Some aspects of perceptual coding of duration in visual duration discrimination*

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Data are presented which indicate two major differences between duration discrimination performance and discrimination performance usually observed in other psychophysical tasks. A decrement in duration discrimination performance with increasing temporal delays between the presentation of two successive stimuli was not found, and the usual difference in level of performance between forced-choice and single-stimulus tasks was not observed. The time-order error in duration discrimination is also discussed.

It is well established that in many psychophysical discrimination tasks involving the sequential presentation on the same trial of the two stimuli to be compared, the temporal interval between the two stimuli is an important variable, discriminability decreasing as the interval is lengthened. For example, Kinchla and Smyzer (1967) and Tanner (1961) have shown this effect for loudness discrimination, Bull and Cuddy (1972) and Moss, Myers, and Filmore (1970) for pitch discrimination, Kinchla and Allan (1969, 1970) for visual movement discrimination, and Allan (1968) for spatial position. A number of quantitative memory models to account for decreased discriminability with increasing interstimulus interval (ISI) have been proposed (Kinchla & Allan, 1969; Massaro, 1970; Wickelgren, 1969).

In a study which required the O to make comparative judgments about the duration of two brief stimulus events, Small and Campbell (1962) did not observe the same phenomenon. Their stimuli were filled auditory intervals. On each trial, two duration stimuli were presented sequentially, and the O was required to indicate which was the longer (or the shorter). They found that duration discrimination performance did not change for ISIs of 5, 200, 800, and 3,200 msec for duration stimuli in the 400-msec range. As stimulus duration was shortened (40-, 4-, and .4-msec ranges), the shorter values of ISI (5 and 200 msec) resulted in a *decrement* in discriminability relative to the fairly constant discriminability level at the longer values.

The absence of a decrement in discriminability with increasing ISI is important in the development of theory concerned with the psychophysics of brief time intervals. The absence of an ISI effect would indicate

that a model for duration discrimination would have to differ in some fundamental aspect from existing psychophysical models concerned with the sequential presentation of the stimuli to be compared. Given our interest in the development of a model for duration discrimination (Allan, Kristofferson, & Wiens, 1971; Carbotte & Kristofferson, 1971; Kristofferson, 1973; Kristofferson & Allan, 1973), we thought it necessary to investigate carefully the relationship between duration discrimination performance and ISI. In the Small and Campbell study, relatively few observations were collected from each O under each experimental condition, and only the data averaged over Os are available. The experiments to be reported in this paper examine the effect of variations in ISI on duration discrimination performance for brief durations. To increase the generality of the results, a visual stimulus was used to mark the duration to be judged.

The two-alternative forced-choice (FC) task is one method of presenting two sequential stimuli for comparison. The FC discrimination task involves the sequential presentation on each trial of two stimuli, S_0 and S_1 , which differ along the same dimension, and the requirement that the O make a comparative judgment about their magnitudes. On some trials, S_0 is presented first, followed by S_1 ; on the remaining trials, S_1 is followed by S_0 . Green and Swets (1966) have presented data from a number of psychophysical studies which clearly indicate that discrimination performance in a FC task is superior to that in a single-stimulus (SS) task. A SS discrimination task involves the presentation of one stimulus on each trial and the requirement that the O make a judgment about the magnitude of that stimulus. Since knowledge about the relationship between FC and SS duration discrimination performance is essential to a theoretical treatment of the psychophysics of brief time intervals, the experiments to be reported were also designed to provide such information. Specifically, when the O is asked to compare two duration stimuli, S_0 and S_1 , is his performance better in the case when the two stimuli are presented on the same trial than in the case when only one stimulus is presented on each trial?

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Fig. 1. $P(C)$ as a function of ISI for each O in Experiment I. The line indicates the O's mean performance over the four values of ISI for a given value of Δd .

