

A Helmholtz-type three-rod target was used. The outer rods were separated from one another by 21 mm., and were at a distance of 4,622 mm. from S. Alternate views of the targets were presented to each eye by means of a system of prisms and motor-driven vanes. Data were obtained from three Ss by the method of constant stimuli with two categories of judgment. Each threshold was based upon 20 judgments at each of five stimulus positions.

Within the limits of the present experiment, the following conclusions may be drawn:

1. Stereoscopic discrimination falls off rapidly as the rate of alternation of views increases, while vernier discrimination is much less affected by increase in rate.

2. Stereoscopic discrimination is not possible at rates much above 4 cy./sec. alternation of the vanes.

3. Vernier discrimination is still possible at rates in excess of 20 cy./sec. alternation.

4. The stereoscopic threshold at the highest rate possible is about five times the vernier at the same rate.

5. It is suggested that some cortical process underlies stereoscopic discrimination, and that this mechanism cannot respond at rates higher than four alternations of the disparate views per second. In line with this suggestion, it may be recalled that data on reaction time show that central processes are of long duration. Also, electrical events (EEG's) in the cortex have very long time characteristics.

(This report has provided useful information for the investigation of pseudostereo-orthostereo alternation as a possible cue in rangefinding.)

99. Riggs, L.A., Ratliff, F., Cornsweet, J.C. & Cornsweet, T.N. The Disappearance of Steadily Fixated Visual Test Objects. J. opt. Soc. Amer., 1953, 43, 495-501.

A system has been devised for causing an image to remain at one point on the retina regardless of eye movements. A beam of light, reflected from a plane mirror on a contact lens, is used to project onto a screen an image of a dark line against a bright background. The screen is viewed by the same eye through an optical system which compensates for the doubling of the angle of rotation of the beam projected from the mirror on the contact lens. Thus, any motion of the eye causes a deviation of the beam such that the retinal image of the projected line undergoes the same displacement as do the retinal receptor cells. By comparison with normal viewing of the same test objects it is found that (1) when first presented, the finest lines are seen with normal or slightly better than normal acuity, (2) within a few seconds the lines begin to disappear, and (3) within one minute even coarse lines are seen only intermittently. The results may be interpreted in terms of local retinal adaptation to a stationary field.

100. Riggs, L.A., Ratliff, F. & Keesey, U.T. Appearance of Mach Bands with a Motionless Retinal Image. J. opt. Soc. Amer., 1961, 51, 702-703.

The authors cite previous experiments which show that lines and contours are perceived quite clearly in motionless images during the first critical few seconds of viewing, and other that show that the gradual fading of contours under prolonged viewing is more rapid with motionless images. These results are interpreted to imply that, although contour perception may require either transient responses produced by the onset or cessation of illumination or transients resulting from motion, it does not require motion per se. The results of three experiments are presented which lead the authors to conclude that normal eye movements during steady fixation do not enhance the appearance of the bands, but may serve to maintain vision of the bands in prolonged viewing. In some preliminary experiments it was found that large slow sinusoidal movements (1 sec of arc, 3 cps) lengthen the time during which Mach bands are visible with a stabilized retinal image, but smaller and faster movements do not. These results are in agreement with those obtained without image stabilization by Fiorentini and Ercoles, who found that displacement frequencies in the range from 2 to 5 cps were optimal for maintaining vision of Mach patterns having various gradients of luminance.

101. Riggs, L.A. & Tulaney, S.U. Visual Effects of Varying the Extent of Compensation for Eye Movements. J. opt. Soc. Amer., 1959, 49, 741-745.

The effects of small, involuntary eye movements have been counteracted by an optical system that fixes a test image at a given point on the retina. This causes the test object to disappear. In the present experiment the relative amount of image motion has been varied over a wide range, with special attention to the condition of nearly complete absence of image motion. The disappearance is greatest for low contrast images with minimal amounts of motion.

102. Ripps, H. & Kaplan, I. T. Influence of Extratest Illumination on the Critical Flicker Frequency of the Human Fovea. J. exp. Psych., 1960, 60, 255-262.

Foveal CFF was studied as a function of inducing field luminance for several different configurations of extratest stimulation. The inducing field effects were determined over a wide range of test field luminances with two Ss.

