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DURATION DISCRIMINATION OF BRIEF VISUAL STIMULI

by

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Duration Discrimination of Brief Visual Stimuli[1]

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Abstract

Four experiments investigated the manner in which human observers discriminate a difference in duration between brief flashes of light. A decision theory analysis of the data indicated that the comparisons are based on the temporal information available in the stimuli, rather than on the difference in apparent brightness between them. Furthermore, it appears that the variability in the sensory states associated with a particular flash is independent of its physical duration, and that the expected value of the distribution of sensory states is a linear function of the physical duration of the flash.

Data from a number of psychophysical investigations (e.g., Aiba and Stevens, 1964; Raab, 1962; Stevens and Hall, 1966; Stevens, 1966) have indicated that an observer's judgement 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, observers 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

$$B = f(dI), \tag{1}$$

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 and Mansfield, 1968). Thus, within the critical duration in 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 msec.) was constant. Three such product-values were investigated (900, 9,000, and 90,000), for stimulus durations varying between 1 msec and

and 150 msec. They recorded from the occipital cortex of human observers and found that the waveform and the amplitude of the average evoked potentials for a constant luminance-duration product showed a striking similarity.

Since changes in the duration of a brief visual flash result in changes in the apparent brightness of the flash, it is conceivable that when observers are asked to compare brief light flashes of different durations, their comparisons 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 observer's task is to decide whether the flash duration was "short" (an A_0 response) or "long" (an A_1 response). If the observer 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. Kristofferson (1965) and Creelman (1962) have developed quantitative models which represent the observer in a duration discrimination task as using only the temporal information available in the two stimuli to be discriminated. These models are useful for brief visual stimuli only if an observer's ability to discriminate a difference between two light flashes which differ in duration is not influenced by a decrease in the luminance of the longer one.

Kristofferson's quantal model of duration discrimination postulates 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 observer. If

$$xq \leqslant d_i < (x + 1)\ q,$$

where x is a non-negative integer, then the probability of traversing x time points, $P(x)$, during d_i msec is

$$P(x) = \frac{(x+1)q - d_i}{q},$$

and the probability of traversing $(x + 1)$ time points is

$$P(x+1) = \frac{d_i - xq}{q}.$$

Thus, for

$$xq \leqslant d_0 \leqslant d_1 < (x + 1)\ q, \tag{2}$$

either x or $(x + 1)$ time points will be traversed on each trial. If the observer bases his judgement of the duration of a stimulus on the number of time points traversed during the stimulus event, he will always make an A_0 response when he counts x, and an A_1 response when he counts $(x + 1)$. These relationships are presented schematically in Fig. 1. Note that for a fixed value of d_0, the probability of an A_1 response given an S_0 stimulus, $P(A_1 \mid S_0)$, should be constant over

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Fig. 1 about here

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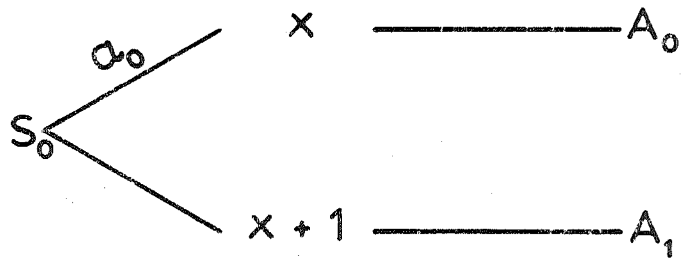
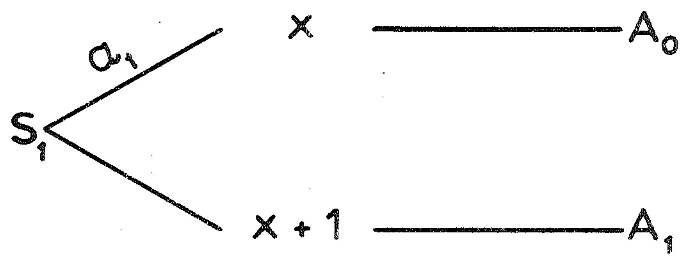
all values of d_1. An estimate of q can be obtained from an observer's performance in the following manner:

$$R = P(A_1 \mid S_1) - P(A_1 \mid S_0) = \frac{\Delta d}{q}. \tag{3}$$

Fig. 1. Schematic of the quantal model.





where

$$a_0 = \frac{(x+1)q-d_0}{q} \quad ,$$

and

$$a_1 = \frac{(x+1)q-d_1}{q} \quad .$$

where

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

Eq. 3 shows that the measure of discriminability, R, is independent of the value of d_0, and increases as a zero intercept, linear function of Δd.

Creelman's (1962) decision theory model of duration discrimination also represents the observer as counting the number of pulses which occur during the duration to be judged. However, the source of the pulses which are counted is assumed to be a large number of independent elements each of which has a fixed probability (λ) of firing at any given moment. It can be shown that the total number of pulses over a given time interval will have a Poisson distribution and that the probability of n counts, P(n), occurring in d_i msec can be written as

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

For sufficiently large λd_i this Poisson distribution can be closely approximated by a Gaussian distribution with expected value equal to λd_i and variance also equal to λd_i. Thus, the expected value of the perceived or apparent duration of a stimulus is assumed to be a linear function of its actual duration. The observer's decision problem in a duration discrimination task involving the presentation of one of two possible stimuli on each trial is illustrated in Fig. 2, which represents two overlapping Gaussian distributions of counts. The distribution with expected value λd_0 represents the distribution of