EXPERIMENT I

Method

Six paid Os participated in this experiment. Each O sat in an IAC sound-attenuated, dimly illuminated, auditory chamber, approximately 66 cm from the visual display. The visual display consisted of a glow modulator bulb (Sylvania R 1131C) driven by an Iconix power supply (Model 6195-4). The bulb was enclosed in a metal box with an aperture, 4 mm in diam, subtending a visual angle of 21 min. The aperture was covered on the inside with a Kodak No. 96 neutral density 2.00 filter and then translucent milk glass. The luminance of the display was 50 fL (150 UB Photo Research photometer). Clearly audible warning signals and feedback information were provided through a speaker in each chamber. The presentation and timing of the signals and the recording of the responses were under the control of a PDP-8/S computer.

For three Os (A.J., S.B., and S.M.), the visual display was illuminated at all times except when a duration stimulus was being presented. The stimulus was a dark period, or "dark flash." For the other three Os (Ma., Ji., and Mo.), the visual display was off at all times except when the duration stimulus was presented. The stimulus was a "light flash." The two-alternative forced-choice paradigm (FC) was used. Each trial consisted of the presentation of two sequential duration stimuli. In each block of trials, on half the trials the longer stimulus was presented first, followed by the shorter stimulus (an S_1S_0 stimulus pattern); on the remaining trials, the shorter was first, followed by the longer (an S_0S_1 stimulus pattern). The order of presentation of the two stimulus patterns was determined randomly. Four values of ISI were used, 500, 1,000, 1,500, and 2,000 msec.

Each trial began with a 1-sec auditory warning signal, followed 200 msec later by an S_1S_0 or an S_0S_1 stimulus pattern. The O was then given 2.5 sec to indicate his response by pushing one of two buttons on the arm of his chair. He was instructed to decide whether the first duration was the longer (an R_{10} response) or whether the second was the longer (an R_{01} response). On S_1S_0 trials, a 100-msec auditory signal was presented at the end of the

response period. No signal was presented on S_0S_1 trials. The next trial began 1.1 sec after the end of the response period with the onset of the 1-sec auditory warning signal.

For the dark-flash Os, the duration of the short stimulus (d_0) was 50 msec. The duration of the long stimulus (d_1) was equal to $d_0 + \Delta d$, where Δd was 10 or 30 msec. Thus, there were eight experimental conditions (two values of Δd and four values of ISI). For the light-flash Os, d_0 was 100 msec and Δd was 20 msec, resulting in four experimental conditions.

Each session consisted of five blocks of 100 trials each, with a 1-min rest interval between blocks. During a session, Δd and ISI were constant. Each O ran two sessions under each of the experimental conditions, with the restriction that each condition be used once before any condition was repeated. The first 100 trials in each session were not included in the data analysis.

Results and Discussion

For each O and each condition, $P(R_{10} | S_1S_0)$, $P(R_{10} | S_0S_1)$, and $P(C)$ are presented in Table 1, where

$$P(C) = 1/2 [P(R_{10} | S_1S_0) - P(R_{10} | S_0S_1) + 1]$$

Each value of $P(C)$ is based on 800 observations. In Fig. 1, $P(C)$ is shown as a function of ISI. The line represents the O's mean performance over the four values of ISI for a given value of Δd . The data very clearly indicate that discrimination performance does not decrease with increasing values of ISI for either dark flashes or light flashes. The data from both the dark flash and the light flash duration discrimination tasks are in agreement with the auditory data from Small and Campbell (1962). Variations in ISI from 500 to 2,000 msec do not result in a decrement in discrimination performance.