One inducing field configuration was a veiling patch superimposed upon the test field and its surrounding regions. At low veiling luminances no change in CFF was observed. As veiling luminance increased beyond a critical value, CFF gradually rose to a maximum and then fell steeply to levels far below that obtained in the absence of the veil. An inducing field adjacent to the test field also produced an increase in CFF followed by a decrease. However, the decrease in CFF was neither as steep nor as large as that produced by the veil. Even the highest luminances of the adjacent inducing field did not reduce CFF appreciably below its original value. For both inducing field configurations, at higher test field luminances the critical inducing field luminance required to raise CFF increased, and the slope and magnitude of the rise in CFF increased.

Analysis of the component parts of the veiling luminance configuration indicated that illumination of the region surrounding the test area was responsible for the increase in CFF. The only effect of a steady luminous field superimposed upon the test field was to decrease CFF. The decrease was slight until an abrupt drop occurred at high inducing luminance. Thus, the sharp decline in CFF which distinguished the effect of a veil from that of an adjacent inducer was a consequence of that portion of the veil which was superimposed upon the test field. The enhancement of CFF results therefore from interaction between adjacent retinal regions.

Other investigators have observed that CFF can be raised by an inducer somewhat removed from the test field. In the present study it was suggested that a veil of stray light from the remote inducer may contribute to the enhancement of CFF, since it was shown that a veiling patch can raise CFF. Thus, the enhancement effect may result from interaction between the test region and its immediate surround, even in the absence of interaction between remote areas of stimulation.

Subjective reports of apparent brightness indicate that a rise in CFF is not necessarily accompanied by a corresponding increase in apparent brightness. When CFF was maximally enhanced by a contiguous inducing field, test field apparent brightness was greatly reduced.

103. Ripps, H., Kaplan, I. T. & Siegal, I. M. Effect of Contrast on CFF and Apparent Brightness. J. opt. Soc. Amer., 1961, 51, 870-873.

Critical flicker frequency and apparent brightness of a foveal test field were determined as functions of the luminance of an adjacent inducing field. Apparent brightness measurements were obtained by a binocular comparison method. Inducing luminance was varied through a range of 4.4 log units at each of three test luminance levels: 0.55, 1.57 and 2.47 log ft-L. The apparent brightness of the intermittent test field, determined at the flicker-fusion threshold, continuously decreased as inducing luminance was raised. CFF, on the other hand, varied in a complex manner: increasing initially, reaching a maximum and then declining. Over a wide range of inducing luminance, the enhancement of CFF was accompanied by a decrease in apparent brightness. This induced divergence is radically different from the parallel changes in CFF and apparent brightness that occur when test luminance is varied. It was hypothesized that entoptic stray light played a minor roles, but that spatial inhibition in the retina could account for both the rise and the fall in CFF as well as the concomitant decrease in apparent brightness.

The results of the study were summarized in figures 2 and 3 of the report.

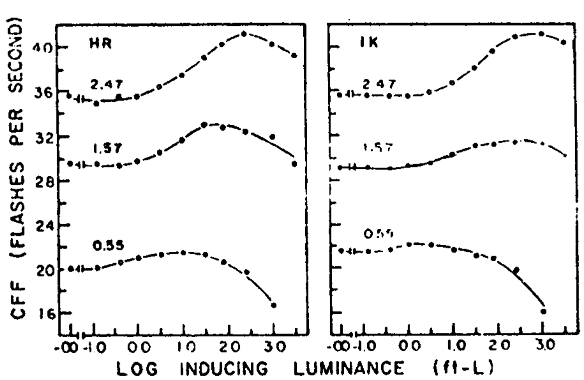

Figure 2. Critical flicker frequency as a function of inducing luminance. The number above each curve indicates the luminance in log ft-L of the light phase of the intermittent stimulus. Data for subjects HR and IK.

