Movement detection thresholds and stimulus duration*

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Movement detection thresholds were measured for varying exposures of a moving spot. A tradeoff was found in which an increase in duration (T) was offset by a decrease in the velocity required for detection (V). In the range of durations studied (about 50-700 msec), $V \times T$ was constant. The $V \times T$ constancy was interpreted in terms of the direct detection of movement as motion, and a comparison was made with Bloch's law.

The threshold for the detection of movement has been measured in many studies (Graham, 1965). However, few studies have systematically examined the relationship between the rate of movement at threshold and the duration for which the movement is exposed. Most studies that have addressed themselves to the investigation of the effect of duration (T) on threshold velocity (V) have tended to use a relatively wide range of exposure durations. Dimmick and Karl (1930) investigated the range 0.5-4.0 sec, Brown and Conklin (1954), the range 0.5-16.0 sec, and Leibowitz (1955a), the range 0.125-16.0 sec. All three studies reported that increasing the duration of exposure lowered the threshold velocity. In no case was a one-to-one tradeoff between V and T reported, although examination of the data of both Dimmick and Karl (1930) and Leibowitz (1955a) suggests that such a tradeoff may occur with relatively short durations.

A more recent study, one by Henderson (1971), investigated the relationship among the variables associated with motion detection, including exposure duration. The emphasis in this study was on the tradeoff between the duration (T) and the extent (S) of the movement at threshold for relatively high rates of motion (greater than 10-20 min/sec) and extremely short exposures (miniexposures, less than the order of 50-100 msec). Data were also obtained for exposures up to about 1 sec, also suggesting the possibility of a tradeoff between V and T in the range 100-1,000 msec.

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The following experiment was designed to study the relationship between V and T over a range of what may be termed short exposures (as distinct from miniexposures), in order to test the prediction that there is, in fact, a one-to-one tradeoff between V and T, with $V \times T$ constant at threshold.

METHOD

Movement thresholds were measured following two procedures: (1) Constant duration procedure (Tc), where thresholds were measured for constant durations by varying the velocity and, consequently, the length of the track of motion; and (2) constant velocity procedure (Vc), where movement thresholds were measured for constant velocities by varying exposure duration and, consequently, the length of the track.

PROCEDURE

The S sat in a semidark room with his head in a headrest. At a horizontal distance of 3.4 m from his eyes was a translucent screen, 75 x 50 cm, having a luminance of 0.10 mL. Onto this screen could be projected, from behind, a small light spot, 6 mm in diam and of 0.40 mL luminance, which moved clockwise in a circular path, 12 cm in diam. Coincident with the point at which the moving spot appeared was a removable fixation spot, 8 mm in diam, 19 cm from the top of the screen and centrally placed in the horizontal plane.

The moving spot could be lighted and extinguished by means of an electronic timer system, so that the duration and length of the motion path could be varied. In the experiment, the spot was exposed only at the top of the circular path, and, regardless of the length of arc exposed, the starting point always remained the same and very close to its zenith.

When using the constant duration procedure, an exposure time was selected. The velocity of the motion

could be varied continuously in the range 20-0.8 min of visual angle/sec, and absolute movement threshold measurements were made using descending series of velocities only (i.e., from movement to no movement responses). Durations used were 50, 70, 90, 120, 150, and 200 msec. Each S came on three separate occasions, and different random orderings of the duration were used in each session.

The S fixated the fixation spot. The E stood behind the screen and could see when the moving lamp, which provided the light spot, began to approach the onset end of its arc, at which time E warned S by saying, "Ready." The fixation spot, which was faint enough to prevent any visible afterimage, was extinguished manually by E about 0.5 sec before the onset of the lamp. The S was to continue fixating that part of the screen where the fixation spot had been until the moving spot had disappeared at the offset end of its arc, at which point he was to report movement or no movement. Instructions to the Ss were to try to respond to motion rather than to displacement. The velocity of the spot was decreased on successive trials until S reported no movement on two consecutive trials.

Fixation was not controlled during the actual threshold measurements. However, only experienced Ss were used and, to test fixation under experimental conditions, trials were run prior to the experiment, using an electrode eye-movement recorder. These tests showed that an S was quite capable of maintaining fixation, even after disappearance of the fixation spot, so it is assumed that the thresholds were measured under conditions of at least approximate fixation.

With the constant velocity procedure, the velocities tested were 1.14, 2.29, 4.01, 5.44, 8.59, and 11.27 min of visual angle/sec. Thresholds were measured by varying the duration in steps of 10 msec. The Vc procedure was similar to that used with the Tc procedure, and, again, only descending series were used. On no trial was the exposure so short that the moving spot was not perceived by the S.