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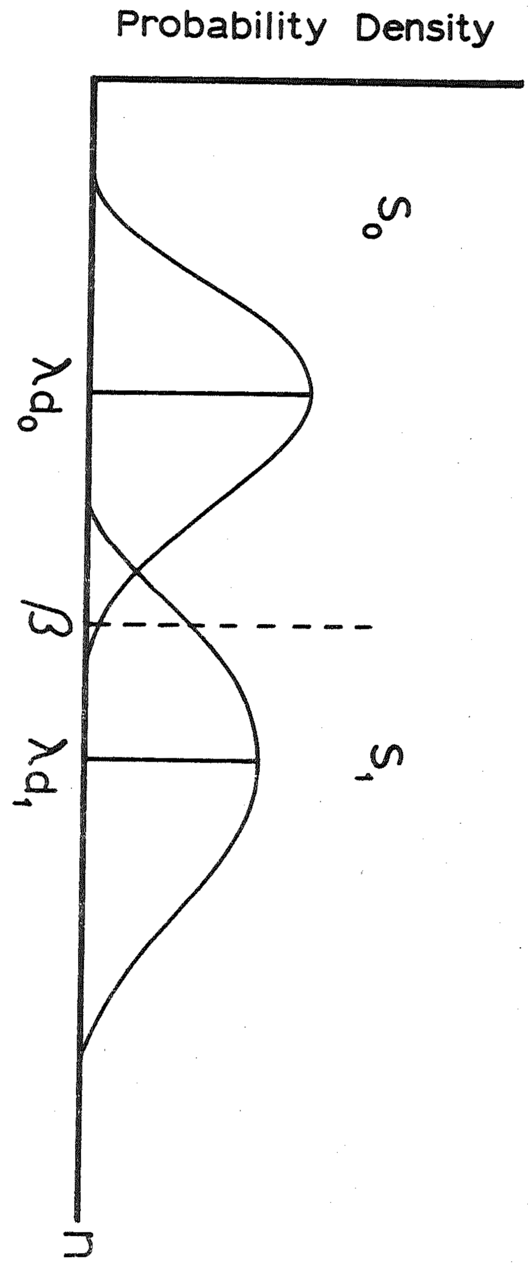
Fig. 2 about here

Fig. 2. Distribution of the number of counts conditional upon the stimulus event.


Probability Density
S_0
S_1
λd_0
β
λd_1
η

counts on S_0 trials; the distribution with expected value λd_1 represents the distribution of counts on S_1 trials. The observer 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. 2 it can be seen that the probability of an A_1 response given an S_1 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 observer 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:

$$d' = Z(A_1 | S_0) - 1/r\ Z(A_1 | S_1), \tag{4}$$

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

$$r = \frac{d_0^{1/2}}{d_1^{1/2}}, \tag{5}$$

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 distance between the expected values of the two counting distributions expressed in standard deviation units of the S_0 distribution. Thus,

$$d' = \frac{\lambda^{1/2} \Delta d}{d_0^{1/2}} \tag{6}$$

Two implications of this model are apparent from Eq. 6. 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.

Both Kristofferson (1965) and Creelman (1962) have reported duration discrimination data from two-interval, forced-choice paradigms. On each trial two stimuli which differed in duration were presented in succession, and the observer 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. In the Kristofferson study the observer had to compare the duration of empty intervals; in the Creelman study, the duration of tones. The Kristofferson study was exploratory in nature but under some conditions the data indicated support for a quantal process in duration discrimination. Creelman's study was quite extensive and his model appeared to provide a reasonable interpretation of his 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 observer, when asked to compare brief light flashes of different durations, bases his comparisons on the temporal information available in the stimuli, or on the apparent brightness of the stimuli. Furthermore, the data will provide a test of both the Kristofferson and Creelman models for visual stimuli.

APPARATUS

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

EXPERIMENT 1[3]

Procedure

Three observers participated in this experiment. Each discrimination 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 observer 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 observers were instructed to base their decisions on the duration of the stimulus and to distribute their responses equally among the four response categories. They did not receive feedback as to the correctness of their responses.

The intensity of the stimuli was constant at 15 foot-lamberts 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, $P(S_1)$, equalled 0.5.

Each of the ten experimental conditions was in effect during three sessions for Observer 1 and Observer 3, and during four sessions for Observer 2, the order of conditions being randomly determined with the limitation that each condition was 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 ten sessions (one session under each condition) were not included in the final analysis. In this way data from 800 trials for two of the observers, and from 1200 trials for the other observer were available for each of the ten experimental conditions.

Results

Each observer's performance under each of the ten 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 $(A_{j,k} | S_i)$, are presented in Table 1.

Table 1 about here

Quantal Model Analysis

The quantal model presented in Fig. 1 specified that for

$$xq \leqslant d_0 \leqslant d_1 < (x + 1)\ q$$

the observer will always make an A_0 response when he counts x time points, and an A_1 response when he counts (x + 1) time points, but did

Table 1

Frequencies Summarizing Each Observer's Performance Under Each of the Ten Conditions in Experiment 1.

Obs.	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

not describe how he would divide his responses between the certain and uncertain categories. For each observer, the probability of an A_1 response to an S_1 stimulus, $P(A_1 | S_1)$, and the probability of an A_1 response to an S_0 stimulus, $P(A_1 | S_0)$, are presented in Table 2. It is clear from Table 2 that $P(A_1 | S_0)$ is not constant for a fixed value of d_0, but systematically decreases as d_1 increases. In terms

Table 2 about here

of the model this means that the observer does not always make an A_0 response when x time points are traversed. If the difference in duration between S_0 and S_1 is small and if d_0 is not much greater than xq, most of the stimuli will traverse x time points, and hence appear subjectively short. However, since the observer was informed that S_0 and S_1 would occur with equal frequency and that he should try to make as many A_1 responses as A_0 responses, he may make an A_1 response on some proportion, β, of the trials on which x time points are traversed (Fig. 3). Note that the value of β should decrease as Δd is increased. Estimates of q can be obtained from the observer's performance

Fig. 3 about here

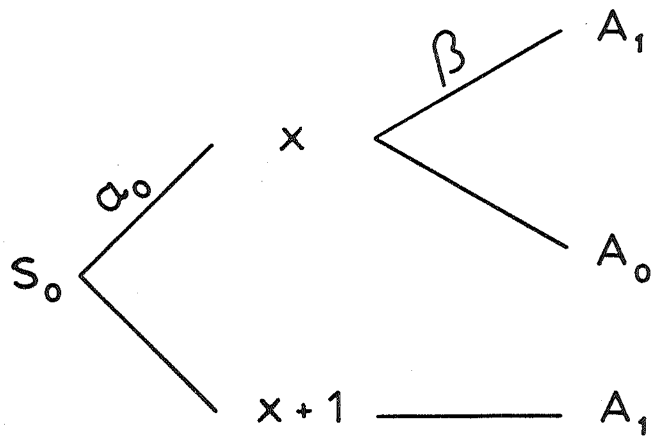
in the following manner:

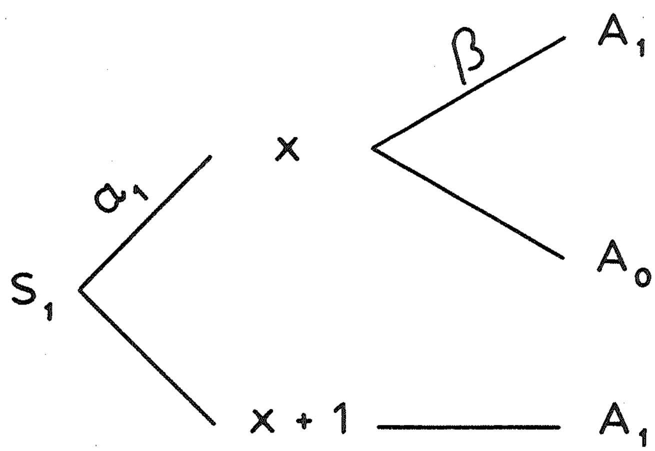
Table 2

Conditional Probabilities for Each Observer Under Each Condition in Experiment 1.

Obs.	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	.97	.84	.60	.36	.18	.08
		20	.94	.80	.64	.20	.21	.05
		30	.98	.72	.63	.06	.22	.01
		40	.99	.66	.84	.06	.38	.01
		50	.98	.44	.87	.04	.42	.01
	100	10	.93	.88	.54	.32	.13	.04
		20	.96	.77	.66	.25	.28	.06
		30	.96	.77	.69	.13	.30	.03
		40	.98	.72	.86	.12	.39	.02
		50	.98	.58	.87	.05	.39	.02
2	50	10	.76	.61	.65	.47	.51	.32
		20	.92	.76	.74	.42	.46	.17
		30	.88	.55	.71	.28	.49	.10
		40	.96	.46	.88	.19	.59	.05
		50	.97	.21	.94	.09	.80	.04
	100	10	.78	.65	.63	.47	.36	.22
		20	.88	.65	.75	.42	.55	.23
		30	.97	.69	.89	.35	.66	.15
		40	.94	.47	.90	.31	.78	.16
		50	.95	.42	.89	.19	.76	.12
3	50	10	.71	.52	.58	.41	.34	.20
		20	.83	.51	.76	.37	.55	.20
		30	.92	.37	.84	.18	.66	.07
		40	.95	.28	.90	.13	.78	.05
		50	.99	.18	.98	.05	.94	.01
	100	10	.76	.52	.66	.38	.50	.24
		20	.84	.49	.76	.35	.63	.22
		30	.94	.40	.89	.18	.76	.07
		40	.98	.28	.94	.14	.85	.06
		50	.99	.20	.97	.08	.89	.02

Fig. 3. Schematic of the quantal model (version II).





$$a_0 = \frac{(x+1)q - d_0}{q}$$

$$a_1 = \frac{(x+1)q - d_1}{q}$$

$$P = \frac{P(A_1 \mid S_1) - P(A_1 \mid S_0)}{1-P(A_1 \mid S_0)} = \frac{\Delta d}{(x+1)\ q - d_0} \quad . \qquad (7)$$

Eq. 7 shows that the observer's performance, P, is a zero intercept, linear function of Δd. Values of P are presented numerically in Table 3, and are plotted as a function of Δd for each observer in Fig. 4. It is clear that the data are not consistent with the relationship specified by Eq. 7.

Table 3 about here

Fig. 4 about here

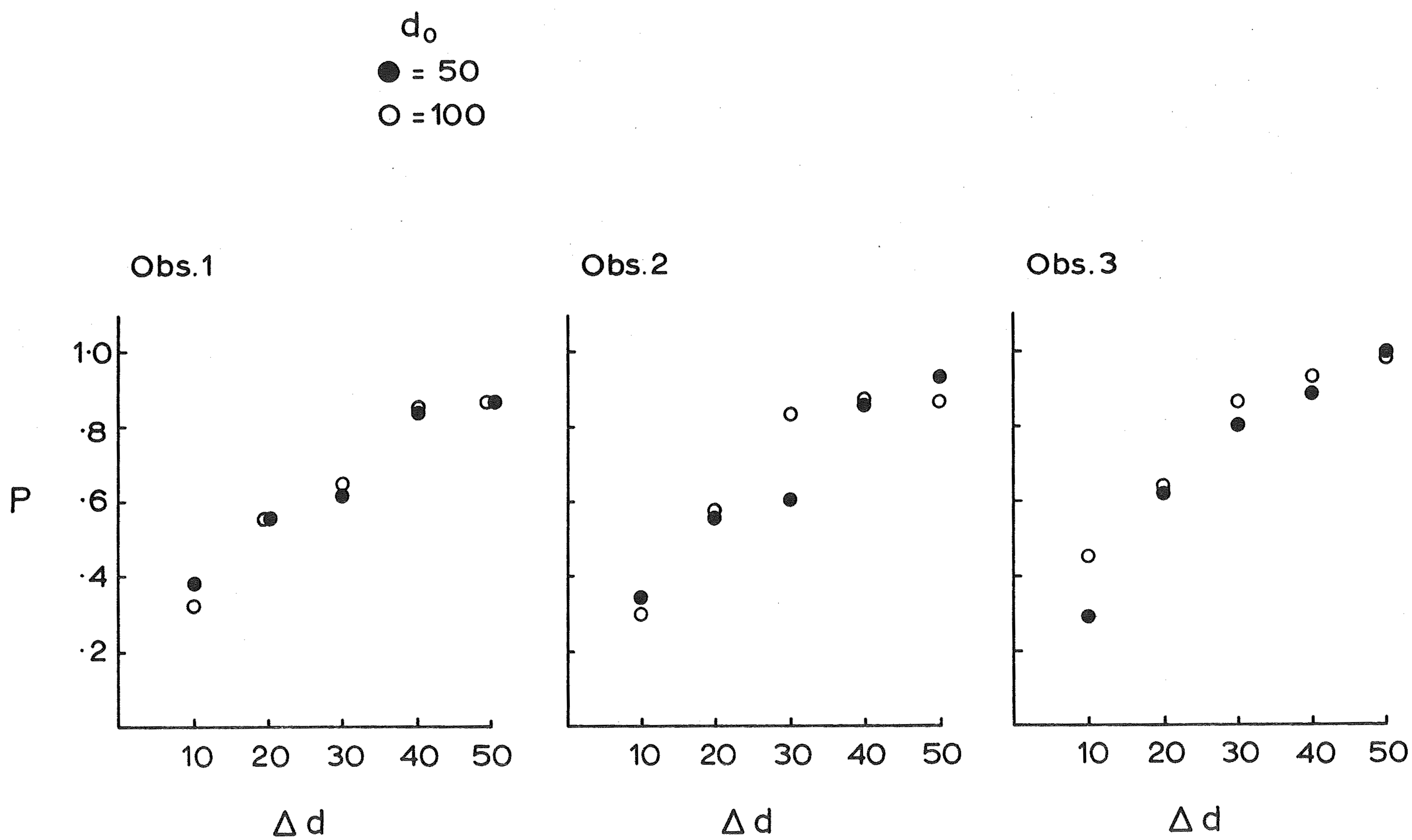
Kristofferson (1967) has reported estimates of q from a number of experimental situations (eg., reaction time tasks and successiveness discrimination tasks) which are approximately 50 msec in magnitude, although they differ a little from 50 for different individuals. For the values of d_0 and Δd used in the present experiment, the relationships described in Expression 2 hold only for q equal to 50 msec. Quantal representations could be developed for a large number of values of q, and the performance observed in the present experiment could be compared with the predictions of each of the representations. However, it seems that a more fruitful approach would be to obtain estimates of an observer's q value from other experimental situations and to select values of d_0 and Δd such that the relationships specified in Expression 2 are valid. Such experiments are presently under

