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PREDICTING THE DETECTION RANGE OF A TARGET IN A MOVING FIELD OF VIEW

A Review of Relevant Research Published Prior to 1957

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INTRODUCTION

The purpose of this paper is to review the major references which report experimental data on visual thresholds for static and moving targets. These data relate to fundamental principles employed in visibility calculations for moving targets. In particular, we are concerned with the prediction of the detection range of a target under observing conditions such that the entire field of view moves across the retina. It is believed that this case is encountered in certain air-to-ground aerial reconnaissance situations. Let it be assumed that, prior to detection of a possible target, the pilot will fly along at a constant altitude with his eyes directed toward the ground at a slant angle, awaiting the appearance of some sufficient visual cue. He may scan slowly, but his eyes are essentially held at an optimal position and the target plus its surround will appear to move across his visual field.[1]

If the target is stationary it cannot change its physical attributes as it is approached and passed over; it cannot change its shape or contours, nor its luminance level and inherent contrast with its background. It does not vary its conspicuity through movement which would destroy or produce concealment provided in the natural environment--a combination of terrain background, surrounding objects, illumination level, and sun angle causing lights and shadows. It is, in truth a static target and can be considered merely an element to be discriminated in the complex, patterned moving field of view. How can we make visibility predictions for this moving target? How can we determine its probable detection and recognition ranges?

In his report, "The Limiting Capabilities of Unaided Human Vision in Aerial Reconnaissance," Dr. S. Q. Duntley (1) answers the above question:

> "Before maximum detection ranges and altitudes can be calculated an effective stimulus duration must be assigned ......the effective duration of the target stimulus has been taken as the time interval required for the image of the object to pass over any given point of the retina of the eye if the eye is held steady and the relative motion between the airplane and the target is responsible for the motion of the image. ...... Once the effective stimulus duration is known, the minimum angular subtense needed for detection can be specified for any given value of contrast and any light level. .... Using the stimulus duration ... and the graphs (visual threshold data for uniform circular targets, illustrated) the minimum angular subtense necessary for detection at any aircraft speed for any object can be calculated as a function of altitude and contrast."**

Detection of a target moving through the visual field depends, among many other factors, upon the effective stimulus duration which can be derived from the target size, speed and range. Once detection has occurred we assume the eyes will fixate the target, hold it as a relatively static foveal image and, as time for examination progresses, the range from observer to target will continuously decrease. (This assumes an approaching path or corrective action to change course toward the fixated target.) The various components of the target pattern will become large enough to be discriminated as discrete, and the fine details

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** Underscore and parenthetical insert not Duntley's.

will be of sufficient angular separation to be resolved. In other words, as the observer approaches the target, his contrast sensitivity and visual acuity threshold requirements will be met and, with the cumulative perception of the various elements of the target pattern, recognition will occur.[2]

If, after detection the observer does not fixate the target but allows it to pass through his visual field, or remain in the field in motion, or if he changes his course and allows the "located" target to pass through his visual field again without direct fixation (daylight observation) recognition will be delayed. There is considerable evidence[3,4,5,6,7] to show that acuity is significantly reduced by movement.

Visual acuity is a sensitive discrimination which takes time; that is, the image must remain "fixed" on the retinal mosaic long enough for a comparative judgment between the dark and light areas to be made. Acuity is determined by measuring the minimum separable threshold; whereas, detection is primarily established by the minimum perceptible threshold. For detection of a target the eye requires sufficient effective energy; for recognition, it requires time--time in the past to accumulate the necessary experience, time on the retina to provide a differential signal, and time in the nervous system to allow association of the present sensory image (sensation) with similar ones experienced in the past.

In the absence of specific measurements of detection ranges for moving targets of interest, visibility calculations may be made and ranges predicted by techniques presented in reference (1). As previously stated the Duntley calculation for detection assumes that ground targets moving with respect to the line of sight can be equated to targets flashed onto the center of the field for a single brief exposure, equal in duration to the time required for the target to move across a point on the retina. If this assumption is correct, we then have available to us the extensive data produced by years of psychophysical research with nonmoving visual stimuli investigating the parameters of stimulus intensity, exposure time and size at a wide range of background light levels. After predicting detection we can assume target fixation and, using appropriate visual acuity data, derive probable recognition ranges.

The major references which report experimental data on visual thresholds for static and moving targets will be reviewed and discussed. The visibility of a stationary target varying with exposure time will be compared to that of a target moving at various angular velocities relative to the observing eye. It will be seen that there exists a possible equality in terms of effective stimulus energy.

