THE DISCRIMINATION OF STIMULUS DURATION BY PIGEONS¹

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Pigeons were trained to discriminate the duration of a stimulus. One response in a psychophysical choice situation was reinforced, given the immediately prior presentation of a stimulus duration in one class of durations called short durations, and the other response was reinforced given the immediately prior presentation of a stimulus duration in a second class called long durations. Durations of equal logarithmic difference from the cutoff, whether in the short or long class, yielded equal accuracy. Accuracy was a function not only of the properties of the stimuli to be discriminated, but also of the experimental contingencies used. Accuracy was greater in variable-ratio than in fixed-ratio schedules of reinforcement of the discriminative responses, and was lower at the beginning than later in individual fixed ratios. Proportion of short or long responses (response bias) was affected by sequential dependencies among long and short durations and was effectively controlled through the use of asymmetric reinforcement and fixed-ratio contingencies.

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Discussion

Duration is a discriminable property of stimuli. The discrimination of stimulus duration or temporal discrimination, as it has been called, is implied by differential responding of an organism to stimuli differing along a temporal continuum. Although the concept of

temporal discrimination has had its main use within discussions of the performance of animals on temporally defined schedules of reinforcement, a number of authors have suggested that such a use might be overemphasized. It has been suggested that the dynamic qualities of reinforcement, the schedule of reinforcement, stimulus control, and past history interact with temporal discriminations in affecting time-based measures of schedule performance (Dews, 1962, 1965; Morse, 1966; Reynolds, 1964, 1966).

Only a few studies have employed alternative procedures in which contingencies for one response are conditional on one duration of a stimulus while the contingencies for a second response (or the emission of other behavior) are conditional on a second duration or durations of that stimulus. Cowles and Finan (1941) trained rats to go to one arm of a T-maze if the animal had been restrained for 10 sec in the start-box and to go to the other arm if the animal had been restrained for 30 sec. In several recent studies differential responding was assessed over a continuum of durations (Reynolds, 1966; Reynolds and Catania, 1962; Rilling, 1967).

The present experiments were designed to investigate a psychophysical relationship between durations of a stimulus and choice responding. The work extends previous research in that performances over several continua of

¹A portion of the research served as a partial fulfillment of the requirements for the Ph.D. degree at The George Washington University. The research was performed at the Institute for Behavioral Research and was supported by Grant NsG-450 from the National Aeronautics and Space Administration. Reprints may be obtained from the author, Institute for Behavioral Research, 2426 Linden Lane, Silver Spring, Maryland 20910.

²I am most grateful for the assistance of Drs. Israel Goldiamond and John Thomas throughout all phases of the research, and to Drs. Stanley Pliskoff and Donald Thompson for their helpful critical comments during the revision of the manuscript. Also, I am indebted to Michael Marvin for developing a computer program for analysis of the data.

durations were compared. Further, choice responding in any discrimination task is a function not only of stimulus factors but also of response factors and of the contingencies under which choice responding is maintained. The effects of these two factors on choice responding were assessed and explicitly controlled (Green and Swets, 1966).

METHOD

Subjects

Six adult male White Carneaux pigeons (numbered 7, 8, 9, 10, 11, and 12) were obtained from Palmetto Pigeon Plant, Sumter, South Carolina. They were approximately one year of age at the beginning of the experiments and were maintained at approximately 80 percent of free-feeding weights throughout.

Apparatus

The experimental chambers were two modified Lehigh Valley Electronics pigeon chambers: an LVE Model 1318C and an LVE Model 1519C. Normally, two response keys are mounted 5 in. apart on the response panel of these chambers. For the present studies, a center key was added midway between them. Each key could be individually transilluminated by a stimulus presentation unit, LVE Model 1349QL. The chambers were placed in a darkened room, the observation window of each was covered, and white noise was provided in each.

Experimental sessions were programmed by a system of switching relays and timers. Data were recorded on counters, cumulative recorders, and a 20-pen event recorder. The programming and recording equipment were located in a room adjacent to the experimental room.

Stimulus durations were programmed by a timer (Foringer GP1621) which pulsed a stepping switch. The system was monitored periodically as a safeguard against possible contamination resulting from fluctuation in the programmed durations.

General Procedure

Experimental sessions were scheduled seven days a week. The typical session lasted for 40 reinforcements or approximately 2.5 hr, whichever was completed first. Each session was preceded and followed by a blackout period during which there was no illumination

in the chamber and responding had no programmed consequences.