Table 3

P Values for Each Observer Under Each Condition in Experiment 1.

Obs.	d_0	Δd	P
1	50	10	.38
		20	.55
		30	.61
		40	.83
		50	.86
	100	10	.32
		20	.55
		30	.64
		40	.84
		50	.86
2	50	10	.34
		20	.55
		30	.60
		40	.85
		50	.93
	100	10	.30
		20	.57
		30	.83
		40	.86
		50	.86
3	50	10	.29
		20	.62
		30	.80
		40	.88
		50	.98
	100	10	.45
		20	.63
		30	.86
		40	.93
		50	.97

Fig. 4. Values of P for each observer under each condition in Experiment 1.



d_o
● = 50
○ = 100
Obs.1
Obs.2
Obs.3
P
1·0
·8
·6
·4
·2
10
20
30
40
50
Δ d

consideration.

Decision Theory Analysis

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

$$P(A_1 \vee A_{0,c} \mid S_i),$$

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

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

for i equal to 1 or 0. The six conditional probabilities determining each of the 30 OC curves (three observers and ten 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 procedure described by Ogilvie and Creelman (1968).[4] These OC curves, when plotted on normal-normal coordinates, are straight lines, and the slope of each OC is an estimate of r. That is, rearranging Eq. 4,

$$P(A_1 \mid S_1) = rZ(A_1 \mid S_0) - rd'.$$

Estimates of r, for each observer under each experimental condition, as well as the values of r predicted by Eq. 5, are presented in Table 4. It is clear that the values of r estimated from the data are not in

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Table 4 about here

Table 4

Observed r, Predicted r, and d' Values Assuming Unit Slope, for Each Observer Under Each Condition in Experiment 1.

Obs.	d_0	Δd	Observed r	Predicted r	d'
1	50	10	1.172	.91	.65+
		20	.931	.84	1.09
		30	.930	.79	2.00
		40	.969	.74	2.62
		50	.845	.71	3.02
	100	10	.867*	.95	.54
		20	1.042	.91	1.08
		30	.839*	.88	1.59
		40	.865	.84	2.26
		50	.927	.82	2.82+
2	50	10	.887	.91	.46
		20	.951	.84	.85
		30	.841*	.79	1.15
		40	.944	.74	2.08
		50	1.233	.71	2.95+
	100	10	.981	.95	.39
		20	1.039	.91	.87
		30	1.179	.88	1.55
		40	1.003	.84	1.81
		50	1.147	.82	2.03+
3	50	10	1.030	.91	.46
		20	.980	.84	.97
		30	.901	.79	1.91
		40	.864	.74	2.51
		50	.963	.71	4.42
	100	10	.917	.95	.68
		20	.926	.91	1.08
		30	.770*	.88	2.18
		40	1.143	.84	2.79
		50	.978	.82	3.65

* Significant deviation from unit slope ($p < .05$)

+ Significant Chi Square ($p < .05$)

agreement with the values of r predicted by Eq. 5. The obtained slopes were tested for significant deviations from unit slope. As Table 4 indicates, 26 of the 30 obtained slopes did not deviate significantly ($p > .05$) from unity (and the remaining four did not deviate significantly at the 0.01 level). The d' values presented in Table 4 represent the best fitting, straight line unit slope OC. Twenty-six of the 30 Chi Square tests for goodness-of-fit of the obtained data points to the straight line, unit slope OC curve (Table 4) were non significant ($p > .05$). These results suggest that the distribution of counts evoked by the stimuli used in the present experiment are Gaussian, and that the variance of these distributions is independent of the value of the stimulus.