Reviews of Research Published Before 1957

In this section the published works of various authors will be briefly summarized and related to the problem of retinal-point-exposure-time thresholds derived from static target durations and from moving target velocity. These reviews present the material directly quoted from the articles in quotation marks; insertions, modifications or interpretations of this information will appear in parenthesis. In addition to the major references included in this section, related references are given in the bibliography following.

Klein, 1942

An excellent review and thorough bibliography is presented by Klein(8) on motion perception, description of movement, and retinal variables in form and motion acuity. He discusses the evidence for and against the hypothesis that the peripheral retina is more sensitive to motion than the fovea and finds through his experiment at a photopic level of illumination (4.9 footcandles) that velocity thresholds measured in the periphery are definitely not as high as in the fovea.

According to Klein there are three types of responses to perceived motion: (1) judgments of absolute velocity of the displacement of a moving stimulus, (2) judgments of relative velocity or displacement in relation to other objects or movements in the visual field, and (3) judgments of direction of displacement with absolute or relative velocity. An observer may experience visual movement in several ways: (1) by perceiving the displacement of images of a moving object across the retina when the eye is fixed, (2) through pursuit movements of the eye across a fixed or moving object, or (3) by induced movement; that is, "apparent" as opposed to "real" movement. Induced (gamma) movement is observed through the successive presentation of two stationary objects juxtaposed in space or through increasing the brightness of a fixed object. There is no physical counterpart for this subjective experience.

Experimental data are presented for photopic form and motion acuity at various retinal locations from 0° to 60° in the periphery. These two processes of spatial discrimination are "strikingly similar over the retinal regions covered."

The threshold distance through which a stimulus must move before it can be seen as moving increases as stimulation proceeds toward the periphery. The required angular size of the detail to be discriminated in the threshold for form also increases from fovea to periphery. When form and motion acuity at various retinal locations are plotted against each other, their close correspondence is demonstrated by a straight line function.

<u>Warden and Brown, H. C., 1944</u>

In an investigation of form and motion acuity at low levels of illumination, Warden and Brown(9) measured thresholds from 5° to 55° in the periphery and found scotopic motion acuity most acute at 10°. "Form and motion acuity rises as peripheral angle is increased and rises as level of illumination is decreased."

<u>Gordon, 1947</u>

Gordon(10) presents experimental data for a scotopic level of illumination (.0001 millilamberts) in which he finds the motion threshold rate to be proportional to the form threshold size at retinal locations from 2° to 50° in the periphery. As peripheral angle increases, form and motion acuity generally decrease. Gordon considers his findings to be in agreement with Klein's data for photopic vision.

<u>Anon., 1952</u>

<u>The Handbook of Human Engineering Data</u>(11) contains an excellent digest of the existing published research on movement perception. In considering the basic characteristics of vision important in human engineering problems, Section VII deals with the perception of motion. The variables influencing the threshold for discrimination of movement are presented in tabular form with a description of the effect of the variable and source references. A second table presents threshold values for discrimination of velocity and describes the conditions under which they were measured. Values are given for the absolute movement thresholds--lower and upper, foveal and peripheral; for the relative movement threshold; for the threshold of movement parallax and for the threshold for direction of movement. The section also briefly presents data on the relation between form and motion acuity, discrimination direction of movement and individual differences. The perception of movement is well presented, however, no data is given on the detection of a moving target as such.

Pollock, 1953

A turning point in psychophysical research with moving targets is this article by W. T. Pollock[12]. It is extremely important and probably the first article on the detection of moving targets per se. He pointed out that there have been a considerable number of research reports dealing with the recognition or perception of movement but only sparse data is available on the detection of a moving target. He discusses the three types of movement recognition thresholds: (a) the lower or absolute limen of movement--how fast must a target move before movement can be perceived, (b) perception of relative or differential movement--how small a change in speed (acceleration) is just barely noticeable for a single target or how small a difference in the speeds of two targets compared is barely perceptible, and (c) the measure of accuracy with which the subject can report the direction of target movement as a function of target luminance, speed and size. However, he says, these recognition data provide no information on the detection of a moving target.

Pollock presents experimental data for monocular luminance thresholds for a moving target (one degree circular spot) as a function of target speed (0° to 2000° per second) and direction of movement (horizontal or vertical to the right, left, up or down). "....The results show that the threshold luminance increases systematically with increases in target speed. The function is best characterized as linear with a slope near unity when threshold luminance and speed are plotted logarithmically...."