Initially the center key was transilluminated by an orange light and the two side keys were dark. A response on the center key produced a change from orange to white light on the center key. The center key remained white for a predetermined period of time and then went off automatically, and simultaneously the two side keys were transilluminated. There were 10 discrete durations: 1, 2, 3,, 10 sec. The durations varied nonsystematically from trial to trial. Each duration occurred equally often over a large series of trials (300 to 400 trials). The order was changed at irregular intervals. The duration of the white light and the onset of the side-key stimuli were not dependent on any behavior by the organism. One of the two side keys was transilluminated red and the other green, varied nonsystematically from trial to trial. The contingencies for a "red-key" or "green-key" response depended on the elapsed durations of the white center-key stimulus. The durations were classified into two groups called "short durations" and "long durations". Short durations were 1 to 5 sec, long durations were 6 to 10 sec. Responding on the key of one color was reinforced if the duration had been short and responding on the other was reinforced if the duration had been long. For Subjects 7, 8, and 9, responding to red was reinforced for a prior short duration and green for a prior long duration. For Subjects 10, 11, and 12, the relation between color and duration was reversed. A "correct" response produced a brief conditioned reinforcer or food (Ferster, 1960; Kelleher, 1966). Food reinforcement was presented for every sixth correct choice response; technically this is a fixed-ratio schedule (FR 6). Conditioned reinforcement consisted of a 0.5-sec illumination of the magazine light during which the house light and key lights were turned off. During reinforcement, the feeder light was illuminated and the house light and key lights were turned off. An incorrect discriminative response produced a timeout period during which all lights were turned off and responding had no programmed consequences. Upon the completion of conditioned reinforcement, food reinforcement, or timeout, the center key was transilluminated orange, reinstating the conditions described above for a new trial. A noncorrect

Table 1

The stimulus-response choice matrix for the discrimination of stimulus duration.

STIMULUS ALTERNATIVES	RESPONSE ALTERNATIVES	
	Short Response (Red key for Birds 7, 8, 9) (Green key for Birds 10, 11, 12)	Long Response (Green key for Birds 7, 8, 9) (Red key for Birds 10, 11, 12)
6- to 10-sec durations	M → TO	CD → Reinforcement (FR 6)
1- to 5-sec durations	Q → Reinforcement (FR 6)	FA → TO

$$P(CD) + P(M) = 1$$

$$P(Q) + P(FA) = 1$$

tion procedure was used: whether the animal made a correct or incorrect response, the programmed series of long and short durations advanced to the next duration in the sequence.

The procedure specifies contingencies for four different responses. The contingencies can be summarized in Table 1. After the terminology of Signal Detection Theory (Goldiamond, 1964; Green and Swets, 1966; Swets, 1964) the four responses will be termed (arbitrarily) as follows: a long response (*i.e.*, a response that would be correct if the duration were 6 to 10 sec) given a prior long duration as a correct detection (CD), a long response given a prior short duration as a false alarm (FA), a short response given a prior short duration as a quiet (Q), and a short response given a prior long duration as a miss (M).

EXPERIMENT I: ESTABLISHMENT OF DISCRIMINATION OF STIMULUS DURATION

The experiment was designed to establish choice responding conditional on the duration of a stimulus presented immediately before. Two different training procedures were used to introduce the 10 stimulus durations. In the first procedure, all 10 durations occurred in each session, but the side key for the inappropriate choice was initially dark, then gradually made brighter over several sessions (Pliskoff and Goldiamond, 1966). In

the second procedure the side keys were of equal intensity, but only the shortest and longest durations were initially used. The other durations were introduced after the discrimination was well established for the two durations. The two methods are two discrimination fading procedures (*cf.* Terrace, 1966).