The d' values assuming unit slope are plotted as a function of Δd in Fig. 5. A z-statistic[5] was calculated for each Δd value to determine whether an observer's ability to discriminate a given increment added to a 50 msec S_0 differed significantly from his ability to discriminate the same increment added to a 100 msec S_0. Note that although

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Fig. 5 about here

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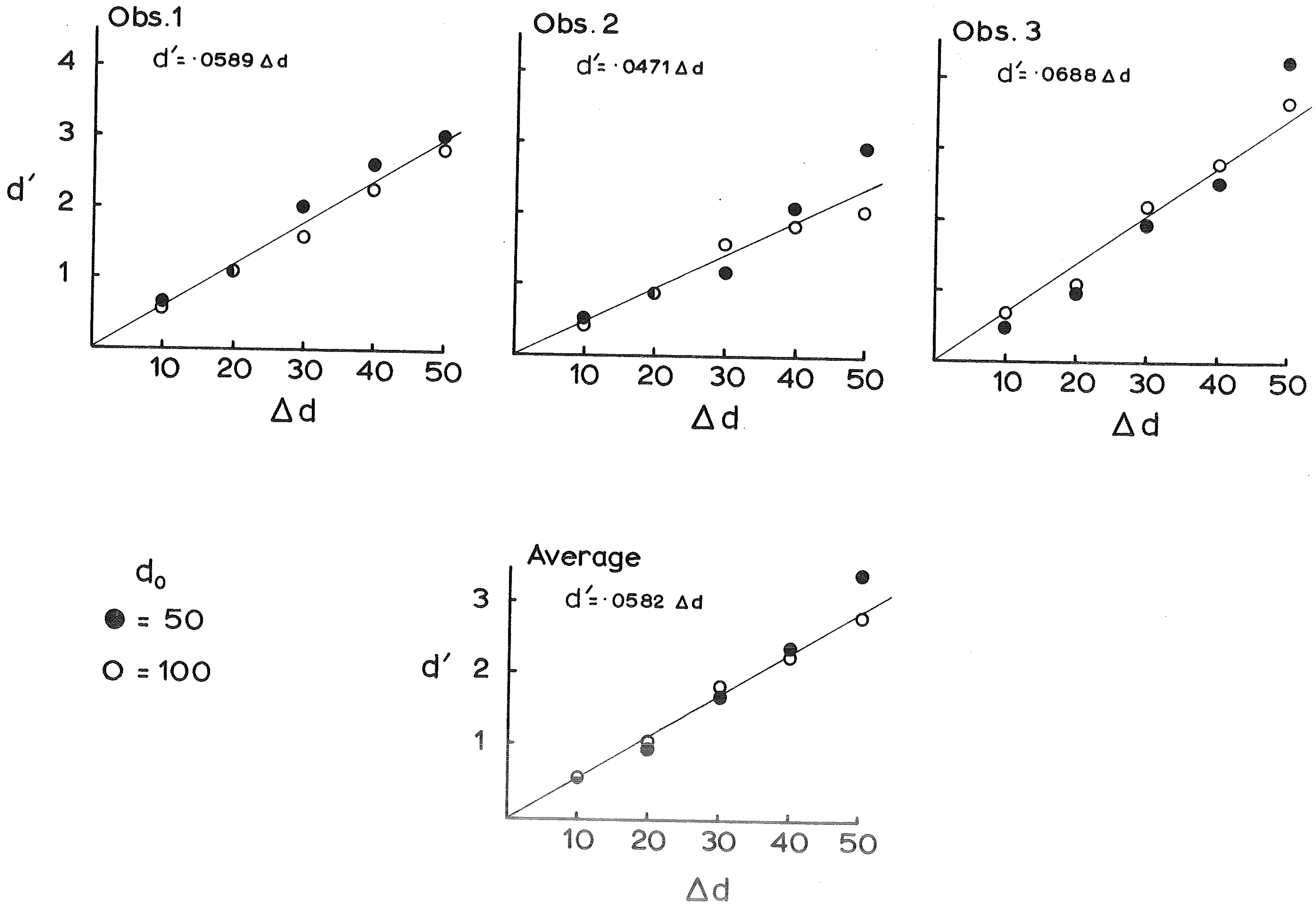
five of the 15 comparisons (Table 5) are significant ($p > .05$), Observer 1

Table 5 about here

Fig. 5. Values of d' for each observer under each condition in Experiment 1.



Obs.1
d′= ·0589 Δd
4
3
2
1
d′
10
20
30
40
50
Δd
Obs. 2
d′= ·0471 Δd
10
20
30
40
50
Δd
Obs. 3
d′= ·0688 Δd
10
20
30
40
50
Δd
d₀
● = 50
○ = 100
Average
d′= ·0582 Δd
3
2
1
d′
10
20
30
40
50
Δd

Table 5

Z-Statistics for Each Δd Value in Experiment 1.

Δd	Observer 1	Observer 2	Observer 3	Average
10	.953	.677	-1.948	- .149
20	.135	- .204	- .886	- .319
30	2.468*	-3.802*	-1.815	- .624
40	1.923	2.202*	-1.545	.703
50	.917	6.275*	2.493*	2.799*

* $p < .05$

and Observer 3 have only one significant difference each, and for Observer 2 the direction of the differences is not consistent. The average d' values over the three observers is also plotted as function of Δd in Fig. 5. A z-statistic was again calculated for each Δd value, and four of the five comparisons (Table 5) indicated no significant difference ($p > .05$).

For each observer, a zero intercept, straight line was fitted to the ten observed data points. These lines, as well as the best fitting, zero intercept, straight line determined on the basis of the average data, are plotted in Fig. 5. It seems clear from Fig. 5 that a linear relationship between d' and Δd, which is independent of the value of d_0, provides a reasonable representation of each observer's performance.

Thus, the results indicate that the variability in the sensory states associated with a particular flash is independent of its physical duration, and that the expected value of the sensory states is a linear function of the physical duration of the flash. This linear relationship suggests that the observers are not basing their discriminations on the difference in apparent brightness between the two stimuli. Data from a number of magnitude-estimation-type studies (eg., Aiba and Stevens, 1966; Anglin and Mansfield, 1968; Raab, 1962; Stevens and Hall, 1966; Stevens, 1966) have indicated that the apparent brightness of a light flash is a power function of its physical duration, for durations within which Bloch's law holds. Unfortunately, data from similar studies which are relevant to the relationship between apparent duration and physical duration for brief durations are not available. However, Stevens and Greenbaum (1966) have demonstrated that apparent duration is essentially a linear function of physical duration for light flashes which varied in duration from 0.3 sec to 7.0 sec.