The same three Ss were used for both conditions. Each S came on six occasions and received each condition three times. The order of testing of conditions was randomized over the six sessions.

RESULTS

Table 1 gives the mean values of V using the Tc procedure and of T using the Vc procedure. Also given are the between-Ss standard deviations.

Plots of log V against log T (means)

Table 1
Mean Values of Exposure (T) and Velocity (V) for Detection of Movement
(Expressed in Msec and Min of Visual Angle Per Sec, Respectively)

Procedure Tc						
T	50	70	90	120	150	200
V	14.4	13.2	10.2	7.2	5.4	4.2
SD	2.88	1.21	1.13	2.11	1.47	1.55
Procedure Vc						
V	11.3	8.6	5.4	4.0	2.3	1.1
T	62	97	139	188	330	680
SD	17.08	21.42	14.16	24.72	77.90	198.68

Table 2
Trend Analysis of Log V and Log T Values for the Tc and Vc Procedures

Source	df	ms	F	p
Procedure Tc				
Treatment (Linear)	1	11.5576	134.234	< .001
Treatment (Residual)	4	0.1368	1.588	
Ss by Treatment (Linear)	2	0.6323	7.343	< .01
Ss by Treatment (Residual)	8	0.0952	1.106	
Within Cells	36	0.0861		
Procedure Vc				
Treatment (Linear)	1	31.3528	146.838	< .001
Treatment (Residual)	4	0.1016	0.476	
Ss by Treatment (Linear)	2	0.0438	0.205	
Ss by Treatment (Residual)	8	0.0392	0.183	
Within Cells	36	0.2135		

are shown in Fig. 1. Two trend analyses were carried out, using the log values (six treatment levels, three Ss, three observations per cell). It was necessary to use the transformed values in the analyses, at least in the case of the Vc data, because of the variation of the SD with the mean. Linear coefficients for the unequally spaced values of the independent variables were calculated according to the method given in Draper and Smith (1966, p. 156). Table 2 gives the results of these analyses.

Using the within-cells variance as error term gave a significant linear component but no significant residual component (quadratic, cubic, quartic, and quintic) for both sets of data. For procedure Tc, the significant Ss by Treatment (linear) interaction means that there were slope differences among Ss. However, the common linear component is still very close to the .05 level of significance when S by Treatments (linear) is used as error term, $F(1,2) = 18.279$.

The regression equations for the best fitting linear plots are given in Fig. 1. The slopes of these plots can be regarded as -1.00 , for both procedures, which means that $V \times T$ at threshold is constant.

In spite of the remarkably close correspondence between the data and the prediction that $V \times T$ is constant, the between-Ss differences would indicate caution in generalizing from these results. However, analysis of Leibowitz's (1955a) data shows $V \times T$ values at threshold for durations of 0.125, 0.25, 1.00, and 2.00 sec, averaged over the luminance range

0.16-5.0 mL, to be 2.19, 1.73, 2.05, and 2.18 min of visual angle, respectively. This shows a fairly high degree of constancy. Similar constancy is shown in the Dimmick and Karl (1930) data for the two lowest durations (0.5 and 1.0 sec), which give $V \times T$ values of 1.28 and 1.19 min of visual angle. In the Leibowitz (1955a) study, the constancy shown for the lower exposure durations was not apparent with the 16-sec exposure; in the Dimmick and Karl (1930) study,

the constancy did not even extend as far as the 2-sec exposure duration.

The data in Henderson's (1971) study are presented graphically, which makes it difficult to abstract precise figures. However, from the curves, it does appear as if S (i.e., $V \times T$) is constant as V varies in the range of 1 to 10-20 min/sec.

Considering the findings of the present study in the light of these earlier studies greatly increases the probability that the relationship $V \times T = a$ constant at threshold has general application, at least for durations in the range 50 msec to 1-2 sec.

The data reported by Brown and Conklin (1954) do not show a $V \times T$ constancy, but this may be due to the method of measurement, which produced very much higher threshold values than the other three studies discussed above. It also should be noted that most of the measurements made in the latter study involved exposures of 1 sec or more.

DISCUSSION

The constancy of the $V \times T$ values can be interpreted in two ways: (1) The spot must move through a minimum displacement (0.7-0.9 min of visual angle in the present experiment) for movement to be detected. The implication is that we are dealing with displacement detection rather than with motion detection, and (2) although a constant displacement appears to be necessary for the detection of movement, we are, in fact, dealing with motion

Fig. 1. Plots of log V against log T (means) for the Tc and Vc procedures.

detection rather than with displacement detection.

The problem of two kinds of movement threshold is, of course, an old issue. It has long been accepted that movement can be detected either directly, as motion, or else indirectly, by inference from displacement (Exner, 1885; Brown & Conklin, 1954; Brown, 1955; Cohen, 1964; Graham, 1965; Bonnet, 1971). However, there has been no general agreement as to which conditions favor which kind of detection.

