Duration discrimination of brief light flashes*

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The data from four experiments indicate that when Os discriminate between light flashes of different durations, for durations for which Bloch's law has been shown to hold, their discriminations are frequently made on the temporal information available in the flashes rather than on their apparent brightness. A model for duration discrimination which specifies that discriminability depends only on the difference in duration between the two brief flashes, and is independent of their durations, is presented and applied to the data.

Data from a number of psychophysical investigations (e.g., Aiba & Stevens, 1964; Raab, 1962; Stevens & Hall, 1966; Stevens, 1966) have indicated that an O's judgment of the apparent brightness of a brief flash of light depends not only on the luminance of the flash but also on its duration. Specifically, for stimuli whose durations are less than a critical duration, d_c, Os tend to label a brief intense flash of light as equal in apparent brightness to a longer, less intense flash. Furthermore, the data suggest that the relationship between luminance and duration is a reciprocal one, so that the apparent brightness of a flash does not change as long as the product of the flash luminance and the flash duration is constant. That is,

$$B = f(d \times I),$$

where B represents the apparent brightness of the flash, d its duration, I its luminance, and

$$d < d_c.$$

The reciprocity relationship in Eq. 1 is often referred to as Bloch's law or the Bunsen-Roscoe law. The exact value of d_c depends upon the luminance of the flash and appears to decrease as a power function of luminance (Anglin & Mansfield, 1968). Thus, within the critical duration for which Bloch's law has been shown to hold, the visual system appears to summate or integrate the light input without regard to its distribution in time. Wicke, Donchin, and Lindsley (1964) have presented physiological data which supplement the psychophysical investigations of Bloch's law. In their study, the luminance and the duration of a light flash were varied reciprocally so that their product (millilamberts x milliseconds) was constant. Three such product values were investigated (900, 9,000, and 90,000), for stimulus durations varying between 1 and 150 msec. They found that the waveform and the amplitude of the average evoked potentials for a constant luminance-duration product showed a striking similarity for different values of duration.

Since changes in the duration of a brief visual flash result in changes in the apparent brightness of the flash, it is possible that when Os are asked to discriminate between brief light flashes of different durations, their discriminations are based on the apparent brightness of the various flashes rather than on their durations. Suppose that on each trial of a discrimination experiment a light is flashed for either d_0 msec, *an* S_0 *stimulus*, or for d_1 msec, *an* S_1 *stimulus*, and that the O's task is to decide whether the flash duration was "short," *an* A_0 *response*, or "long," *an* A_1 *response*. If the O is basing his discrimination on the difference in apparent brightness between S_0 and S_1, then decreasing the luminance of S_1 should result in decreased discriminability. However, if he is basing his discrimination on the difference in duration between the two stimuli, a decrease in the luminance of S_1 should not affect the discriminability of the two stimuli.

Creelman (1962) has developed a decision theory model which represents the O in a duration discrimination task as using only the temporal information available in the two stimuli to be discriminated. The model pictures the O as using a mechanism which "counts" pulses during the duration to be judged. The source of pulses which are counted is viewed as a large number of independent elements, each with a fixed probability of firing at any given moment. The basis for the O's decision is the number of pulses which the counting mechanism receives during the duration to be judged. It can be shown that the probability of n counts, P(n), occurring in d_i msec is

$$P(n) = \frac{(\lambda d_i)^n e^{-\lambda d_i}}{n!}, \qquad (1)$$

where the constant λ represents the rate of firing of the pulse source. Equation 1 describes the Poisson distribution, which for large λd_i is closely approximated by a Gaussian distribution with expected value equal to λd_i and variance also equal to λd_i. Note that the expected value of the perceived or psychological duration of a stimulus is directly proportional to its actual duration. The O's decision problem in a duration discrimination task involving the presentation of one of two possible stimuli on each trial is illustrated in Fig. 1, which represents two overlapping Gaussian distribution of counts. The distribution with expected value λd_0 represents the distribution of counts on S_0 trials; the distribution with expected value λd_1 represents the distribution of counts on S_1 trials. The O is assumed to adopt a criterion number of counts, β, and to make an A_1 response only if the observed number of counts exceeds β.

From Fig. 1 it can be seen that the probability of an A_1 response given an S_1

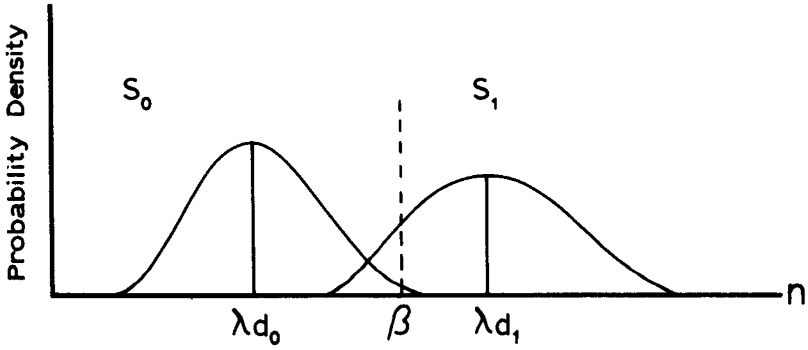

Fig. 1. Distribution of the number of counts conditional upon the stimulus event.