One possible explanation of the absence of a

decrement in discriminability with increasing ISI is that the O actually ignores one of the stimuli on each trial. Variations in ISI would therefore be an ineffective variable. It has often been suggested in the literature (for example, Harris, 1952; Bull & Cuddy, 1972) that a "roving-standard" design increases the likelihood that the O makes a comparative judgment on each trial. The roving-standard design applied to the FC duration discrimination paradigm means that during any block of trials more than one value of d_0 is used and the O is uncertain as to which d_0 will occur on each trial. Recently, Carbotte (1972) has examined the relationship between duration discrimination performance and ISI, making use of the roving-standard design. Two empty intervals bounded by 10-msec 2,000-Hz pulses were presented on each trial. Six values of ISI (0, 125, 250, 500, 1,000, and 2,000 msec), four values of d_0 , ranging between 115 and 250 msec, and one value of Δd were used. During a session, ISI was constant and d_0 was varied, the four values occurring with equal frequency in each block of trials. Carbotte's results are similar to those of Small and Campbell (1962). Variations in ISI from 500 to 2,000 msec had little effect on performance. For ISIs less than 500 msec, performance is disrupted relative to the fairly constant level for ISIs greater than 500 msec.

It appears that the processing of duration information differs in some fundamental way from the processing of sensory information (for example, amplitude, pitch, movement, position). Lengthening the temporal interval between two duration stimuli which are to be compared does not produce a decrement in discriminability. This is the case for dark flashes, light flashes, empty auditory intervals, and filled auditory intervals. Manipulation of ISI over the same range of values does produce a decrement in other psychophysical discrimination tasks.

A number of duration discrimination studies (e.g., Blakely, 1933; Stott, 1933, 1935; Woodrow, 1951) have reported that for durations briefer than a critical value, d_c , $P(R_{10} | S_1 S_0) > P(R_{01} | S_0 S_1)$, the difference between the two conditional probabilities decreasing as the stimulus durations approach d_c , where d_c is referred to as the time-order indifference duration. For durations longer than d_c , the difference is in the opposite direction, $P(R_{01} | S_0 S_1) > P(R_{10} | S_1 S_0)$, the difference becoming larger as the stimulus durations increase. The difference in the magnitude of the two conditional probabilities is referred to as the time-order error, and the usual interpretation is that for durations briefer than d_c , the duration of the second stimulus is underestimated, resulting in larger values of $P(R_{10} | S_1 S_0)$ than of $P(R_{01} | S_0 S_1)$. For durations longer than d_c , the duration of the second member is overestimated, resulting in larger values of $P(R_{01} | S_0 S_1)$ than of $P(R_{10} | S_1 S_0)$. The exact value of d_c varies widely over studies, and an explanation of the transition of underestimation to overestimation is lacking.

It should be noted that in duration discrimination,

Table 1
Probabilities Summarizing Each Observer's Performance Under Each of the Experimental Conditions: Experiment I

O	d_0	Δd	ISI	$P(R_{10} S_1 S_0)$	$P(R_{01} S_0 S_1)$	P(C)
A.J.	50	10	500	.817	.228	.797
			1000	.771	.194	.888
			1500	.844	.225	.812
			2000	.794	.192	.800
		30	500	.995	.013	.991
			1000	.993	.017	.983
			1500	.993	.020	.887
			2000	.990	.023	.984
S.B.	50	10	500	.698	.310	.694
			1000	.706	.267	.718
			1500	.561	.279	.645
			2000	.613	.197	.707
		30	500	.932	.202	.866
			1000	.917	.080	.919
			1500	.898	.062	.919
			2000	.890	.041	.914
S.M.	50	10	500	.755	.225	.765
			1000	.724	.324	.702
			1500	.798	.273	.765
			2000	.751	.401	.680
		30	500	.963	.041	.961
			1000	.935	.117	.910
			1500	.965	.042	.962
			2000	.948	.067	.941
Ma.	100	20	500	.781	.240	.770
			1000	.789	.189	.800
			1500	.807	.173	.817
			2000	.770	.241	.764
Ji.	100	20	500	.692	.123	.784
			1000	.877	.170	.854
			1500	.828	.186	.821
			2000	.834	.151	.842
Mo.	100	20	500	.965	.053	.956
			1000	.915	.056	.930
			1500	.945	.053	.946
			2000	.942	.063	.940

interest has been in the relationship between stimulus duration and the relative size of the two conditional probabilities. In other discrimination tasks (for example brightness, amplitude, weight), interest has been in the relationship between ISI and the relative size of the two conditional probabilities. It has often been found that $P(R_{01} | S_0 S_1) > P(R_{10} | S_1 S_0)$, the difference increasing as ISI is increased (Woodworth & Schlosberg, 1954).