Dimmick and Karl (1930) favor a complete explanation of movement detection in terms of displacement thresholds. They propose that for short exposures (less than 1 sec) the displacement of the movement must exceed that of the "spatial limen" for movement, to be detectable; for long exposures, they suggest that movement thresholds are related to the "spatial limen for successive stimuli."

Leibowitz (1955b) supports a two-process model, where movement is detected directly as motion at relatively short exposures but is implied from displacement at long exposures. Evidence cited in favor of this distinction is that the presence of reference lines in the field of movement drastically lowers the threshold for perceived movement at long exposures (16 sec) but does not affect the threshold at short exposures (0.25 sec). Leibowitz (1955a) also notes that the general shape of the functions relating luminance and threshold velocity are similar to those relating luminance and intensity discrimination, flicker, grating acuity, and vernier acuity. He concludes that motion thresholds may depend on similar mechanisms to those underlying the other types of discrimination, and that, for short exposures, photochemical mechanisms are critical for all the above types of discrimination, including motion detection.

Accepting Leibowitz's distinction between displacement and motion thresholds in principle, it is proposed that the conditions of the present experiment were conducive to the detection of motion rather than displacement. Further, since $V \times T$ appears to be constant within a critical range of exposure durations, it is proposed that the rate of the motion should be regarded in the same way as is brightness in luminance detection thresholds, namely, as an intensity measure. Bloch's law states that, within certain limits, intensity $\times$ exposure duration is constant at the luminance detection threshold. Similarly, for motion detection, the intensity of the motion, that is its rate,

x exposure duration, is also a constant. (This interpretation makes the assumption that S_s did not vary their criteria for detecting movement with varying exposure times in the above experiment. While it is possible that such a criterion change did occur, the obtained $V \times T$ constancy does suggest that a constant criterion was used.)

The analogy between Bloch's law and the $V \times T$ constancy obtained for motion thresholds breaks down in that Bloch's law holds up to only about 100 msec (Bartlett, 1965), whereas the constancy relationship between velocity and duration appears to hold up to about 1-2 sec. However, whereas photochemical mechanisms provide the theoretical basis for Bloch's law, such mechanisms are not being proposed for motion detection. Physiological studies with animals have produced evidence for the presence in the visual system of detectors that are especially sensitive to motion (see, for example, Barlow & Hill, 1963a, b). There is also evidence for such detectors at the human level (Sekuler & Ganz, 1963; Cohen, 1965; Pantle & Sekuler, 1969; Bonnet & Pouthas, 1972). Since the perception of motion is supposedly related to the rate of firing of motion-sensitive detector cells (Barlow & Hill, 1963a, b) and not to photochemical processes, the difference in the range of applicability for Bloch's law and the $V \times T$ constancy relationship is not a critical issue.

It would also appear that the $V \times T$ constancy relationship breaks down at the lower end of the scale, that is, for miniexposures. For miniexposures, Henderson (1971) reports that, at threshold, the extent of the movement varies inversely with the duration, which he interprets along the same lines as Dimmick and Karl (1930). Perceived motion, and, in Henderson's case, more especially perceived direction of motion, is the result of the retina's being able to discriminate successive events. He argues against an energy explanation in favor of an interaction model where extent and duration are considered to be basic variables interacting to give motion perception.

It is also possible to explain Henderson's (1971) data for miniexposures in terms of motion detectors. The rate of firing of motion detectors in the rabbit, for example, has been shown to be dependent on the rate of the motion (Barlow & Hill, 1963a, b). The $V \times T$ constancy found in the present experiment is consistent with the notion that the detection of motion involves a critical number of firings, rather than a critical rate of firing, corresponding to $V \times T$. If it is simply assumed that there is a limit to

the rate at which motion detectors can fire, then increases in V will be unable to offset decreases in T above a certain value of V , say about 10-20 min/sec. The only way in which the number of firings can be increased to the critical value under miniexposure conditions is by increasing the number of receptors involved, that is, by increasing the extent of the motion. Thus, in the range investigated here, the critical number of firings is attained by a tradeoff between V and T . However, for very fast movement, increasing V can no longer offset a decrease in T , for which reason an increase in S also becomes necessary. For long exposures, above 1-2 sec, the authors agree with Leibowitz (1955a, b) that the detection of displacement becomes increasingly important. The implication for the motion detector model is that with slow velocities, the time between firings from successive detectors is too great for the required integration of firings from several detectors to occur. That is, there is a limit on the time allowed for the detector system to attain the critical number of firings necessary for the direct detection of motion.

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