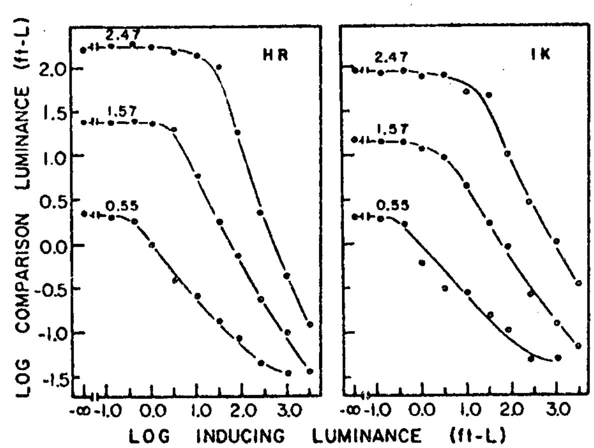

Figure 3. Comparison luminance as a function of inducing luminance. The number above each curve indicates the luminance in log ft-L of the light phase of the intermittent stimulus. Data for subjects HR and IK.

105. Ronchi, Lucia and di Francia, G. Toraldo. On the Response of the Human Eye to Light Stimuli Presenting a Spatial or Temporal Gradient of Luminance. J. opt. Soc. Amer., 1957, 47, 639-642.

The authors discuss the results of the experiments on vision of spatial and temporal gradients of luminance. There is some evidence that the cone mechanism is responsible for the vision of Mach bands; on the other hand it appears both from measurements in the peripheral retina and from electroretinographic investigation that the rod system contributes to the sensation of higher brightness of the graded field.

A possible relation is pointed out between the phenomena occurring in the vision of a field with a spatial gradient of luminance and the vision of a field with a temporal gradient of luminance.

This report concerns the same research reported in reference No. 40.

106. Scott, B. Further Studies of a 9-cps Resonant-Frequency Effect in the Human Fovea-Cortex System. J. opt. Soc. Amer., 1962, 52, 1082-1083.

There is insufficient evidence to explain the "resonance effect". De Lange suggests that a negative-feedback system which changes to positive feedback at 9 cps is a likely mechanism and that this process may occur centrally or peripherally. Bartley concluded that the brightness enhancement at 9.5 cps was a central phenomenon since it occurred in this frequency range for all luminances and all practical bright-dark ratios.

It is known that within certain limits a repetitive visual stimulus can evoke a corresponding cortical electrical response. However, the frequency characteristic involved in driving the alpha rhythm does not appear to have been studied.

If the "resonance effect" is a central phenomenon it would seem natural to expect that there might be a similar increase in sensitivity at 9 cps for an auditory stimulus. Riesz using "beats" around 1000 cps found an increase in sensitivity at 3-cps beat frequency. This writer (in unpublished results) also found a maximum in sensitivity at 3 cps using amplitude modulation. An "auditory resonance" effect does exist but not at the same frequency as the visual one. Thus it does not help in determining whether the visual resonance effect is central. It has been suggested that the visual "resonance" effect is linked to the alpha rhythm at 9 cps. Another spontaneous cortical rhythm at a frequency corresponding to the auditory-resonance effect, i.e., 3 cps is the delta rhythm. The observations of Loomis, Harvey, and Hobart, and Davis et al., suggest that delta waves are closely associated with auditory stimulation.

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lthough the evidence is meager the present observations suggest that the [illegible] -an-'st. of the visual-resonance phenomenon and probably also the auditory-resonance phen.menon involve the interaction of the output of the sense organ with that of closely associated spontaneous cortical electrical rhythm which produces an increase in sensitivity at the natural frequency of the cortical rhythm.

107. Sekuler, R.W. & Ganz, L. Aftereffect of Seen Motion with a Stabilized Retinal Image. Science, 1963, 139, 419-420.

Prolonged inspection of uniformly moving contours affects differentially the luminance threshold for the detection of test contours as a function of the direction of motion of the test contours. This finding supports a new explanation of the well-known aftereffect.

The authors conclude that the results of the reported experiments definitely support an explanation of motion aftereffect on the basis of direction-specific cortical adaption, such as Sutherland has proposed.