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stimulus, $P(A_1 | S_1)$, is the area to the right of β under the S_1 distribution; similarly, $P(A_1 | S_0)$, is the area to the right of β under the S_0 distribution. The possible combinations of $P(A_1 | S_1)$ and $P(A_1 | S_0)$ available to the O through variations in his decision criterion are his operating characteristic (OC), which can be specified by two parameters, d′ and r, in the following manner:

$$d' = Z(A_1 | S_0) - 1/r\, Z(A_1 | S_1), \quad (2)$$

where r represents the ratio of the standard deviation of the S_0 distribution to the standard deviation of the S_1 distribution,

$$r = \frac{d_0^{1/2}}{d_1^{1/2}}, \quad (3)$$

and $Z(A_1 | S_0)$ is that value of a normal deviate which is exceeded with probability $P(A_1 | S_0)$, and $Z(A_1 | S_1)$ is a similar transformation of $P(A_1 | S_1)$. Note that d′, which is referred to as the discriminability measure, is the difference between the expected values of the two counting distributions expressed in standard deviation units of the S_0 distribution. Thus,

$$d' = \frac{\lambda^{1/2} \Delta d}{d_0^{1/2}}, \quad (4)$$

where

$$\Delta d = d_1 - d_0.$$

Two implications of this model are apparent from Eq. 4. For a fixed value of d_0, d′ should increase as a zero intercept, linear function of Δd, and for a fixed value of Δd, d′ should decrease as a power function of d_0.

Creelman (1962) has reported data from a two-interval forced-choice discrimination task. On each trial two auditory stimuli which differed in duration were presented in succession, and the O had to indicate which was longer. On some proportion of the trials, the longer stimulus was presented first; on the remaining trials, the shorter stimulus was presented first. The study was quite extensive and, under some conditions, the model appeared to provide a reasonable interpretation of the data.

The present series of four experiments provide data from a visual duration discrimination task involving the presentation of one of two possible flash durations on each trial. The data are relevant to determining whether an O, when asked to discriminate between brief light flashes of different durations, bases his discriminations on the temporal information available in the stimuli or on the apparent brightness of the stimuli. Furthermore, the data provide a test of Creelman's duration discrimination model for visual stimuli.

APPARATUS

The same apparatus was used in the four experiments. The O was seated in a chair in a dark room, with his face placed against the rubber mask attached to a Scientific Prototype tachistoscope (Model 320GB), and viewed the stimuli binocularly. Four small fixation points, 1 in. from each other and arranged in a diamond shape, were visible in an otherwise dark field throughout the session. The stimulus was presented in the center of the four fixation points and consisted of a ½-in. square patch of light subtending a visual angle of .6 deg. Luminance was measured at the center of the stimulus by a 150 UB Photo Research Corporation photometer, and the timing of the stimulus presentations was electronically controlled. The O indicated his response by pressing an appropriate pushbutton located on the arm of his chair.

EXPERIMENT 1

Procedure

Three Os participated in this experiment. Each trial began with a 1-sec auditory warning tone. Following a 0.2-sec delay, the stimulus was presented for either d_0 msec (an S_0 stimulus) or d_0 plus Δd msec (an S_1 stimulus). The O was then given 3.5 sec to indicate one of four decisions regarding the duration of the stimulus light: short-certain ($A_{0,c}$), short-uncertain ($A_{0,u}$), long-uncertain ($A_{1,u}$), or long-certain ($A_{1,c}$). The Os were instructed to base their decisions on the duration of the stimulus and to distribute their responses equally among the four

Table 1
Frequencies Summarizing Each O's Performance Under Each of the 10 Conditions in Experiment 1

O	d_0	Δd	$(A_{1,c}\|S_1)$	$(A_{1,u}\|S_1)$	$(A_{0,u}\|S_1)$	$(A_{0,c}\|S_1)$	$(A_{1,c}\|S_0)$	$(A_{1,u}\|S_0)$	$(A_{0,u}\|S_0)$	$(A_{0,c}\|S_0)$
1	50	10	73	169	145	13	32	114	190	64
		20	85	169	124	22	19	63	239	79
		30	86	165	142	7	3	20	263	114
		40	150	185	62	3	3	23	240	134
		50	167	182	45	6	2	14	158	226
	100	10	53	161	158	28	17	110	227	46
		20	110	152	121	17	25	75	208	92
		30	122	155	108	15	11	40	257	92
		40	156	186	51	7	6	41	243	110
		50	155	194	44	7	6	13	212	169
2	50	10	306	83	64	147	190	91	86	233
		20	278	163	113	46	101	148	208	143
		30	295	129	102	74	62	106	164	268
		40	355	175	43	27	28	84	166	322
		50	475	88	21	16	24	29	75	472
	100	10	213	164	91	132	132	151	109	208
		20	330	121	82	67	140	109	141	210
		30	395	138	50	17	90	118	207	185
		40	468	74	24	34	94	91	99	316
		50	458	78	35	29	72	41	138	349
3	50	10	136	98	50	116	78	87	45	190
		20	221	82	29	68	81	68	55	196
		30	263	72	35	30	28	46	75	251
		40	310	51	20	19	19	34	58	289
		50	375	17	5	3	4	10	21	365
	100	10	198	66	38	98	94	59	54	193
		20	251	53	33	63	87	52	58	203
		30	303	53	21	23	28	44	88	240
		40	340	35	17	8	23	33	54	290
		50	357	31	8	4	8	23	50	319

Table 2
Estimates of the Conditional Probabilities for Each O Under Each Condition in Experiment 1