EXPERIMENT 2

This experiment is essentially a replication of Experiment 1, except that there were only two response categories, and feedback was provided on each trial.

Procedure

Six new observers participated in this experiment. The procedure was similar to that described for Experiment 1 except that the observer 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 observer 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 observer, data from 1600 trials were available for each of the eight experimental conditions.

Decision Theory Analysis

Each observer's performance under each of the eight experimental conditions can be summarized by two conditional probabilities, $P(A_1 | S_1)$ and $P(A_1 | S_0)$, and these probabilities are presented in Table 6, along with the observed d' values (Eq. 4), for r equal to 1. These values, as well as the average d' values over the six observers, are plotted as

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Table 6 about here

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a function of Δd in Fig. 6. For three of the observers (Observers 4, 5,

Table 6

$P(A_1|S_1)$, $P(A_1|S_0)$, and d' Values for Each Observer
Under Each Condition in Experiment 2.

		d_0=50			d_0=100		
Obs.	Δ d	$P(A_1\|S_1)$	$P(A_1\|S_0)$	d'	$P(A_1\|S_1)$	$P(A_1\|S_0)$	d'
4	10	.72	.33	1.02	.73	.30	1.14
	20	.86	.14	2.16	.88	.15	2.22
	30	.92	.10	2.68	.95	.05	3.28
	40	.98	.01	4.37	.99	.01	4.64
5	10	.56	.39	.43	.51	.31	.53
	20	.64	.27	.97	.68	.34	.88
	30	.71	.16	1.54	.74	.19	1.52
	40	.85	.14	2.12	.85	.14	2.12
6	10	.78	.33	1.21	.73	.38	.92
	20	.88	.21	1.98	.89	.20	2.07
	30	.97	.05	3.52	.95	.12	2.82
	40	.98	.03	3.93	.98	.03	3.93
7	10	.66	.34	.82	.70	.39	.80
	20	.84	.14	2.07	.81	.20	1.72
	30	.95	.06	3.19	.91	.12	2.52
	40	.97	.02	3.93	.94	.05	3.19
8	10	.69	.28	1.08	.80	.38	1.14
	20	.90	.08	2.68	.88	.19	2.06
	30	.97	.02	3.93	.90	.11	2.51
	40	.99	.01	4.64	.97	.05	3.52
9	10	.70	.38	.83	.70	.30	1.05
	20	.78	.17	1.72	.85	.16	2.03
	30	.90	.11	2.51	.94	.06	3.10
	40	.91	.04	3.09	.97	.04	3.63

and 6), d' appears to be independent of the value of d_0, and to increase

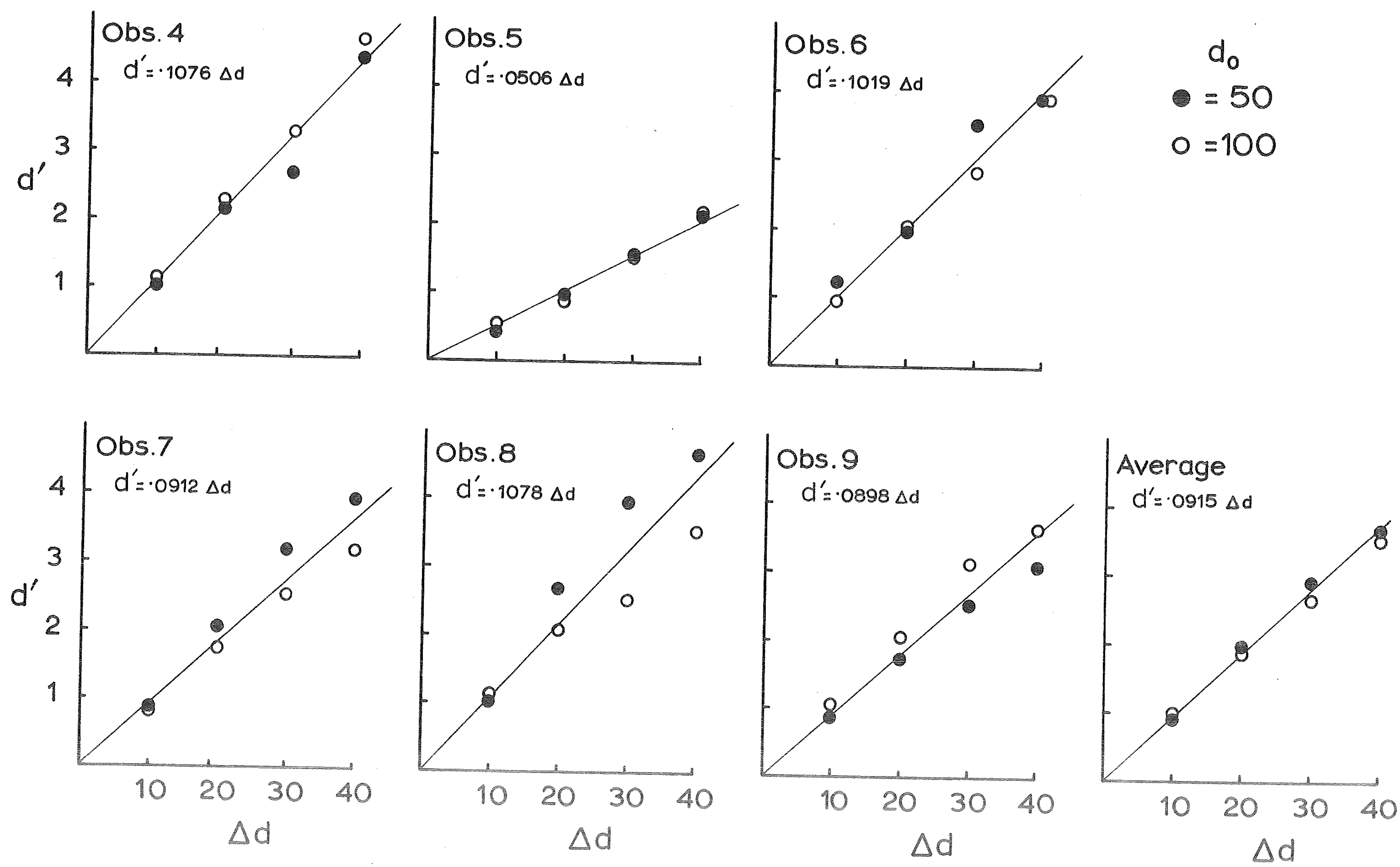
Fig. 6 about here

as a zero intercept, linear function of Δd. Two of the other observers (Observers 7 and 8) display greater discriminability when d_0 equals 50 msec, while the remaining observer (Observer 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 observers judge the duration of brief visual stimuli.