Procedure

Subjects 10, 11, and 12 participated in the first procedure. Pigeon chamber LVE Model 1519C (chamber 1) was used. The subjects were first trained to eat from the food magazine and then responses on the center key were successively approximated with food reinforcement. Next, the following sequence of behavior was established. The center key was transilluminated orange; a response changed the color to white. After a given programmed duration, the center-key transillumination was turned off and one side key was illuminated—the color to be correlated with reinforcement in the later discrimination training sessions. The alternate key was not illuminated. Gradually, over approximately 45 sessions, the intensity of the alternate was increased until it equalled the intensity of the light behind the reinforced key as determined by eye. The subjects were then run until stable behavioral baselines were established. Subject 10 was run for 95 sessions, Subject 11 for 80 sessions, and Subject 12 for 93 sessions. Stability in this case, as well as for all conditions in the ex-

periment, was determined visually. Several changes in the size of the FR were made in order to find an FR value that would maintain behavior and allow the subjects to obtain 40 reinforcements in a session. Accordingly, an FR 6 requirement was adopted. Only correct responses advanced the ratio. Access to food was 5 sec; timeout for incorrect responses was fixed at 30 sec.

Subjects 7, 8, and 9 participated in the second procedure. Pigeon chamber LVE Model 1318C (chamber 2) was used. The differences from the preceding procedure were as follows: initially, the birds were trained only on problems having stimulus durations of either 1 or 10 sec. Both side-key colors in the discrimination component were equal in intensity (judged visually). After approximately 45 sessions the remaining eight durations were introduced. The subjects were then run until stable behavioral baselines occurred. Bird 7 was run 33 sessions, Bird 8 for 46 sessions, and Bird 9 for 46 sessions. The same general contingencies were in effect as for the other subjects except that food was available for 3 instead of 4 sec, and the timeout duration was 60 rather than 30 sec.

Results

Percent of long responses is presented in Fig. 1 as a function of stimulus duration plotted on a logarithmically-scaled abscissa. A higher proportion of long responses was made the longer the duration. Long responses were incorrect (FA) for the 1- to 5-sec durations and correct (CD) for the 6- to 10-sec durations. Correct short responses (Q) are the inverse of FA responses. In terms of accuracy, choice responding was a function of the difference in duration from the cutoff; durations more peripheral from the cutoff were correlated with higher choice accuracies. In the present context the term cutoff refers to the time less than which one choice response is reinforced and greater than which the other choice response is reinforced; for the present task the cutoff lies between 5 and 6 sec. The curves for the birds approximate ogival functions that are truncated at 10 sec.

Birds, 10, 11, 12, and 8 responded in accord with the reinforcement contingencies: these birds emitted a higher proportion of short responses for the 1- to 5-sec durations and a higher proportion of long responses for the

6- to 10-sec durations. For these birds the transition, or duration which occasioned an equal probability of long and short responses, occurred between 5 and 6 sec, and stimuli of equal logarithmic difference in time from the cutoff tended to occasion equal accuracy levels of choice responding (e.g., 3 and 10 sec). That is, choice responding was to some degree a function of the relative rather than absolute difference in time of a duration from the cutoff. This relation, however, broke down for durations near the cutoff, i.e., accuracy tended to be higher for long durations near

Fig. 1. Median percent of long responses (FA, given the 1- to 5-sec durations; CD, given the 6- to 10-sec durations) as a function of the durations to be discriminated. Durations are plotted on a logarithmic scale.

the cutoff (6 and 7 sec) than for short durations (4 and 5 sec).

Birds 7 and 9 differed from the other four birds in that these two emitted relatively more long responses, *i.e.*, a higher proportion of both FA and CD responses. One result was to decrease accuracy for the 1- to 5-sec durations but to increase accuracy for the 6- to 10-sec durations. Total accuracy, or combined accuracy for all durations, for Birds 7 and 9 was within the range of total accuracy levels for the other birds. The higher proportion of long responses was correlated with a transition from predominantly short to predominantly long responses between the 4- and 5-sec durations.

Birds 7, 8, and 9 exhibited predominance of long responses upon the introduction of all 10 durations during training. The relevant results of the training of these birds will be presented to the extent that they relate to stabilized performances.

After being trained with the 1- and 10-sec durations, the birds were presented with all 10 durations. The first session during which all 10 durations were presented can be considered to be a generalization or transfer task, with the exception that the reinforcement contingencies remained in effect (Honig, 1965; Pliskoff and Goldiamond, 1966; Risley, 1964). Long responding for each duration is presented in Fig. 2 for the first session. The three birds

exhibited predominantly long responses, the transition of 50% long responses occurring between the 3- and 4-sec durations for Birds 7 and 8 and between the 2- and 3-sec durations for Bird 9. The transition approximates 3.1 sec, the time that is an equal logarithmic distance between the 1- and 10-sec stimuli on which the animals were trained. The reinforcement and timeout contingencies were programmed with a cutoff based on an equal absolute temporal difference from the two training stimuli. The contingencies did not markedly control choice responding for the "generalization" session; if they had, the transition would have occurred nearer to the 5- and 6-sec durations. Eventually, over a number of sessions, choice responding shifted more in accord with the contingencies; however, Birds 7 and 9 persisted in emitting a relatively higher proportion of long responses.