O	d_0	Δd	$P(A_1 \cup A_{0,u} \mid S_1)$	$P(A_1 \cup A_{0,u} \mid S_0)$	$P(A_1 \mid S_1)$	$P(A_1 \mid S_0)$	$P(A_{1,c} \mid S_1)$	$P(A_{1,c} \mid S_0)$
1	50	10	.967	.840	.605	.365	.182	.080
		20	.945	.802	.635	.205	.212	.047
		30	.982	.715	.627	.057	.215	.007
		40	.992	.665	.837	.065	.375	.007
		50	.985	.435	.872	.040	.417	.005
	100	10	.930	.885	.535	.317	.132	.042
		20	.957	.770	.655	.250	.275	.063
		30	.962	.770	.692	.127	.305	.027
		40	.982	.725	.855	.117	.390	.015
		50	.982	.577	.872	.047	.387	.015
2	50	10	.755	.612	.648	.468	.510	.317
		20	.923	.762	.735	.415	.463	.168
		30	.877	.553	.707	.280	.492	.103
		40	.955	.463	.883	.187	.592	.047
		50	.973	.213	.938	.088	.792	.040
	100	10	.780	.653	.628	.472	.355	.220
		20	.888	.650	.752	.415	.550	.233
		30	.972	.692	.888	.347	.658	.150
		40	.943	.473	.903	.308	.780	.157
		50	.952	.418	.893	.188	.763	.120
3	50	10	.710	.525	.585	.412	.340	.195
		20	.830	.510	.757	.372	552	.202
		30	.925	.372	.837	.185	.657	.070
		40	.952	.277	.902	.132	.775	.047
		50	.992	.087	.980	.035	.938	.010
	100	10	.755	.517	.660	.382	.495	.235
		20	.842	.492	.760	.347	.627	.217
		30	.942	.400	.890	.180	.757	.070
		40	.980	.275	.938	.140	.850	.057
		50	.990	.202	.970	.077	.892	.020

Table 3
Estimates of r, Predicted r, and Estimates of d′ Assuming Unit Slope for Each O Under Each Condition in Experiment 1

O	d_0	Δd	r	Predicted r	d′
1	50	10	1.148	.91	.652
		20	.935	.84	.927
		30	.937	.79	1.702
		40	.928	.74	2.203
		50	.969	.71	2.527
	100	10	.885	.95	.487
		20	1.015	.91	.997
		30	.833	.88	1.363
		40	.849	.84	1.880
		50	.964	.82	2.200
2	50	10	.875	.91	.455
		20	.910	.84	.812
		30	.846	.79	1.127
		40	.938	.74	1.923
		50	1.200	.71	2.727
	100	10	.984	.95	.393
		20	.979	.91	.863
		30	.971	.88	1.490
		40	.877	.84	1.743
		50	.969	.82	1.963
3	50	10	1.034	.91	.458
		20	.989	.84	.970
		30	.910	.79	1.843
		40	.838	.74	2.363
		50	.902	.71	3.833
	100	10	.924	.95	.690
		20	.909	.91	1.073
		30	.704	.88	2.050
		40	1.027	.84	2.633
		50	.896	.82	3.253

response categories. They did not receive trial-by-trial feedback as to the correctness of their responses.

The intensity of the stimuli was constant at 15 fL throughout the experiment. Both d_0 (50 or 100 msec) and Δd (10, 20, 30, 40, or 50 msec) were constant during a particular session but varied between sessions. Each session consisted of five blocks of 100 trials, with a 1-min rest between blocks. In each block of trials the probability of an S_1 stimulus, $P(S_1)$, equaled 0.5.

Each of the 10 experimental conditions was in effect during three sessions for O 1 and O 3, and during four sessions for O 2, the order of conditions being randomly determined with the limitation that each condition be used an equal number of times before any condition was repeated. In an attempt to control warm-up effects and to allow sufficient time for dark adaptation (about 10 min), the first block of trials for each session was not included in the final data analysis. Furthermore, in order to provide stable data, the first 10 sessions (1 session under each condition) were not included in the final analysis. In this way data from 800 trials for two of the Os and from 1,200 trials for the other O were available for each of the 10 experimental conditions.

Theoretical Analysis

Each O's performance under each of the 10 experimental conditions can be summarized by eight frequencies: the number of S_i trials on which an $A_{j,k}$ response is made, for i and j equal to 1 (long) or 0 (short), and k equal to c (certain) or u (uncertain). These frequencies, denoted as $(A_{j,k} \mid S_i)$, are presented in Table 1.

Operating characteristic (OC) curves can be generated from the frequencies presented in Table 1 using the procedure described by Green and Swets (1966, pp. 101-103). Each OC is determined by six conditional probabilities of the form

$$P(A_1 \cup A_{0,u} \mid S_i),$$

$$P(A_1 \mid S_i),$$

$$P(A_{1,c} \mid S_i),$$

for i equal to 1 or 0. Estimates of the six conditional probabilities determining each of the 30 OC curves (three Os and 10 conditions) are presented in Table 2. For each set of three points, the best fitting OC, based on the assumption of underlying Gaussian distributions, was determined using the following procedure. Rearrangement of Eq. 2,

$$Z(A_1 \mid S_1) = rZ(A_1 \mid S_0) - rd',$$

shows that the OC, when plotted on Z-coordinates, is a straight line with slope r and $Z(A_1 \mid S_1)$ - intercept equal to rd′. Values of $Z(A_1 \mid S_1)$ and $Z(A_1 \mid S_0)$ were calculated from each O's performance, and for each condition the best fitting, straight line, OC was determined by minimizing