In general, the observed values of d' in Experiment 2 were considerably higher than those observed in Experiment 1. Trial-by-trial feedback was not available in Experiment 1, and there is some evidence in the literature that the absence of feedback results in considerable variability in decision criterion from trial to trial (eg., Allan, 1968; Kinchla, 1966; Tanner, Haller, and Atkinson, 1967), which in turn could yield spuriously low estimates of d'. Suppose that the value of the criterion adopted by an observer is not constant over trials, but has a Gaussian distribution with expected value β, and variance π_β. Since the addition of this Gaussian distribution of criteria to a Gaussian distribution of sensory states with expected value equal to d_i and variance equal to π is mathematically equivalent to a Gaussian distribution of sensory states with expected value d_i and variance $(\pi + \pi_\beta)$ and a constant criterion β, then

$$d' = \frac{\Delta d}{(\pi + \pi_\beta)^{1/2}}$$

Fig. 6. Values of d' for each observer under each condition in Experiment 2.


Obs. 4
d′ = ·1076 Δd
Obs. 5
d′ = ·0506 Δd
Obs. 6
d′ = ·1019 Δd
d₀
= 50
=100
Obs. 7
d′ = ·0912 Δd
Obs. 8
d′ = ·1078 Δd
Obs. 9
d′ = ·0898 Δd
Average
d′ = ·0915 Δd
d′
1
2
3
4
10
20
30
40
Δd

Unfortunately, the number of observations necessary for reliable estimates of π_β is considerably greater than the number obtained under any of the experimental conditions in the present studies.

EXPERIMENT 3

This experiment investigated the effect of decreasing the luminance of S_1 on an observer's ability to discriminate a difference in duration between two stimuli.

Procedure

The procedure was similar to that described for Experiment 2, and five of the six observers from that experiment (Observers 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 foot-lamberts), in this experiment S_0 was always 15 foot-lamberts, while the luminance of S_1 was varied between sessions (15, 13, or 11 foot-lamberts). Thus, during a session the difference in luminance between the two stimuli, ΔI, could be 0, 2, or 4 foot-lamberts. The observers were not informed that the luminance of S_1 would vary between sessions. For each observer data from 1200 trials were available for each of the three experimental conditions.

Decision Theory Analysis

Values of $P(A_1 | S_1)$, $P(A_1 | S_0)$, and d' are presented in Table 7 for each observer. These values of d', as well as the values

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Table 7 about here

Table 7

$P(A_1|S_1)$, $P(A_1|S_0)$, and d' Values for Each Observer Under Each Condition in Experiment 3.

Obs.	Δ I	$P(A_1\|S_1)$	$P(A_1\|S_0)$	d'
5	0	.66	.26	1.05
	2	.73	.26	1.25
	4	.69	.30	1.03
6	0	.89	.22	2.00
	2	.86	.26	1.72
	4	.85	.17	1.99
7	0	.84	.12	2.16
	2	.86	.10	2.36
	4	.88	.07	2.64
8	0	.87	.19	2.01
	2	.84	.20	1.83
	4	.85	.17	1.99
9	0	.88	.09	2.52
	2	.91	.07	2.81
	4	.89	.08	2.63

of d' averaged over the five observers, are plotted as a function of ΔI in Fig. 7. The variation in d' is quite small, and the form of the function is not consistent

Fig. 7 about here

over the five observers. On the average, changes in ΔI appear to have no effect on an observer's ability to discriminate a difference in duration. Furthermore, the data imply that the three observers (Observers 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 the differences in luminance between S_0 and S_1 in the previous experiment were too small to be discriminated.

Procedure

Observers 5, 7, 8, and 9 participated in this experiment. One value of d_0 (100 msec), 1 value of Δd (0 msec), and three values of ΔI (0, 2, or 4 foot-lamberts) were used. The observer 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 observer, data from 800 trials were available for each of the three experimental conditions.

Fig. 7. Values of d' for each observer under each condition in Experiment 3.

Results

Since we have not presented a model to represent the manner in which an observer 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

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

Values of $P(A_1 | S_1)$, $P(A_1 | S_0)$, and $P(C)$ are presented in Table 8 for

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Table 8 about here

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each observer. It is clear that observers are able to discriminate the differences in luminance used in Experiment 3.