EXPERIMENT II: VARIATION OF THE STIMULUS DURATION TO BE DISCRIMINATED

The present study was concerned with the effects on the discrimination of varying the cutoff and the length of stimulus durations. The experiment was designed to compare discriminative responding over different ranges of durations.

Procedure

The subjects were Birds 10, 11, and 12. Chamber 1 was the experimental environment.

Once stable behavioral baselines had been established on the discrimination of stimulus durations 1 to 5 sec from durations 6 to 10 sec, the task was changed. The durations of all stimuli were doubled, as was the cutoff. In other words, durations 2 to 10 sec were programmed as short with a response on the green side key being reinforced. Durations 12 to 20 sec were programmed as long with a response on the red side key being reinforced. Once stable performances were obtained for the three subjects, the durations and the cutoff were again doubled. Durations 4 to 20 sec were classed as short and durations 24 to 40 sec were classed as long. To facilitate transition from durations of 2 to 20 sec to durations of 4 to 40 sec, several sessions of 3 to 30 sec were interposed. For the 4 to 40 sec, sessions

Fig. 2. Percent long responses as a function of the durations to be discriminated. Data are from the first session on which all stimulus durations were presented. The session followed training with only durations of 1 and 10 sec. Durations are plotted on a logarithmic scale.

generally lasted beyond 2.5 hr, session length being variable. Session length was increased due to the increased length of the stimulus durations and more importantly due to the increased pausing of the subjects before starting a problem. Once stable performances were observed, the original discrimination task (1- to 10-sec task) was reinstated. Finally, the animals performed on a task involving durations that were equal logarithmic distances from the cutoff: short durations were 1 to 5 sec and long durations were 6, 8, 10, 15, and 30 sec. If durations are plotted on a logarithmic scale, 5 and 6 sec are equal in logarithmic difference from the cutoff; further, 4 and 8 sec, 3 and 10 sec, 2 and 15 sec, and 1 and 30 sec are of equal logarithmic difference. The equating of the pairs of short and long durations is approximate, being equal to the nearest second. Stability in all cases was determined by eye. The number of sessions for each bird for each condition is summarized in Table 2.

Table 2

Number of sessions under the various conditions for Birds 10, 11, and 12.

Stimulus Durations	Birds		
	10	11	12
1 to 10 sec (1-sec steps)	95	80	93
2 to 20 sec (2-sec steps)	78	43	50
4 to 40 sec (4-sec steps)*	101	127	115
1 to 10 sec (1-sec steps)	34	33	34
1 to 30 sec (6- to 30-sec steps match the 1- to 5-sec steps logarithmically)	36	32	39

*Under 4- to 40-sec sessions, approximately 10 sessions were of the transitional task, 3- to 30-sec.

Results

Percent long responses are presented in Fig. 3 as a function of stimulus durations for the 1- to 10, 2- to 20, 4- to 40-sec tasks and for the replication of the 1- to 10-sec task. Stimulus durations are expressed in tenths of the longest duration. Duration 3, for example, is 3 sec in the 1- to 10-sec task, 6 sec in the 2- to 20-sec task and 12 sec in the 4- to 40-sec task. For all tasks the results are quite similar for each bird. The one exception is the performance of Bird 12 for the 4- to 40-sec task; relative to performance under the other tasks, accuracy is somewhat lowered especially at the longer durations. All of the curves, with the one exception for Bird 12, approximate trun-

cated ogives. Accuracy levels were approximately equal for all birds under all tasks at equal logarithmic durations from the cutoff;

Fig. 3. Median percent of long responses as a function of duration to be discriminated. Each stimulus duration is represented in tenths of the longest durations for that task. Durations are plotted on a logarithmic scale.

as was the case in the previous experiment, this relationship broke down near the cutoff. The inconsistencies were in the direction of higher accuracy for long durations as compared with short durations with the result that combined accuracy for long durations was nearly the same as combined accuracy for short durations.