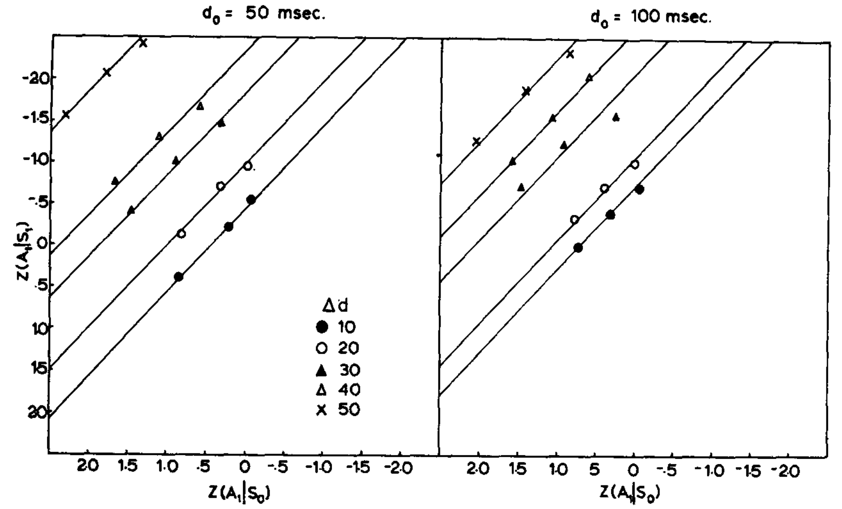

Fig. 2. Observed performance and OC curves based on equal-variance Gaussian distributions for O 3.

the sum of the squared perpendicular discrepancies between the O's performance and the line. Specifically,

$$r = \sqrt{\frac{N\Sigma y^2 - (\Sigma y)^2}{N\Sigma x^2 - (\Sigma x)^2}},$$

and

$$rd' = \frac{\Sigma y - r\Sigma x}{N},$$

where $y = Z(A_1 \mid S_1)$, $x = Z(A_1 \mid S_0)$, and $N = 3$. Estimates of r for each O under each experimental condition, as well as the value of r predicted by Eq. 3, are presented in Table 3. It is clear that the estimated values of r are not related to changes in Δd in the manner specified by the Creelman model. In fact, for large differences in Δd, the estimated slope is often very close to unity. If the observed deviations from unity are simply the result of sampling error, then a straight-line unit-slope OC should provide a reasonable representation of the observed performance. The OC curves for O 3 are plotted on Z-coordinates in Fig. 2. Figure 2 indicates that OC curves generated from an assumption of underlying equal-variance Gaussian distributions closely approximate the performance of this O. Straight-line unit-slope OC curves also provide an adequate representation of the performance of the other two Os. The data indicate that an equal-variance assumption is better than the particular unequal-variance assumption which follows from Creelman's theory. The sum of the squared discrepancies between observed and predicted values of r is larger in the case of the unequal variance assumption; specifically, .2280 vs .1017, .3263 vs .1089, and .1708 vs .1584 for Os 1, 2, and 3, respectively. Thus, while the results support the prediction that the distribution of counts evoked by a brief stimulus can be approximated by a Gaussian distribution, they do not support the prediction that the variance of the distribution increases systematically with an increase in the physical duration of the stimulus.

The d′ values assuming unit slope are presented numerically in Table 3 and are plotted as a function of Δd in Fig. 3. It is of interest to note that although the two values of d_0 differed by 50 msec, the ability to discriminate a particular difference in duration between the two light flashes is similar for the two values of d_0. For each O, a zero-intercept straight line was fitted to the 10 data points and is plotted in Fig. 3. Figure 3 indicates that a linear relationship between d′ and Δd which is independent of the value of d_0 is an adequate description of each O's performance. This linear relationship accounts for 0.95, 0.92, and 0.94 of the total variance in d′, for Os 1, 2, and 3, respectively.

We shall now present a model for duration discrimination which specifies that discriminability depends only on the difference in duration between the two brief stimuli and is independent of their total durations. Suppose that at some time after the onset of a d_i-msec stimulus an internal timing process is activated by the stimulus onset and that this internal timing process is the basis for discrimination. The time which elapses between the onset of the stimulus and the beginning of the internal timing process is called *the psychological onset time*. Similarly, the offset of the stimulus terminates the internal timing process after a time delay referred to as *the psychological offset time*. Assume further that the psychological onset time and the psychological offset time have uniform distributions, $f_1(u)$ and $f_2(u)$, respectively, over an interval of q msec, where q is independent of the duration of the stimulus. That is,

$$f_1(u) = \begin{cases} 1/q \text{ if } 0 < u < q \\ 0 \text{ otherwise} \end{cases}$$

and

$$f_2(u) = \begin{cases} 1/q \text{ if } d_i < u < d_i + q \\ 0 \text{ otherwise} \end{cases}$$

Furthermore, $E(U_1) = q/2$, and $E(U_2) = d_i + q/2$, where $E(U_1)$ denotes the expected value of the onset random variable, U_1, and $E(U_2)$ denotes the expected value of the offset random variable, U_2. It can be shown (Parzen, 1960) that the distribution of durations of the internal timing process, denoted as $g(u')$, which is associated with d_i-msec stimulus is