108. Sen, T.K. & Mowbray, G.H. Influence of Size and Brightness Parameters on the Differential Sensitivity of the Central Retina to Photic Flicker. J. opt. Soc. Amer., 1962, 52, 603. (Abstract)

Differential thresholds for intermittent white light (produced by a Sylvania R113C glow-modulator tube) were obtained for 5 luminance levels, 5 areas of the central retina stimulated, and 10 frequencies of intermittence. In general, for constant values of other parameters, differential sensitivity of the central retina was found to be a complex function of frequency, thus confirming the results of a previous study. The point of minimum sensitivity, however, was found to be a joint function of frequency and luminance level. An analysis of variance with the DL values showed no significant effect due to retinal area of luminance level per se, but showed significant interactions between (1) retinal area and luminance level and (2) retinal area and frequency. Along with other factors, the results are also discussed with respect to the apparent contribution of the density of the retinal receptors.

109. Senders, V.L., Visual Resolution with Periodically Interrupted Light. J. exp. Psychol., 1949, 39, 453-465.

In order to test the hypothesis that visual acuity is a form of brightness discrimination, a situation was sought in which visual acuity and brightness discrimination might be shown to have a different functional relation to the same independent variable. By using interrupted, rather than steady light, and measuring the intensity required for resolution as a function of the light-time fraction in the interruption cycle, such a situation was found. The resolution contours obtained in this manner lay significantly below the brightness contour, as expressed by the Talbot-Plateau Law. (This law states that the brightness of fused interrupted light is the s ıe as if the total light energy per cycle were evenly distributed throughout the cycle -- i.e., that decrease in brightness is proportional to the decrease in light-time per cycle.) Extensive results were obtained from three Os, under several different conditions of image size, retinal location, flash frequency, and wavelength composition.

It was therefore concluded that visual acuity cannot be a form of brightness discrimination, although the two processes may be related. Specifically, this means that the quantitative generalizations applicable in one case need not necessarily be applicable in the other. The following mechanism was suggested to account for the obtained data. Peaking of the image may occur because the retinal elements in the center of the fluctuating distribution of intensities are non-refractory for a relatively greater portion of the time when the light is interrupted than when it is steady, resulting in an increase in the relative proportion of neural impulses coming from this central portion. It was concluded that the data cannot be accounted for at a strictly retinal level, and that any explanation must take account of neural processes central to the retina.

The log-log plot in figure 1 of the report illustrates the type of results obtained. The deviations from the Talbot contour are greatest at 4 cps, next for 8 cps, and least above fusion. It must be noted that these results indicate only that intermittent light is more efficient in that the intensity of intermittent light does not have to be increased as much to provide steady-light resolution as it does to provide steady-light brightness. That there was no enhancement of resolution is indicated by the fact that the curves for intermittent light do not drop below the intensity required for resolution under steady light, indicated in figure 1 by the point on the Talbot brightness contour where the light-time fraction = 1.00. However, the curves indicate that there was little or no degradation in resolution at 4 cps, at and above a light time fraction of .50. (See reference No. 20 for recent evidence for contrast enhancement.)

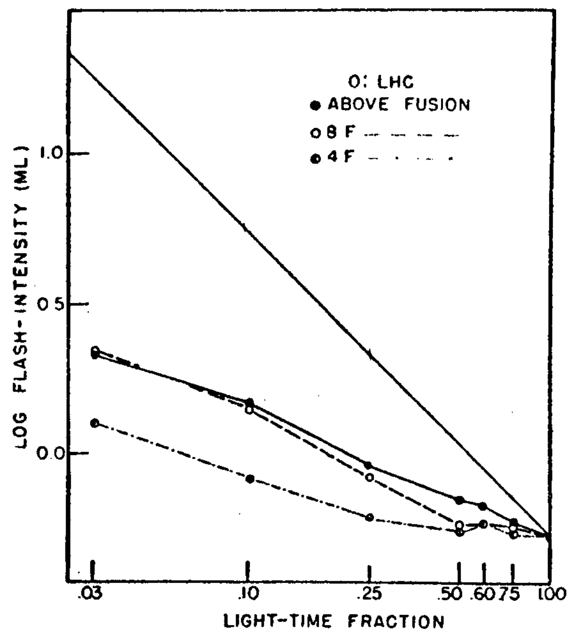

Figure 1. The relationship between the logarithm of the flash-intensity required for resolution and the logarithm of the light-time fraction, for different flash frequencies. A 2° x 2° test patch, centered at the fovea, is used with the red light. All data are expressed as multiple of the steady light threshold for the series obtained with a flash frequency above fusion. The 45° line is the contour for the constant Talbot (fused) brightness.