Individual differences over the conditions were apparent. Under the 2- to 20-sec task, for example, Bird 11 exhibited a higher proportion of long responses for all durations relative to its performance under the other tasks. The relatively higher proportion of long responses was also exhibited by Bird 10, but to a lesser degree, for the 1- to 10-sec task replication. It should be pointed out, however, that these small shifts did not affect total accuracy level. The transition of 50% long responding tended to vacillate over tasks between 4.5 and 5.5 durations (in tenths of longest duration). The shift of the transition of 50% long responding, however, was not systematically related to the tasks.

The birds were run under a condition in which long durations were chosen to match to the nearest second durations of 1 to 5 sec in terms of logarithmic distance from the cutoff. The results are presented in Fig. 4. The extension of the range of durations to 30 sec allows for the ogival form of the curves to be more apparent than in the previous results. The results demonstrate further that accuracy was a function of relative rather than absolute difference of a duration and the cutoff. Durations 1 and 30 sec, for example, were respectively 4.5 and 24.5 sec from the cutoff in terms of absolute time but of equal logarithmic differences. Equal accuracy levels were related to equal logarithmic differences from the cutoff.

The possibility exists that the general findings of the effects of stimulus duration on accuracy might have been affected by certain sequential aspects of the task. Nevin, Cumming, and Berryman (1963) found, for example, that accuracy was lower for the first trials of a matching-to-sample task when compared with accuracy for trials just before reinforcement. Signal detection research with humans (Green, 1964; Green and Swets, 1966) and psychophysical research on human "time estimation" (Treisman, 1963) have found that responding is sometimes dependent to a small

degree on prior responding or prior stimuli. A computer analysis was made of data combined over a number of sessions of the replications of the 1- to 10-sec task in order to assess accuracy over the fixed ratio and to assess possible effects of prior problems on choice responding. Data are from 3480 trials for Bird 10, 3157 trials for Bird 11, and 5146 trials for Bird 12.

Percent long responses as a function of stimulus duration is presented for the first and last positions of the fixed ratio in Fig. 5. There were six FR positions; a correct response advanced one position, an incorrect response did not. The three birds exhibited a lower proportion of long responses for durations 1 to 5 sec and a higher proportion of long responses for durations 6 to 10 sec for the last FR position as compared with the first. This finding indicated a higher relative accuracy at all durations for the final FR response. The ogival form of the functions for the birds was not apparent with first-position choice responding. Percent of long responses for stimulus durations in the positions not presented lies between the two functions shown in Fig. 5 being more similar to performance in the last FR position. The effects of FR position on accuracy were not selective; all stimulus durations were affected.

Fig. 4. Median percent of long responses as a function of stimulus duration. Long durations (6, 8, 10, 15, and 30 sec) matched the short durations (5, 4, 3, 2, and 1 sec respectively) in logarithmic distance from the cutoff to the nearest sec. Durations are plotted on a logarithmic scale.

Choice responding was assessed as a function of second-order sequences of stimulus durations. Percent of long responses was calculated for each duration as a function of the

preceding duration, such that a comparison could be made of choice responding on any trial given a prior trial of either short or

Fig. 5. Median percent of long responses as a function of stimulus durations for two positions of an FR 6 schedule of reinforcement: the first positions and the sixth or last positions. Durations are plotted on a logarithmic scale.

Fig. 6. Median percent of long responses as a function of stimulus duration given a prior duration of either the short (1- to 5-sec) class or the long (6- to 10-sec) class. Durations are plotted on a logarithmic scale.

long duration. The results are presented in Fig. 6. For Bird 10, the data show that for all durations a relatively higher percentage of long responses occurred if the preceding stimulus duration had been long rather than short. Given a prior long stimulus duration the result was to enhance accuracy slightly if the present duration were also long but to decrease accuracy slightly if the present duration were short. The same relationship also held for short durations, *i.e.*, higher accuracy for a short duration given a prior short duration but lower accuracy for a long duration given a prior short duration. The results for Bird 11 and Bird 12 were similar to the results of Bird 10, though not as clear. For all three birds the effects were small. The effects of a stimulus duration on responding in the presence of the following duration held for all durations. The effects did not appear to any greater or lesser degree for certain durations, such as durations near the cutoff.