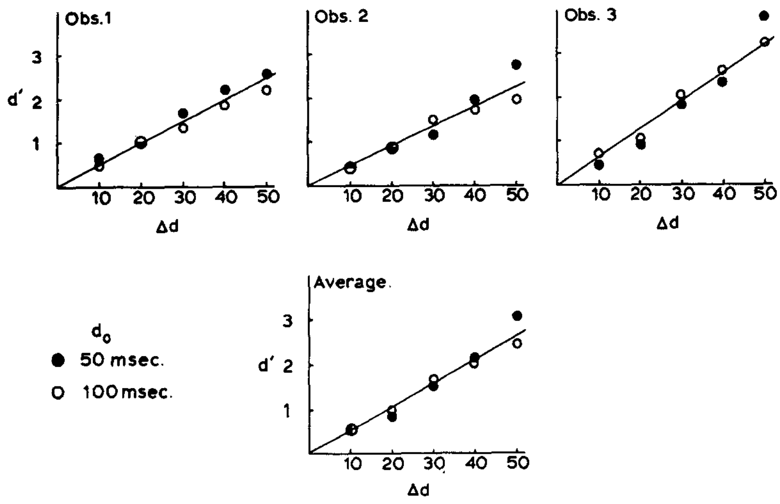

Fig. 3. Estimates of d′ for each O under each condition in Experiment 1.

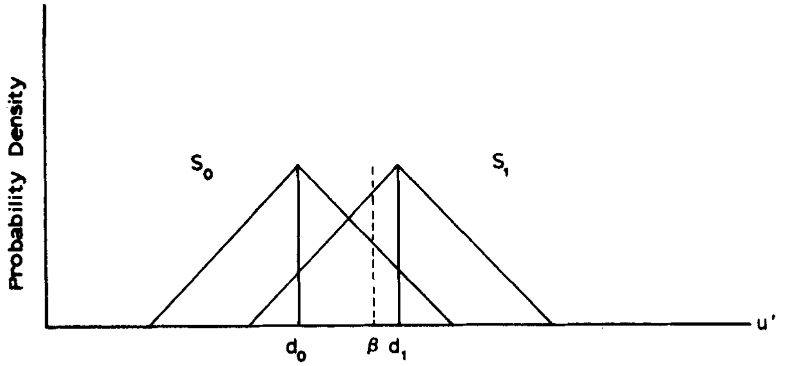

Fig. 4. Distribution of psychological durations conditional upon the stimulus event.

$$g(u') = \int f_2(u)\, f_1(u - u')\, du. \quad (5)$$

If it is assumed that U_1 is independent of U_2, then integrating Eq. 5 yields

$$g(u') = \begin{cases} \dfrac{q + d_i - u'}{q^2} & \text{if } d_i < u' < d_i + q \\ \dfrac{q - d_i + u'}{q^2} & \text{if } d_i - q < u' < d_i \\ 0 \text{ otherwise} & \end{cases} \quad (6)$$

Thus, the distribution of durations of the internal timing process, which we shall also refer to as the psychological durations, is triangular over an interval of 2q msec, and the expected value of the psychological duration random variable, U′, is

$$E(U') = E(U_2) - E(U_1)$$
$$= d_i.$$

The O's decision problem in a duration discrimination task involving the presentation of one of two possible stimuli on each trial is illustrated in Fig. 4, which represents two overlapping triangular distributions of psychological durations. The distribution with expected value d_0 represents the distribution on S_0 trials; the distribution with expected value d_1 represents the distribution on S_1 trials. The O is assumed to adopt a criterion value of psychological duration, β, and to make an A_1 response only if u′ exceeds β. The O's OC can be specified by one parameter, d_q, in the following manner:

$$d_q = Q(A_1 \mid S_0) - Q(A_1 \mid S_1), \quad (7)$$

where $Q(A_1 \mid S_0)$ is the distance in q units from the mean of the S_0 distribution to the criterion, and $Q(A_1 \mid S_1)$ is the distance in q units from the mean of the S_1 distribution to the criterion. Thus, $Q(A_1 \mid S_i)$ is that value of a psychological duration, expressed in q units, which is exceeded with probability $P(A_1 \mid S_i)$. Note that d_q, a dimensionless variable, is the difference between the expected values of the two distributions expressed in q units. That is,

$$d_q = \frac{\Delta d}{q}. \quad (8)$$

It is clear from Eq. 8 that d_q is independent of the value of d_0 and increases as a zero-intercept linear function of Δd. Note that q can be estimated from the slope of the function relating d_q to Δd.

Equation 7 shows that the OC, when plotted on Q– coordinates, is a straight line with unit slope and $Q(A_1 \mid S_1)$ – intercept equal to d_q. Values of $Q(A_1 \mid S_1)$ and $Q(A_1 \mid S_0)$ were calculated from each O's performance, and for each condition the best fitting straight line, OC, was determined by minimizing the sum of the squared perpendicular discrepancies between the O's performance and the line. The estimated slopes are presented in Table 4. It is clear that the deviations of the estimated slopes from unit slope are not systematically related to changes in Δd. OC curves assuming unit slope are plotted on Q-coordinates in Fig. 5 for O 3. In general, these lines closely approximate the observed performance, suggesting that the psychological durations evoked by a brief flash of light can be represented by a triangular distribution with a base which is independent of the duration of the light flash. The d_q values assuming unit slope are presented numerically in Table 4 and are plotted as a function of Δd in Fig. 6. For

Table 4
Estimates of Slope, of d_q Assuming Unit Slope, and of q for Each O in Experiment 1

O	q	d_0	Δd	Slope	d_q
1	51.28	50	10	1.106	.26
			20	.940	.38
			30	.974	.63
			40	.907	.83
			50	1.073	.97
		100	10	.899	.19
			20	.993	.41
			30	.833	.56
			40	.835	.75
			50	.968	.87
2	52.08	50	10	.911	.19
			20	.889	.35
			30	.842	.49
			40	.944	.81
			50	1.088	1.14
		100	10	.986	.17
			20	.998	.38
			30	.884	.62
			40	.808	.75
			50	.879	.84
3	37.59	50	10	1.021	.20
			20	1.000	.42
			30	.914	.79
			40	.836	1.01
			50	.784	1.50
		100	10	.932	.30
			20	.904	.47
			30	.705	.88
			40	.838	1.10
			50	.800	1.31