In "signal detection" language, the interpretation of the time-order error in duration discrimination by Blakely and Stott is a "sensory" one. A response preference explanation is just as plausible. Specifically, it could be argued that the O has a preference for making a R_{10} response at short durations, and that this preference decreases as stimulus duration increases. Kinchla and Allan (1969) and Kinchla and Smyzer (1967) provide detailed discussions about the response preference view of the time-order error in amplitude and movement discrimination.

Table 2
Probabilities Summarizing Each Observer's Performance Under
Each of the 10 Conditions in the Single-Stimulus
Task: Experiment II

O	d_0	Δd	$P(R_1 S_1)$	$P(R_1 S_0)$	$P(C)$
R.M.	50	10	.737	.349	.696
		20	.790	.254	.768
		30	.884	.156	.864
		40	.930	.075	.928
		50	.958	.036	.961
	100	10	.689	.472	.611
		20	.802	.390	.712
		30	.913	.270	.822
		40	.928	.161	.884
		50	.973	.128	.923
S.M.	50	10	.679	.272	.704
		20	.939	.092	.924
		30	.935	.090	.923
		40	.980	.013	.984
		50	.983	.031	.976
	100	10	.583	.413	.585
		20	.698	.281	.695
		30	.885	.184	.851
		40	.908	.096	.901
		50	.968	.061	.954
L.B.	50	10	.768	.326	.721
		20	.879	.147	.866
		30	.960	.071	.945
		40	.965	.025	.970
		50	.990	.018	.986
	100	10	.583	.454	.565
		20	.736	.430	.654
		30	.845	.241	.802
		40	.854	.215	.804
		50	.915	.173	.871

Examination of the appropriate conditional probabilities tabulated in Table 1 indicates that for four of the six Os $P(R_{10} | S_1 S_0)$ and $P(R_{01} | S_0 S_1)$ are about equal for any experimental condition. In general, $P(R_{01} | S_0 S_1) > P(R_{10} | S_1 S_0)$ for S.B., while the opposite is true for S.M. A sensory interpretation of the time-order error would have difficulty incorporating these results. A response preference interpretation would not.

EXPERIMENT II

Method

Six Os participated in this experiment, three of whom (A.J., S.B., and S.M.) participated in Experiment I. Three performed the FC task, three the SS task. The duration stimuli were dark flashes.

For the FC task, the trial structure was identical to that described in Experiment I. ISI was constant at 500 msec.

In the SS task, each trial began with a 1-sec auditory warning signal, followed 200 msec later by an S_1 stimulus or an S_0 stimulus, the two stimuli occurring with equal frequency in each block of trials. The O was then given 2.5 sec to indicate his response, long (R_1) or short (R_0). On S_1 trials, a 100-msec auditory signal was presented at the end of the response period. The next trial began 1.1 sec after the end of the response period.

Two values of d_0 (50 and 100 msec) and five values of Δd (10, 20, 30, 40, and 50 msec) were used. During a session, d_0

and Δd were constant. Each session consisted of five blocks of 100 trials. Each O ran three sessions on each of the 10 combinations of d_0 and Δd , with the restriction that each combination be used an equal number of times before any of the 10 was repeated. Data from the first cycle and from the first block of trials were not included in the data analysis.

Results and Discussion

For each O in the SS task, $P(R_1 | S_1)$, $P(R_1 | S_0)$, and $P(C)$ are shown for each condition in Table 2. Similarly, for each O in the FC task, $P(R_{10} | S_1 S_0)$, $P(R_{01} | S_0 S_1)$, and $P(C)$ are shown in Table 3. In both tables, each value of $P(C)$ is based on 800 observations. In Fig. 2, performance averaged over the three Os in the SS task and over the three Os in the FC task is presented as a function of Δd . On the average, there is little difference in performance between the two tasks.