110. Senders, V. L. On Reading Printed Matter with Interrupted Light. J. exp. Psychol., 1954, 47, 135-136.

The author re-examines the data published by Gerathewohl and Taylor (see reference No. 48). It is demonstrated that the decrease in print visibility obtained was not, as these authors concluded, close to that predicted by the Talbot effect. The author concludes that the data show exactly the same effect that she reported in a previous experiment, i.e., regardless of the flash frequency used, less energy is required for resolution when light is interrupted than when it is steady.

The authors re-plot of Gerathewohl and Taylor's data is shown in figure 1 of the report.

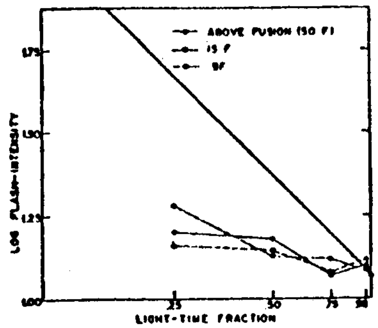

Figure 1. The relationship between the logarithm of the flash intensity required to read a line of print and the logarithm of the light-time fraction. The 45° line is the contour for the constant Talbot (fused) brightness. Data are from Gerathewohl and Taylor (1, p. 281).

111. Simonson, E. & Brozek, J. Flicker Fusion Frequency. Background and Applications. Project No. 21-32004. Report No. 2. USAF School of Aviation Medicine, Randolph Field, Texas. 1953. (AD 14766)

While the principal topic of this review is the applications of CFF to physiological stress and medicine, it provides a very valuable summary of equipment, methods, fundamental variables, and findings related to the study of flicker.

The non-equivalence of results obtained with electronically produced versus shutter produced flicker is discussed.

112. Thomas, G. J. Effect of Contours on Binocular CFF Obtained with Synchronous and Alternate Flashes. Amer. J. Psychol., 1956, 69, 369-377.

From a hypothesis suggested by results of an earlier study of the effect of phase of flash on binocular CFF, it was predicted that addition of contours to the stimulus-patches which fall on corresponding retinal areas would enhance the Sherrington effect, i.e., the superiority of flicker-sensitivity when flashes are delivered synchronously to the two eyes as compared to CFF obtained with alternate flashes. An experiment is described in which binocular CFF with both in-and-out of phase flashes in the two eyes was determined over a range of about 6 log-units of flash luminance under two conditions. In one condition the stimulus-patch viewed by the left eye and that viewed by the right eye contained grid-patterns of vertical lines arranged to fall on corresponding retinal areas when the stimuli were unified binocularly. In the other condition the grid-lines of the two stimulus-patches were perpendicular to each other. The stimulus patches were circular in shape and identical in size and luminance. The results show an increase in the magnitude of the Sherrington effect when the stimulus-patches contain additional contours as compared with that reported in an earlier paper and obtained under comparable conditions. The arrangement of the lines of the grids (either vertical for both eyes, or vertical for the left and horizontal for the right) had, however, no effect on the magnitude of differences between CFF with in-phase flashes and CFF with out-of-phase flashes. An alternative test of the hypothesis is proposed.

113. Truss, C.V. Chromatic Flicker Fusion Frequency as a Function of Chromaticity Difference. J. opt. Soc. Amer., 1957, 47, 1130-1134.

The critical color fusion frequency (ccff) was measured for each of fifteen pairs of six colors at equal luminance. Measurements were made at five levels of luminance ranging from 9 to 67 trolands. Two subjects were used. The six colors were of high chromatic purity. Their dominant wavelengths covered the range of 445 mμ to 670 mμ in nearly equal steps. The relative chromatic separation between the member of each pair was estimated from Judd's RUCS and from Wright's data on the size of equally noticeable color steps in the CIE chromaticity diagram.

The results show that log reciprocals of cff and ccff are nearly parallel and linear functions of luminance in log trolands. The product-moment correlation between persistence (1/ccff) and log chromatic separation on the RUCS was 0.84 and 0.91 when log chromatic separation was computed from Wright's data.