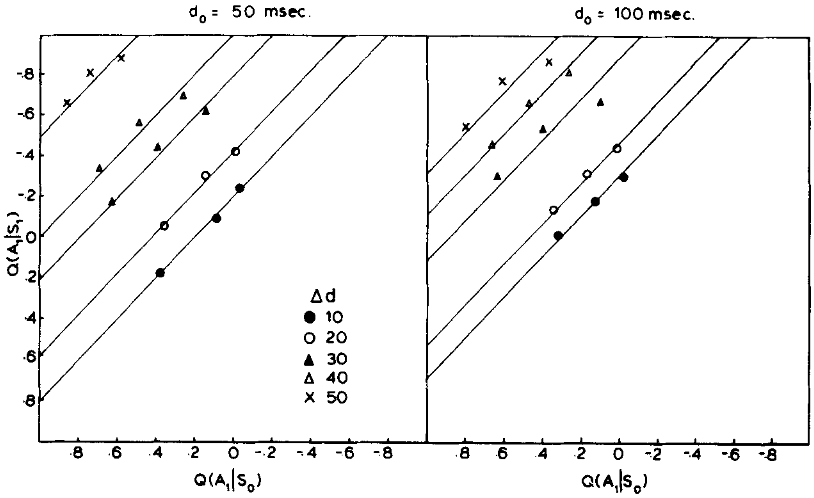

Fig. 5. Observed performance and OC curves based on equal base triangular distributions for O 3.

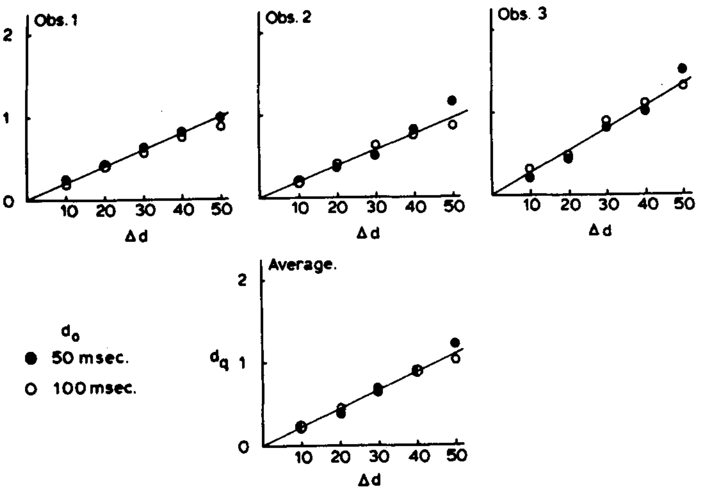

Fig. 6. Estimates of d_q for each O under each condition in Experiment 1.

each O a zero-intercept straight line was fitted to the 10 data points and is plotted in Fig. 6. This linear relationship accounts for 0.97, 0.93, and 0.97 of the total variance in d_q, for Os 1, 2, and 3, respectively. An estimate of q was obtained for each O from the slope of his function and these estimates are presented in Table 4. We shall discuss a plausible interpretation of q after presenting the data from the other three experiments.

EXPERIMENT 2

Six new Os performed in an experimental situation similar to that of Experiment 1, except that there were only two response categories and feedback was provided on each trial.

Procedure

The procedure was similar to that described for Experiment 1 except that the O was given 2.0 sec on each trial to indicate one of two choices regarding the duration of the stimulus light: short (A_0) or long (A_1). Furthermore, the O was informed, by means of an auditory signal, as to the correctness of his response on each trial. Two values of d_0 (50 or 100 msec) and four values of Δd (10, 20, 30, or 40 msec) were used. For each O, data from 1,600 trials were available for each of the eight experimental conditions.

Theoretical Analysis

Each O's performance under each of the eight experimental conditions can be summarized by estimates of two conditional probabilities $P(A_1 \mid S_1)$ and $P(A_1 \mid S_0)$, and these estimates are presented in Table 5, along with the estimated d_q values (Eq. 7). These estimates of d_q are plotted as a function of Δd in Fig. 7. For each O, a zero-intercept straight line was fitted to the eight data points and is plotted in Fig. 7. For three of the Os (Os 4, 5, and 6), d_q appears to be independent of the value of d_0 and to increase as a zero-intercept linear function of Δd. Two of the other Os (Os 7 and 8) display greater discriminability when d_0 equals 50 msec, while the remaining O (O 9) displays greater discriminability when d_0 equals 100 msec. Thus, these results, while supporting the findings of Experiment 1, also suggest that there may be individual differences in the manner in which Os judge the duration of brief flashes of light. An estimate of q was obtained for each O from the slope of his function and these estimates are presented in Table 5.

EXPERIMENT 3

Experiment 3 was designed to investigate whether the Os were basing their discriminations on the temporal information available in the stimuli or on the apparent brightness of the stimuli.