Bouman and Van den Brink, 1953

Bouman and Van den Brink[13] present results of absolute threshold measurements for moving point sources. "The fundamental aspect of all threshold determinations lies in the fact that sufficient energy must be presented within a sufficiently short time in a sufficiently small area of the receptor layer to provide a just perceptible effect." The hypothesis presented and supported by the experiment was that the two-quanta theory developed for nonmoving targets would apply to moving targets. "Because of the eye's complete integrating capacity (within critical limits)... it does not matter whether the threshold energy is evenly distributed over the (critical time) with respect to the (critical area). Consequently, when a moving point source provides an absorbed energy (requirement) somewhere in a line-shaped part of the retina, at some time within (the critical time and area limits), a visible effect is achieved.".... "When .....v is the velocity on the retina in minutes of arc per second, and t is the flashtime (exposure time), ...(the threshold for the moving target will equal that of a) line-shaped target with length $l = vt$ and time of observation t as far as vt (is less than the critical area) or t (is less than the critical duration)." ....."...it is evident that the distributions of the energy...over the line segment $vt = l$ are equal whether the distribution originates from a uniform moving point source or from simultaneous presentation in time t in the line-shaped target."

Absolute and contrast thresholds for moving point sources were "...tested as a function of the velocity and observation time." Theoretical prediction curves derived from the two-quanta theory for exposure time data were found to fit the moving target thresholds when velocity is plotted in terms of effective exposure time.

Brown, R. H., 1954 (Jan.)

With the publication of Naval Research Laboratory Report No. 4299[14] Dr. Brown introduced what has turned out to be a most significant series of experiments on visual discrimination of movement. In this first report he deals with velocity threshold as a function of the rate of movement and other factors and concludes: "As the speed with which an object travels increases, within limits, the frequency with which man discriminates its direction also increases ....sensitivity to differences in velocity improves with velocity at slow speeds."

Brown and Conklin, (1954 (Mar.)

Brown and Conklin[15] measured the lower threshold for visible movement and showed that the threshold decreases (becomes more acute) as exposure time is increased; this decrement becomes less as the exposure time becomes longer.

Leibowitz and Lomont, 1954 (Mar.)

The concept of isochronal threshold velocity was presented by Leibowitz and Lomont in this publication[16]. Isochronal threshold for velocity is defined as the minimum detectable rate of target movement for a constant exposure time. Foveal movement thresholds were measured for a wide range of target luminance values and exposure durations. Results indicate that threshold velocity decreases with increased luminance, rapidly at first and then more slowly, before reaching a limiting value after which an increase in luminance has little effect. Having established the threshold velocity curve in terms of target luminance for a specific exposure time, the effect of increasing the exposure time is to shift the entire function to lower threshold values. Movement perception is more precise at higher target luminances and longer exposure times. When detection of target motion is important, exposure time of at least two seconds will produce lowest thresholds even under poor conditions of luminance. Motion perception becomes increasingly dependent on the inference of movement at longer stimulus durations.

Brown, 1954 (May)

In this report[17] Brown deals with visual discrimination of velocity as a function of stimulus duration and luminance. Dr. Brown is one of the first to discuss the applicability of the Bunsen-Roscoe reciprocity law to velocity threshold data. This law "states that the effect of a flash of light depends upon the product of the intensity (I) and the exposure time (t)."...."...there is a reciprocal relation between stimulus intensity and exposure time. In the equation form

where I is a constant." On the retina "...the sensory event stimulated by the flash occurs and the nerve fibers begin transmitting signals to the brain. The reciprocity law holds, therefore, only for exposure times shorter than the time required to complete the sensory event. Under optimal conditions this time is of the order of 0.1 second." ... "When the stimulus size is small enough to minimize interaction and statistical effects within the retina, constant energy in a flash produces a constant visual effect for exposure times less than the critical duration (t_c)."...."An increase in exposure time beyond the critical duration has no effect since the sensory event is over, and the visual effect is determined entirely by the energy It_c. We may say that I = C where t (is greater than) t_c and C is a constant equivalent to K/t ." ....The Bunsen-Roscoe law of "the reciprocity of luminance and duration has been demonstrated...to hold for the excitation of single photoreceptor units in the king crab, for threshold excitation of the peripheral retina and fovea of the human eye, for production of a constant visual acuity in man, and for the discrimination of number."

Brown hypothesized that the reciprocity law would apply to the visual discrimination of velocity. Through analysis of his data the prediction is confirmed and he therefore concludes that "....the visual discrimination of velocity under the experimental condition is a single discriminatory event controlled by photochemical activity in the retina. For exposure times less than 0.1 second the discrimination is determined by the product of stimulus luminance and duration. For longer intervals, the discrimination tends to be dependent upon luminance alone. Results further showed that duration and speed interact with each other as determinants of the discrimination." Analysis of these data is extended in a later publication in the Journal of the Optical Society of America[18].