114. Valsi, E., Bartley, S.H. & Bourassa, C. Further Manipulation of Brightness Enhancement. J. Psychol., 1959, 48, 47-55.

The present study consisted in a further attempt to determine whether brightness enhancement is increased as PCF (pulse-to-cycle fraction) of intermittent stimulation is decreased below 0.3, and whether using the one eye for the reference target and the other for the comparison target is more effective than when using the same eye for both. It was found that the PCF reductions were not effective in the manner expected, and that in some cases using both eyes as just indicated was more effective than using only one.

The failure to obtain the expected PCF results was discussed at length, with certain plausible reasons given for the obtained results.

The results of the study are shown in Table 1 of the report. The frequency used was 10 cps.

TABLE 1

This table shows the relation between target intensity in candles per square feet (c/ft^2), pulse-to-cycle-fraction (PCF), and the relative effectiveness of the intermittent target, for two observers (V and B) and for four different general conditions. Conditions I, II, steady target seen with one eye, intermittent with the other. Conditions III and IV, only one eye used, both targets seen with it. Conditions I and III, small targets; Conditions II and IV large targets. The numbers in the PCF columns are the relative effectivenesses of the intermittent targets relative to the steady ones.

	PCF			PCF			PCF			PCF		
c/ft^2	.04	.3	.5	.04	.3	.5	.04	.3	.5	.04	.3	.5
						Observer V						
		I			II			III			IV	
24	1.1	1.65	1.95	1.0	1.9	1.7	.8	1.45	1.9	.35	1.5	1.8
44	0.8	1.80	1.35	1.1	2.75	2.15	1.0	2.15	1.6	.6	1.7	1.6
95	0.9	1.15	2.12	1.0	4.45	3.25	.95	2.85	1.4	.85	1.35	1.35
175	0.7	4.7	2.4	1.9	3.9	3.55	1.25	2.95	2.6	.65	2.45	2.3
310	1.45	4.65	2.75	1.8	3.05	5.4	1.5	2.95	2.55	1.35	2.45	1.54
						Observer B						
24	1.35	2.55	3.05	1.3	3.1	2.55	.55	2.80	2.20	1.3	3.4	2.6
44	1.15	2.40	3.00	1.25	3.55	2.6	.85	2.3	1.75	1.3	4.35	2.0
95	1.55	5.4	5.35	1.5	6.9	3.95	1.10	2.5	1.75	1.7	7.0	2.8
175	3.05	6.6	3.95	2.45	5.55	5.1	1.35	2.3	2.15	2.5	7.45	3.8
310	6.15	9.6	5.15	3.25	5.15	6.0	1.5	1.2	1.9	2.35	8.5	3.9

The authors note that the value of the reversal point where decreasing PCF begins to decrease instead of increase brightness enhancement was not closely determined because of the large interval between 0.3 and 0.04. The results are discussed in terms of the Bunsen-Roscoe Law. See reference No. 17.

115. Veringa, F. On Some Properties of Nonthreshold Flicker. J. opt. Soc. Amer., 1958, 48, 500-502.

Results are reported on the foveal discrimination thresholds between combinations of percent of sinusoidal modulation and frequency, at several different levels of constant luminance. The results are compared with those of deLange.

116. Volkmann, F.C. Vision During Voluntary Saccadic Eye Movements. J. opt. Soc. Amer., 1962, 52, 571-578.

Vision seems to be a continuous process even though eye movements occupy a portion of the time spent in reading or inspecting objects in the field of view. This observation has led to the supposition that a "blanking out" of vision occurs with saccadic eye movements. Some workers attribute this effect to the rapid motion of the image on the retina. Others have suggested a central inhibition, possibly related to the physiological mechanisms of attention. The present research compared vision during saccades with vision during fixation by means of three representative psychophysical tasks. Each stimulus pattern was presented to the fovea in the form of an instantaneous flash that was delivered before, during, or after an eye movement. The flash lasted only 20 μ sec, so that retinal blur due to movement was reduced to a negligible amount. The time of the stimulus flash was signaled on a continuously moving film on which the eye movements were recorded by a corneal reflection technique. Detection thresholds for dot patterns and recognition thresholds for words were found to be about 0.5 log unit higher during saccades than during steady fixation. Similar differences, though smaller and less consistent, were found in the minimum angles for the resolution of gratings. It is concluded that vision is not "blanked out" during eye movements, but that it is significantly depressed even under conditions that minimize blur due to movement of the retinal image, and that assure foveal stimulation.