Procedure

The procedure was similar to that described for Experiment 2 and five of the six Os from that experiment (Os 5, 6, 7, 8, and 9) participated. One value of d_0 (100 msec) and one value of Δd (20 msec) were used. Whereas in the previous experiments the luminance of the two stimuli was the same (15 fL), in this experiment S_0 was always 15 fL, while the luminance of S_1 was varied between sessions (15, 13, or 11 fL). Thus, during a session the difference in luminance between the two stimuli, ΔI, could be 0, 2, or 4 fL. The Os were not informed that the luminance of S_1 would vary between sessions. For each O data from 1,200 trials were available for each of the three experimental conditions.

Theoretical Analysis

Estimates of $P(A_1 \mid S_1)$, $P(A_1 \mid S_0)$, and d_q are presented in Table 6 for each O. These estimates of d_q are plotted as a function of ΔI in Fig. 8. The variation in d_q is quite small, and the form of the

Table 5
Estimates of $P(A_1|S_1)$, $P(A_1|S_0)$, d_q, and q for Each O Under Each Condition in Experiment 2

			d_0 = 50			d_0 = 100		
O	q	Δd	$P(A_1\|S_1)$	$P(A_1\|S_0)$	d_q	$P(A_1\|S_1)$	$P(A_1\|S_0)$	d_q
4	22.96	10	.725	.327	.45	.728	.295	.49
		20	.862	.142	.94	.875	.153	.95
		30	.920	.097	1.16	.948	.047	1.37
		40	.975	.010	1.63	.992	.010	1.72
5	46.08	10	.563	.387	.18	.508	.312	.22
		20	.635	.268	.41	.683	.345	.37
		30	.712	.160	.67	.738	.187	.67
		40	.848	.143	.91	.848	.143	.91
6	23.95	10	.782	.327	.53	.732	.378	.40
		20	.877	.210	.85	.885	.196	.89
		30	.970	.053	1.42	.947	.123	1.17
		40	.980	.033	1.54	.978	.028	1.55
7	26.25	10	.663	.343	.35	.697	.392	.33
		20	.838	.145	.89	.813	.195	.77
		30	.947	.062	1.32	.910	.122	1.08
		40	.970	.020	1.55	.943	.053	1.33
8	22.12	10	.690	.275	.47	.800	.380	.50
		20	.898	.082	1.15	.883	.190	.90
		30	.973	.015	1.60	.903	.107	1.10
		40	.998	.002	1.88	.972	.047	1.45
9	26.46	10	.698	.380	.35	.702	.303	.45
		20	.780	.168	.76	.848	.160	.88
		30	.897	.112	1.08	.937	.065	1.29
		40	.910	.037	1.30	.970	.043	1.46

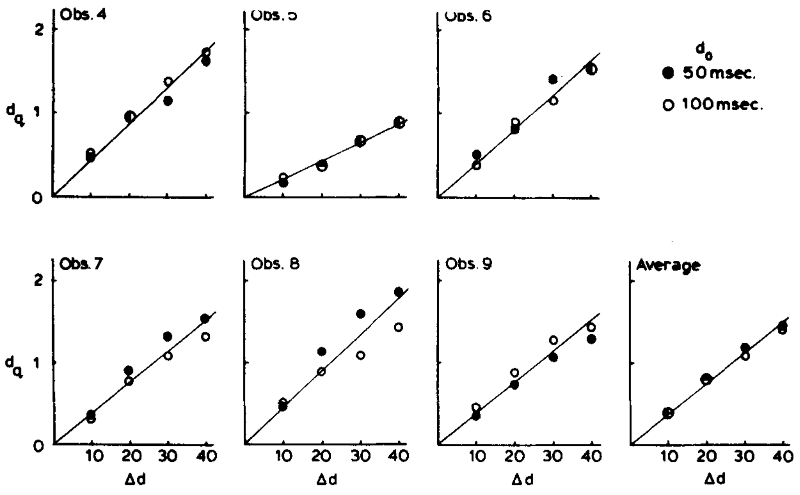

Fig. 7. Estimates of d_q for each O under each condition in Experiment 2.

Table 6
Estimates of $P(A_1|S_1)$, $P(A_1|S_0)$, and d_q for Each O Under Each Condition in Experiment 3

O	ΔI	$P(A_1\|S_1)$	$P(A_1\|S_0)$	d_q
5	0	.665	.260	.46
	2	.732	.258	.56
	4	.686	.304	.43
6	0	.891	.222	.86
	2	.862	.264	.75
	4	.855	.167	.88
7	0	.836	.126	.93
	2	.861	.096	1.03
	4	.882	.069	1.14
8	0	.867	.190	.86
	2	.845	.198	.81
	4	.852	.172	.87
9	0	.884	.092	1.09
	2	.912	.074	1.22
	4	.889	.075	1.14

function is not consistent over the five Os. On the average, changes in ΔI have little effect on an O's ability to discriminate a difference in duration. Furthermore, the data imply that the three Os (Os 7, 8, and 9), whose ability to discriminate a given duration was dependent on the value of S_0, were not basing their discriminations on the apparent brightnesses of the flashes.

EXPERIMENT 4

This experiment was designed to investigate whether or not the differences in luminance between S_0 and S_1 in the previous experiment were large enough to be discriminated.

Procedure

Os 5, 7, 8, and 9 participated in this experiment. One value of d_0 (100 msec), one value of Δd (0 msec), and three values of ΔI (0, 2, or 4 fL) were used. The O was informed that the stimuli differed only in brightness and that he should make an A_0 response when he thought the stimulus was bright and an A_1 response when he thought it was dim. For each O, data from 800 trials were available for each of the three experimental conditions.