Leibowitz, 1955

Leibowitz[19] reports on the relation between the rate threshold for the perception of movement and luminance for various durations of exposure. He finds threshold velocity decreasing with increased luminance and with increased exposure time. The threshold velocity-luminance function is less sensitive to luminance changes at longer exposure times.

Brown, 1956

Brown[20] presents results for conditions similar to the Pollock experiment which were found to be in good agreement. With a 16.8 minute visual angle diameter circular target moving horizontally across a dark 100° field, he determined the discrimination of motion (direction of movement) as a function of stimulus luminance. He summarizes his results as follows: "(1) For a given extent of motion, the threshold luminance for visibility of a moving spot increases directly with its speed when the exposure time is shorter than the critical duration. (2) The threshold luminance for discrimination of motion also increases directly with speed but approaches a limiting asymptotic velocity at high speeds. (3) At moderate luminances and exposures shorter than the critical duration, the upper speed threshold increases directly with luminance. (4) With intense luminances, the upper speed threshold is approximately constant." "...These findings agree with the results obtained in other experiments with a stationary spot of light ... The effect of the moving spot upon the eye depends on the duration and luminance of the exposure... In addition, the ... experiment shows that the eye ... detects the direction of motion if it is not so rapid that the sensory excitation apparently occurs simultaneously."

Rose, 1952, on Visual Acuity and Target Recognition

A paper on visual acuity and angular speed of objects was presented by Rose (21) before the Armed Forces-NRC Vision Committee. He said that the size of objects at the limit of recognition can be described by the reciprocal value of their angular subtense in minutes; that is, as a dimension equal to visual acuity. The influence of speed of an object moving relative to the eye in a straight line is obviously dependent on the distance from the eye to the object and the angle between the line of vision and the direction of relative movement. Experimental data collected using dots and dashes presented at high speed then slowed down until the subject recognized them; there were subjects with low and high acuity. At low speed and high acuity the threshold curve is determined by the subject's native acuity. Nearly all subjects could follow 3.6° per second velocity and the target motion was compensated for by motion of the eyes following it. At high speed and low acuity the slope of the threshold curve is determined by blurring either due to target movement or unresolved images. It was impossible for the subjects to follow the target at 100° per second.

The following references have not been available for review for this paper and, from their titles, appear to be pertinent:

(a) Craik, K.J.W. and Vernon, M. D., "Report on the perception of stationary and moving airplane silhouettes in plain and clouded fields." 1941

(b) Ludvigh, E. J., "The influence of dynamic visual acuity on the visibility of stationary objects viewed from an aircraft flying at constant altitude, velocity and direction." 1953 (23)

Discussion

At high speeds, above the upper limit for perceived motion, a target will appear to the observer as a line, streak or blur. It is moving so fast that stimulation is effectively simultaneous across the retina and no movement will be perceived. At speeds below this upper limit, the target may be perceived as moving or movement may be inferred through displacement of the image on the retina in successive observations. At very slow speeds the lower limit of movement discrimination may be reached and, without specific reference cues as to target location and re-location, no movement will be perceived.

Sufficient psychophysical data now exist in the literature to show positively that, at moderate and slow speeds, the visual experience of a target moving across the retina can be assumed to be a series of single sensory events, each of which is predictable on the basis of known characteristics for its specific condition. Data have been collected which directly compare static and moving targets and their equivalence in terms of effective energy to the retina has been demonstrated. Effective stimulus duration may be derived from exposure time of a stationary target or from the exposure time of a point on the retina derived from the size and relative angular velocity of a moving target.

For the retinal sense receptors there is a critical stimulus duration on the order of one tenth of a second for certain conditions. For durations longer than this critical limit, observation time is sufficient for effective sensory stimulation to occur and the detectability of a target is dependent upon the other stimulus parameters combining to provide the required total energy; i.e., the discrimination is a function of stimulus intensity or size, etc.

Below the critical duration, the retinal receptors respond to integrated energy. Shortening the exposure time will decrease detectability and must be compensated for by increasing some other stimulus parameter. As several of our authors have pointed out, this integrated retinal event will occur within a very brief moment of time <u>if</u> the target is bright enough or large enough to meet the threshold requirements of the observing eye. The stimulation within this time need not be uniform--it will be integrated across time or space into effective energy if it is of sufficient magnitude and can do no more than push the button to fire the receptor-system.

Conclusion

Experimental evidence is presently available which clearly demonstrates that targets moving across the visual field can be equated to stationary targets flashed on for a single brief exposure, equal in duration to the time required for the target to move across a point on the retina.

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