The observed probability of occurrence of the four classes of duration sequences was close to an equal probability of occurrence, $p = 0.25$. The observed probability of occurrence ranged over the three birds between 0.220-0.227 for a short duration given a prior short duration, 0.261-0.262 for a short given a prior long, 0.261-0.263 for a long given a prior short, and 0.250-0.255 for a long given a prior long. The observed probability of occurrence of sequences of durations was not correlated with the observed sequential behavior pattern: there was not a relatively greater proportion of occurrences of a duration following a duration in the same class.

Although the study of choice responding as a function of duration was the main aim of the present experiment, two other aspects of the birds' behavior on the task are of related interest: latency of responding, and behavior in the presence of the stimulus durations to be discriminated.

The animal was required to respond on the center key to initiate the stimulus duration. Cumulative latencies to initiate the stimulus duration are presented for Bird 10 in Fig. 7. Pausing before initiating the duration increased markedly as the mean duration of the set of durations to be discriminated in a task increased. Further, the longest pauses occurred after a reinforcement, or, stated differently, at the beginning of the FR. The

performance of Bird 10 was similar to the performances of the other two birds. Different choice latencies were not exhibited in the discrimination component. Neither position of the FR nor the average length of the duration to be discriminated noticeably affected latency of choice responding.

Responding in the presence of the stimulus duration to be discriminated had no programmed consequences; termination of the stimulus component was independent of behavior. It was possible for responding in the presence of the stimulus duration component to be reinforced "accidentally" by the onset of the following component and to be maintained superstitiously (Herrnstein, 1966; Morse, 1955; Skinner, 1948). An analysis was made of responding in the presence of the stimulus duration. Responding was maintained throughout the course of the ex-

Fig. 7. Portions of cumulative records for Bird 10 under the different experimental tasks. The cumulative recorder motor ran only during the start component of a trial, *i.e.*, until the animal responded to initiate the stimulus duration. Each correct response stepped the pen. Downward pips indicate reinforcements. Each record was taken from one of the last nine sessions of each condition. The record in the upper left-hand portion is from the first discrimination of the 1- to 10-sec task.

periment, but responses occurred so infrequently that number of responses definitely was not correlated with choice responding. Visual observation of the birds during the stimulus duration component showed the birds to be active, but no systematic modes of behavior that could be related to choice responding were observed.

EXPERIMENT III: CONTROL OF ACCURACY AND RELATIVE PROPORTION OF LONG RESPONSES

In the previous experiments, choice responding was a function of the relative distance of a duration from the cutoff in time. However, choice responding was a function of several other factors. Accuracy was a function of the proximity of a problem to food and relative proportion of long responses over all durations was to a small degree a function of the class (long or short) of the prior problem. The present study was designed to use procedures to control both accuracy and the relative proportion of long responses by contingency manipulations.

Procedure

The subjects were Birds 7, 8, and 9. The experimental chamber was chamber 2.

Reinforcement and FR reset contingencies were used to control relative proportions of long responses over all durations (Ferster and Hammer, 1966). The birds performed on the FR schedule described previously with the following changes for two procedures. For the first, correct and only correct responses (CD and Q) counted toward food reinforcement. However, only CD responses produced a conditioned reinforcer. For Q, the 0.5-sec presentation of the magazine light was omitted. False-alarm responses produced a new problem. Incorrect responses given a long duration (M) produced a reset of the FR 6. A stimulus was added making the reset a discriminated event. The center key illumination was blue, rather than orange, for the first problem of the FR sequence. Once stable baselines were observed the contingencies were reversed. All correct responses counted toward food. Only Q responses produced the conditioned reinforcer while FA responses reset the FR requirement. Both CD and M responses simply produced a new problem.

After completing the above procedure the birds were placed on a variable-ratio (VR) schedule. On the average, every tenth correct response was reinforced with food; the range of trials between reinforcements was 1 to 32. Correct responses, other than those reinforced with food, produced the conditioned reinforcer; incorrect responses produced a 7.5-sec timeout. Once stable performance was observed, three procedural modifications were employed in an attempt to lower the relative proportion of long responses. The first change eliminated the conditioned reinforcement contingency for CD; all other contingencies remained the same, except that the timeout value was reduced to 0.5 sec. The second change eliminated food reinforcement for CD; though CD responses counted toward food, they were reinforced with neither food nor conditioned reinforcement. Thus, only Q responses produced conditioned reinforcement and food reinforcement. Both FA and M produced a 0.5-sec timeout. The third change reinstated conditioned reinforcement for CD responses, but only Q responses were reinforced with food.