Results

Since we have not presented a model to represent the manner in which an O discriminates a difference in luminance between two stimuli, we will consider the relationship between the probability of a correct response, P(C), and changes in the luminance of S_1, where

$$P(C) = P(S_1)P(A_1 | S_1) + P(S_0)\,[1 - P(A_1 | S_0)].$$

Estimates of $P(A_1 | S_1)$, $P(A_1 | S_0)$, and P(C) are presented in Table 7 for each O. It is clear that Os are able to discriminate the differences in luminance used in Experiment 3.

DISCUSSION

In summary, the OC curves generated from the data from Experiment 1 suggest that the psychological durations evoked by a brief light flash can be approximated by a triangular distribution with a base which is independent of the duration of the flash. Secondly, the data from Experiment 1 and Experiment 2 indicate that for six of the nine Os d_q, a measure of an O's ability to discriminate a difference in duration between two brief flashes of light, is directly proportional to the duration difference between the two stimuli and is independent of the stimulus duration, at least for the range of brief durations used. Lastly, the data from Experiments 3 and 4 indicate that discriminable changes in the luminance of the longer flash have little effect on an O's duration-discrimination performance. Thus, when Os are asked to discriminate between flashes of different durations, for durations for which Bloch's law has been shown to hold, their discriminations are frequently made on the temporal information available in the two

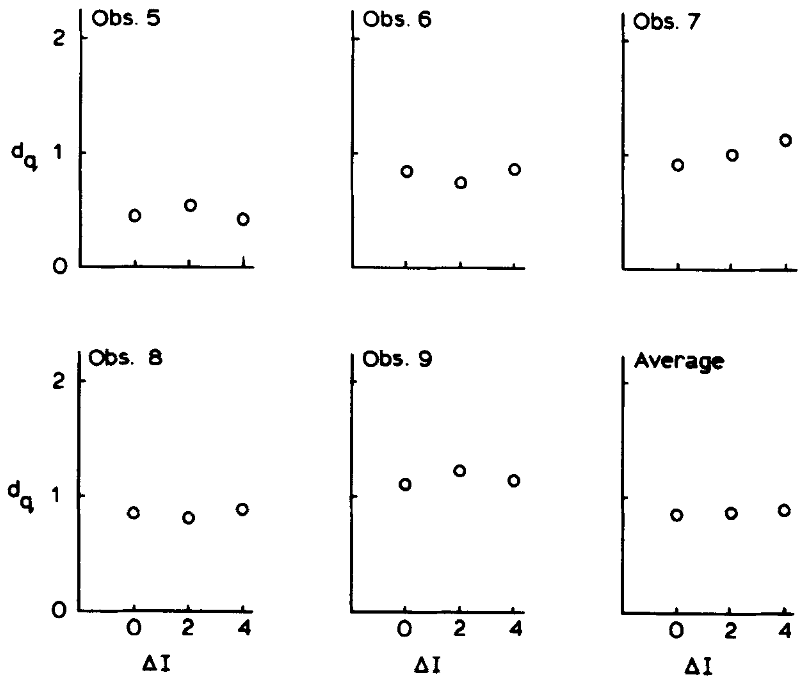

Fig. 8. Estimates of d_q for each O under each condition in Experiment 3.

Table 7
Estimates of $P(A_1|S_1)$, $P(A_1|S_0)$, and $P(C)$ for Each O Under Each Condition in Experiment 4

O	ΔI	$P(A_1\|S_1)$	$P(A_1\|S_0)$	P(C)
5	0	.35	.34	.50
	2	.40	.37	.52
	4	.47	.27	.60
7	0	.40	.40	.50
	2	.46	.23	.62
	4	.71	.14	.78
8	0	.47	.41	.53
	2	.63	.34	.64
	4	.80	.13	.84
9	0	.41	.35	.53
	2	.59	.25	.67
	4	.75	.05	.85

stimuli rather than on their apparent brightness.

Baron (1969) has also suggested that the time between the occurrence of a stimulus and its perception is variable from trial to trial. However, he has assumed that the distribution of these times is Gaussian. A Gaussian assumption about psychological onset and offset time would result in a Gaussian rather than a triangular distribution of psychological durations. The form of the OC curve has often been used (see Green & Swets, 1966) to distinguish between different underlying distributions of sensory states. It is clear from a comparison of Fig. 2 with Fig. 5 that the OC curves generated from an assumption of uniform distributions provide as good a representation of the observed data as those generated from an assumption of Gaussian distributions. Our preference for assuming uniform distributions of onset and offset times over Gaussian distributions is related to the estimates of q that we have obtained.

Kristofferson (1967a) has postulated an "internal clock" which generates a succession of equally spaced points in time which are independent of the presentation of an external stimulus event. These time points occur at the rate of one every q msec, and under normal conditions the rate is assumed to be constant for any O. He has presented data which support the assumptions that the time points are the instants at which attention can switch from one input channel to another and that they determine when information which is in one stage or state of central processing can be transferred into a subsequent stage. Estimates of q have been obtained from the performance of individual Os in successiveness discrimination tasks and in simple and choice reaction-time situations. These estimates are usually around 50 msec (Kristofferson, 1967a, b), although recently data has been reported (Kristofferson, 1969) which suggest a quantum size of 25 msec. It is of interest that the estimates of q obtained from the performance of the Os in the present experiments are very similar to those estimated from successiveness discrimination and reaction-time performance. Of course, further research is needed to determine whether these similarities are of theoretical significance or simply coincidental.

It should be noted that the model of duration discrimination that is developed in this paper states that variability in psychological duration is caused by a quantal process but that psychological duration itself is not quantized but is, on the contrary, a continuous variable.

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