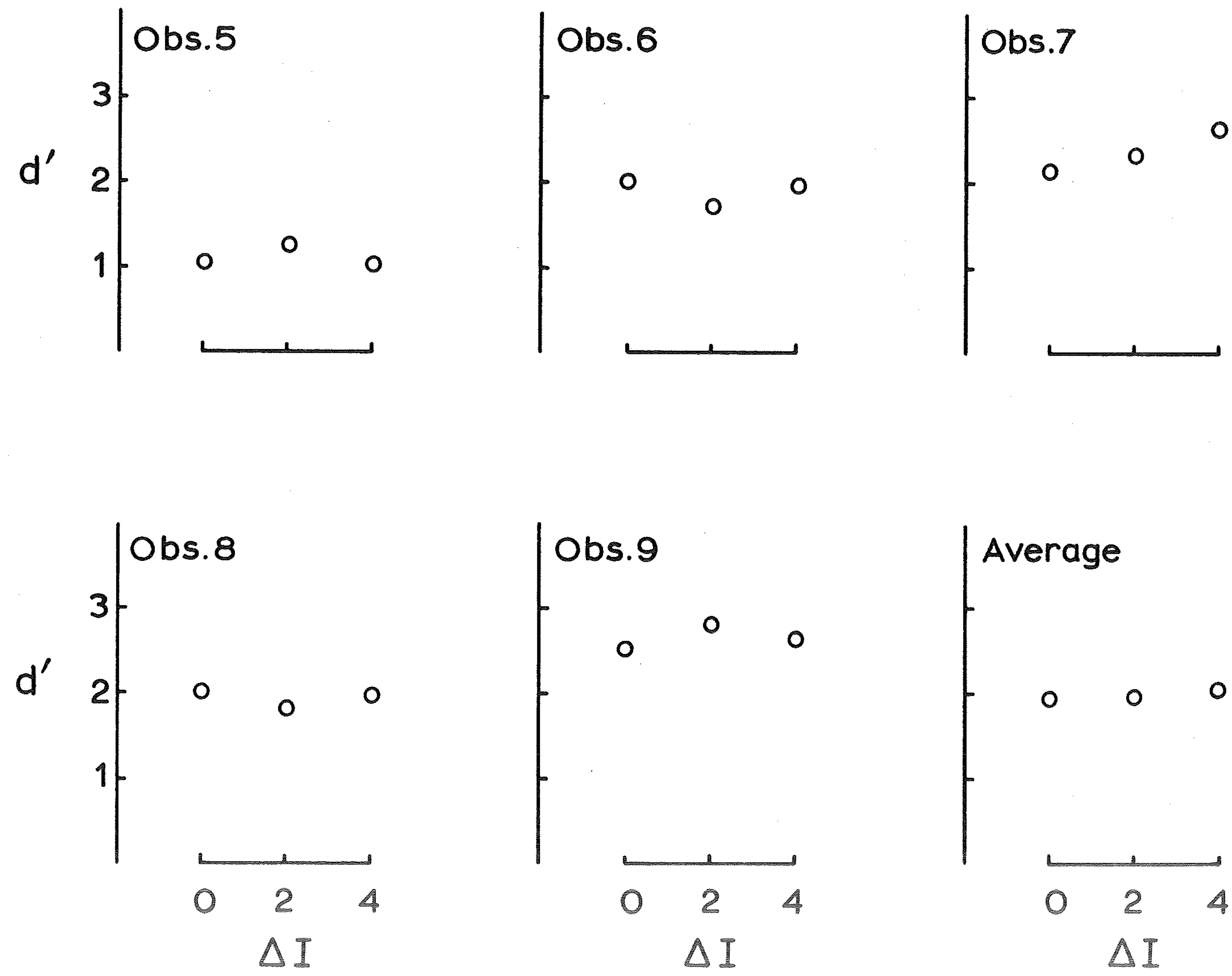
DISCUSSION

In summary, the decision theory analysis of performance in a duration discrimination task involving brief flashes of light revealed the following relationships in the data. The OC curves generated from the data from Experiment 1 suggest that the variability in the sensory states associated with a particular flash is independent of the actual flash duration. Secondly, the data from Experiment 1 and Experiment 2 indicate that d', a measure of an observer's ability to discriminate a difference in duration between two brief flashes of light, increases as a linear function of the duration difference between the two stimuli. Thirdly, for six of the nine observers used in the present experiments, the ability to discriminate a given difference in duration appears to be independent of the actual stimulus durations used. That is, the linear relationship between d' and Δd is independent of the value of d_0. Lastly,

Table 8

$P(A_1|S_1)$, $P(A_1|S_0)$, and P(c) for Each Observer
Under Each Condition in Experiment 4.

Obs.	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


Obs.5
Obs.6
Obs.7
Obs.8
Obs.9
Average
d′
3
2
1
0
2
4
ΔI

the data from Experiments 3 and 4 indicate that discriminable changes in the luminance of the longer flash do not have an appreciable effect on an observer's ability to discriminate a difference in duration. Thus, in general it appears that when observers are asked to compare flashes of different durations, for durations within which Bloch's law has been shown to hold, their comparisons are made on the temporal information available in the two stimuli, and not on their apparent brightnesses.

Creelman's decision theory model of duration discrimination, which represents the observer as counting the number of pulses which occur during the duration to be judged, is not consistent with the present data, since his model specifies that the variability in the apparent duration associated with a particular flash is dependent on the stimulus duration. Suppose that at some time after the onset of the stimulus a "temporal process", T, is activated, and that this process continues until after the offset of the stimulus. Assume further that the distribution of starting times is Gaussian with expected value t_s and variance π_s, and similarly that the distribution of ending times is Gaussian with expected value t_e and variance π_e. The expected value of the temporal process, E(T), for a d_i msec stimulus is

$$E(T) = d_i - t_s + t_e,$$

and the variance, Var (T), is

$$\mathrm{Var}\ (T) = \pi_s + \pi_e.$$

Thus, the observer's ability to discriminate a d_0 msec flash from a d_1 msec flash can be defined as follows:

$$D = \frac{\Delta d}{(\pi_s + \pi_e)^{1/2}}, \qquad (8)$$

and can be calculated from the data in the following manner:

$$D = Z(A_1 | S_1) - Z(A_1 | S_0).$$

Eq. 8 shows that D is independent of the value of S_0, and increases as a zero intercept, linear function of Δd, and that the variance of T is independent of the values of d_0 and Δd. Note that the slope of the function relating D to Δd yields an estimate of Var (T).

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Footnotes

1. This research was supported by grants APA-0112 and APA-0175 from the National Research Council of Canada, and by grant NGR-52-059-001 from the National Aeronautics and Space Administration.

2. Now at Dalhousie University.

3. Experiment 1 is based on an Honours Thesis by E. W. Wiens.

4. Ogilvie and Creelman (1968) use maximum-likelihood estimation of the best fitting OC derived from a theoretical model which assumes underlying logistic distributions. They show, however, that a simple relationship exists between the parameters estimated on the basis of a logistic model and those estimated on the basis of a Gaussian model.

5. $$Z = \frac{d'_{50} - d'_{100}}{\sqrt{(SE_{50})^2 + (SE_{100})^2}}$$

The Ogilvie-Creelman procedure for determining OC curves provides an estimate of the standard error (SE).