Table 3 presents the order in which the subjects received the conditions and the number of sessions for each condition. In all cases stability was determined by eye.

Table 3

Number of sessions under the various experimental conditions for Birds 7, 8, and 9.

	7	8	9
CD and Q—food (FR 6)			
CD—conditioned reinforcement	13	13	16
M—FR reset			
CD and Q—food (FR 6)			
Q—conditioned reinforcement	12	12	12
FA—FR reset			
CD and Q—food (VR 10)	22	22	22
FA and M—TO			
CD and Q—food (VR 10)	12	12	13
Q—conditioned reinforcement			
FA and M—TO			
Q—food (VR 10)			
Q and CD—conditioned reinforcement	14	14	14
FA and M—TO			
Q—food and conditioned reinforcement (VR 10)			
CD—new duration	12	11	11
FA and M—TO

Fig. 8. Median percent long responses as a function of the duration of a stimulus. In the left-hand portion are curves for Birds 7, 8, and 9 under two sets of asymmetric payoff contingencies, given an FR schedule of reinforcement. In the right-hand portion are curves for the three birds under one set of symmetric payoff contingencies and three asymmetric sets, given a VR schedule. Durations are plotted on a logarithmic scale.

Results

The effects of the contingency manipulations on both accuracy and relative proportion of long responses are presented for the three birds in Fig. 8. In the left-hand portion are performances under the FR schedule; the right-hand portion shows performances under the VR schedule. Considering performances under the FR schedule first, manipulations of conditioned reinforcement and reset contingencies affected the relative proportion of long responses. The effect of the two sets of contingencies was to shift the ogival functions. One aspect of the shift was a 2- to 3-sec change in the transition of 50% long responses from the 2- to 4-sec durations to the 6- to 7-sec durations. A second aspect of the shift was different asymptotic accuracy levels for the two sets of contingencies. A comparison of percent long responses at each duration between the results presented in Fig. 8 and the corresponding curves for each bird presented in Fig. 1 shows that percent long responses under the original training conditions generally lie between the two percent levels of Fig. 8 at all stimulus durations.

Under the VR schedule, for the condition for which there were no differential contingencies for long or short responses (only for correct vs. incorrect), accuracy levels were higher than the accuracy levels recorded under the FR schedule. The high degree of accuracy was evidenced by the following: zero percent long responding at duration 1 sec as well as an extremely low percent of responding at durations 2 and 3 sec; a steep slope of transition from short to long responding; and a high proportion of long responses at durations 8 to 10 sec. Percent long responses were lower at the extreme short durations under the VR schedule in comparison with the FR schedule with the contingencies of conditioned reinforcement for Q and reset for FA; and, percent long responses were higher at the extreme long durations in comparison with the FR schedule with the contingencies of conditioned reinforcement for CD and reset for M.

Under the conditions in which both CD and Q counted toward food, but only Q responses produced the conditioned reinforcer, a relative shift in long responses did not occur; the only effect was a possible slight dec-

rement in accuracy which is indicated by slightly less-steep curves, especially for Bird 8.

Under the conditions in which only Q responses were reinforced with food, but both CD and Q occasioned conditioned reinforcement, percent of long responses decreased radically. Considering durations 1 to 5 sec together the birds were correct above 95%, but considering duration 6 to 10 sec together the birds were correct only 13 to 33% (Bird 9 and Bird 8 respectively). Even at duration 10 sec none of the birds responded long even 50%.

When only Q responses produced either the conditioned reinforcer or food and CD responses simply counted toward food, the proportion of long responses decreased further. One obvious effect of both this condition and the previous one is to lower total accuracy, even below the total accuracy level of the birds under the FR conditions.

DISCUSSION

In the present series of experiments, pigeons were trained in a psychophysical choice procedure to discriminate stimulus duration. Choice responding was assessed and controlled in relation to three aspects of the experimental situation. First, choice responding was a function of the stimulus dimension: accuracy of responding was a function of the relative difference in time between a stimulus duration and the cutoff. Second, choice accuracy could be shifted for all durations as a function of the experimental contingencies. Third, the proportion of choice responses of the two classes, long and short, was shifted as a function of sequential aspects of the schedule, possibly past history, and manipulations of the experimental contingencies. These three aspects of choice responding will be discussed in turn.