117. Wallin, W. Wave Synthesizing Light Chopper. J. opt. Soc. Amer., 1955, 45, 287-292.

A method is described for modulating light according to any function describable by Fourier series. Any such wave shape can be synthesized although the mean light level cannot in general be controlled. Polar equations are developed for apertures that can be used in conjunction with rotating shutters having radial edged sectors left open, the combination generating sin $\eta\theta$. Of particular interest are cases in which the aperture is restricted to any desired zone of the aperture disk. Synthesis is then accomplished by constructing a disk of several zones, each being used for a particular harmonic.

118. Watson, C.W. Physiological Mechanisms Determining Irradiation of Stimulus in Light Sensitive Individuals and Light Sensitive Animals. Progress Report for March 31, 1957 to May 1, 1958. Contract No. DA-49-007-MD-734-01 No. 5-57. Research and Development Division, Office of the Surgeon General, Department of the Army, Washington, D.C. (AD 201293)

Epileptic seizures may occur in otherwise normal human subjects as the result of exposure to flashing light of certain qualities. The prior detection of such a liability among pilot personnel is essential to successful accomplishment of mission involving aircraft, particularly helicopters. Helicopter pilots are exposed to high intensity sunlight flickered by the rotor blades at ca. 15 cps, a frequency of particular effectiveness in seizure precipitation in the susceptible.

These studies have as their principal aim the provision of necessary method and instrumentation for early, simple and dependable detection of every pilot candidate susceptible to such seizures. Specific aims are related to development of (1) an effective Stimulus Test Program; (2) an instrument which can be used for application of the Stimulus Test Program to large numbers.

The present studies indicate that such an ideal Stimulus Test Program for the detection of the least susceptible subjects (i.e., those suitable for pilot training) will include high intensity, short duration flashes in the 12-30 cps range. The favorable mode of presentation is that of intermittent series ("group flashing") at 15 cps for five minutes or more in darkness and also continuous cyclic variation of frequency (glissando). Both eyes are illuminated by white, red and green flashing light of high intensity (up to 1,500,000 cp) of short flash duration (10 microsec.) through closed lids.

A new, reliable and accurate instrument (Stimulus Program Unit) for preservation and reproduction from ferromagnetic tape of the Stimulus Test Program of light flashes has been designed, constructed and tested. Such an instrument is a prerequisite to the testing of large numbers in a uniform and effective manner.

As a basis for more effective clinical screening of light sensitive individuals, the clinical characteristics of the light sensitive seizure state as it occurred in 35 affected subjects were documented in detail.

A field test of the instrument with application of the presently developed Stimulus Test Program to a suitable number of helicopter pilot candidates is considered necessary. The results will serve as a basis for revision of instrument design and standard testing procedure.

Future studies should include a precise definition of the most favorable environmental test conditions.

119. Wulfeck, J. W. The Minimum Amplitude of Vibration Visually Perceptible as Related to Frequency of Vibration and Other Variables. Unpublished Master's Thesis. Tufts College, 1948.

Determinations of visual thresholds were made under varying conditions of frequency of vibration, size of stimulus objects, levels of illumination, and temporal position of a single determination within a series of determinations. Vibration was defined as harmonic motion, where amplitude was defined as the double amplitude or total displacement of the stimulus, and frequency was defined as the number of such total displacements per unit time. An extensive description is given of the "vibrometer", the apparatus used. The vibrometer produced apparent movement which was assumed to be equivalent to real movement for the purposes of this experiment.

All main effects and interactions of the variables described above as well as the subject variable were statistically significant at the .01 level except for the serial position and frequency x illumination effects which were significant at the .05 level, and the effect of type size which was not significant.

The appendix consists of a theoretical treatment of the perception of vibration as a special instance of the perception of motion, and includes a discussion of the early work of G. M. Stratton, as reported in "Visible Motion and the Space Threshold." Psychol. Rev., 1902, 9, 433-443.