The absence of a difference in discriminability between the FC and SS tasks could merely be a result of using two groups of three different Os. However, Carbotte (1972), using empty auditory intervals and two d_0 values, 150 and 250 msec, found no systematic differences in discriminability between the two tasks when the same three Os were tested under both tasks.

Examination of Table 3 reveals that in general

Table 3
Probabilities Summarizing Each Observer's Performance Under
Each of the 10 Conditions in the
Forced-Choice Task: Experiment II

O	d_0	Δd	$P(R_{10} S_1 S_0)$	$P(R_{01} S_0 S_1)$	$P(C)$
A.J.	50	10	.838	.191	.824
		20	.958	.041	.959
		30	.988	.010	.989
		40	.988	.010	.989
		50	1.000	.010	.996
	100	10	.580	.370	.605
		20	.761	.199	.781
		30	.903	.082	.911
		40	.962	.035	.964
		50	.998	.016	.991
S.B.	50	10	.681	.252	.736
		20	.835	.245	.796
		30	.922	.110	.906
		40	.894	.096	.899
		50	.960	.029	.966
	100	10	.539	.349	.595
		20	.684	.208	.731
		30	.804	.209	.798
		40	.814	.171	.821
		50	.863	.135	.865
P.H.	50	10	.655	.180	.738
		20	.852	.119	.867
		30	.829	.121	.855
		40	.922	.080	.921
		50	.920	.052	.935
	100	10	.561	.346	.608
		20	.682	.328	.676
		30	.721	.216	.752
		40	.820	.121	.848
		50	.772	.127	.822

$P(R_{10} | S_1 S_0)$ and $P(R_{01} | S_0 S_1)$ are quite similar for any experimental condition.

It is clear from Tables 2 and 3 that, for both the FC task and the SS task, performance for $d_0 = 50$ msec is considerably better than performance for $d_0 = 100$ msec. We have reported previously (Allan et al, 1971) that for light flashes discriminability often was not influenced by a change in d_0 from 50 to 100 msec. Recently, we (Kristofferson, 1973) have presented data which begin to resolve this apparent contradiction. Results from duration discrimination tasks using light flashes and empty auditory intervals appear to support the hypothesis that discriminability is constant for changes in d_0 over certain ranges of d_0 , but changes between ranges. An elaboration of the model for duration discrimination developed in Allan et al (1971) is also discussed in Kristofferson (1973).

CONCLUDING COMMENTS

In this paper, we have presented evidence that indicates two major differences between duration discrimination performance and discrimination performance usually observed in other psychophysical tasks. A decrease in performance was not found with increasing temporal delays between the presentation of two successive stimuli, and the usual difference in level of performance between FC and SS tasks was not observed.

Decision theory discrimination models, when applied to the FC paradigm, usually assume that the O compares the internal representations of the two stimuli presented on each trial (Green & Swets, 1966). This results in two equal-variance distributions of differences, one representing the possible differences on $S_1 S_0$ trials, the other on $S_0 S_1$ trials. The O is represented as adopting a criterion difference, and if the observed difference exceeds the criterion as making an R_{10} response. Such a model predicts better FC than SS performance.

Kristofferson and Allan (1972) and Allan and

Kristofferson (in press) discussed an alternative decision process for the FC paradigm. They suggested that the O adopts a criterion value of the internal dimension, and makes an independent decision after each stimulus presentation. His response on each trial is then based on these two decisions. Such a decision process yields the prediction that, for a fixed criterion, SS and FC psychometric functions should be identical. Furthermore, it could be argued that if the O were making a decision after each stimulus, the time between the two stimuli (ISI) would be unimportant, as long as the O had enough time to make his decision. Thus, qualitatively, a decision theory model incorporating the response comparison decision process would account for the major results of the experiments reported in this paper.

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Fig. 2. $P(C)$ as a function of Δd in Experiment II.

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