Figure 9 of the appendix summarizes the findings of this study with respect to the effects of frequency as well as those of the study by Stratton which investigated much lower frequencies of real movement.

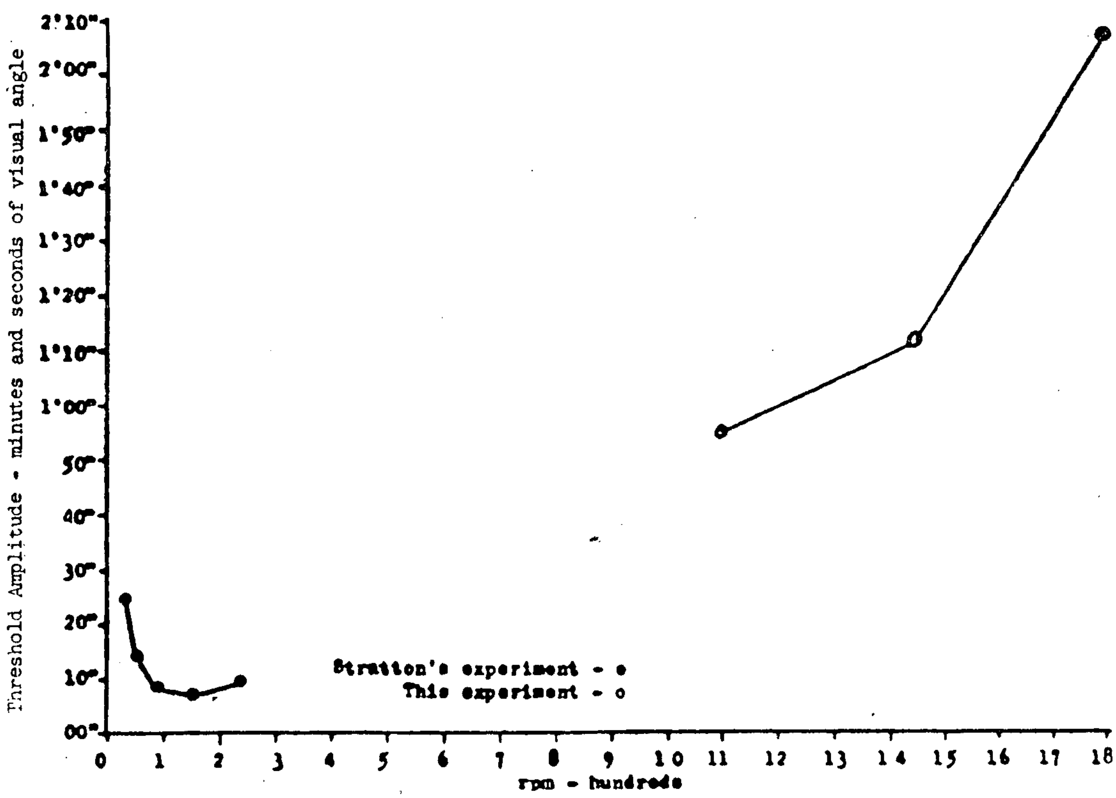

Figure 9. Minimum amplitude of vibration visually perceptible at three frequencies, plotted with Stratton's measures of motion acuity.

Stratton determined the threshold of static vernier acuity to be 6 sec of arc while the lowest threshold of horizontal oscillatory movement (found at 150 rpm = 2.5 cps) was determined to be 7.7 sec of arc. (See figure 9.) This finding appears contradictory to the SSD rangefinding studies, where more precise image alignment was obtained with an apparently moving image. (See references 90 and 91.) It is consistent, however, with SSD's hypothesis that static coincident rangefinding is approximately equal in accuracy to apparent movement ("flicker") rangefinding for ideal vernier acuity targets (i.e., high-contrast targets having long vertical lines, such as a smokestack silhouetted against the sky). For the typical military target such as a vehicle against a background of foliage, it is grossly inferior. (It is much harder to superimpose two images of a poorly defined target than to tell whether or not the image is oscillating.)

This study by Stratton is the only study identified thus far in which the threshold of oscillatory movement was measured as a function of frequency, where the frequencies investigated are in the range where enhancements have been found to occur.