The present method is comparable to the psychological method of single stimuli (*cf.* Guilford, 1954; Wever and Zener, 1928) with the addition in the present situation of explicit response contingencies. Within the framework of psychophysical, it is possible to make statements regarding the "sensory performance" of the animals over the range of durations studied. The results of choice responding over several ranges of durations (Fig. 3 and 4) showed a very high degree of similarity. The high degree of similarity indi-

cates equal sensitivity of performance over the ranges of stimuli employed. Computations of a difference limen (*cf.* Guilford, 1954; Treisman, 1963) yield a constant Weber fraction for the birds. Also a method of computing d' as a measure of sensitivity (Treisman and Watts, 1966; Green and Swets, 1966) yields equal sensitivity within a signal detection framework. The data of the present study can be compared with psychophysical data on human temporal discrimination (Creelman, 1962; Treisman, 1963; Wallace and Rabin, 1960) but any comparison is a result in part of the contingencies under which the sensitivity measure was established. For comparison, the data for Birds 7, 8, and 9 under the VR symmetric payoff contingencies were used. Using the method for calculating a Weber fraction (Treisman, 1963) one arrives at a fraction ranging around 0.25 for the birds; that is, a difference in duration of 0.25 from the duration of 50% long responses was the measure of the "just noticeable difference."³ This figure compares with figures ranging from 0.03 to 0.17 for humans (Treisman, 1963). The results of studies on humans vary due to different procedures; different ranges of durations, and different methods of computing a Weber fraction. Perhaps a reasonable estimate for humans would lie around 0.08 to 0.12 for comparative purposes (*cf.* Treisman, 1963).

Choice accuracy was not only a function of the difference between a duration and the cutoff but also of the experimental contingencies. Accuracy for all durations was lower at the beginning of the FR schedule than at the end (Fig. 5) and accuracy was lower for all durations for the FR schedule than for the VR schedule (Fig. 1 and 8). Changes in accuracy of choice affected all durations in roughly the same manner; change in percent correct was approximately constant over durations.

One effect of the changes in accuracy as a result of the contingencies was a shift in the

asymptotic level of accuracy. For example, the asymptotic level of performance of the birds under FR contingencies was above 90%, whereas the asymptotic level of performance under VR contingencies clearly reached 100%. The high degree of correlation of changes in sensitivity and asymptotic level of accuracy at the extreme durations allows one to use asymptotic performance as an index of the degree of control by the contingencies. The use of such an index serves to separate the effects of contingencies and the stimulus dimension.

The effects of contingency manipulations on measures of sensitivity represent a problem area which generally is not considered in human psychophysical research. Normally, sensitivity measures remain relatively constant given changes in the experimental procedure. The present results, coupled with the results of studies on conditional discriminations in animals, demonstrate that the experimental contingencies as well as the stimulus dimension affects the animals' choice accuracy or sensitivity (*cf.* Miller, 1966, for related findings with humans).

The present results replicate the findings of matching-to-sample research on color discriminations (Cumming and Berryman, 1965; Nevin *et al.*, 1963). The results of matching studies showed that accuracy is relatively lower at the beginning of an FR schedule than at the end and that VR accuracy is higher than FR accuracy.

The third aspect of choice responding that was assessed and controlled in the present experiment concerned the relative proportion of long and short responses. This aspect is related to the "constant error of judgment" of classical psychophysics (Guilford, 1954) and "shifts in response criterion" and "response bias" of signal detection research (Goldiamond, 1962, 1964; Green and Swets, 1966). For the remainder of the discussion the term response bias will be used. Response bias refers to a relatively greater proportion of one class of responses in a choice procedure. As used, the term is simply descriptive, like the term accuracy. In the present situation a response bias is indicated by a relatively greater proportion of long (or short) responses than short (or long) responses. Such a bias might be observed over all durations or just a few, such as those near the cutoff.

³The measure for the Weber fraction is $\Delta T/T$, with the standard deviation of % long responses used to calculate ΔT , and the transition of 50% long responses (point of subjective equality) used as T . The measure contrasts with a second measure, in which ΔT is calculated by the difference between the first and third quartiles of % long responses. The use of the standard deviation measure gives a Weber fraction roughly two thirds the fraction obtained using the quartile measure (Guilford, 1954).

A number of instances of response bias were observed in the present experiment. These instances resulted from several factors.

In comparing the performances of different birds (Fig. 1) and the performances of Birds 10, 11, and 12 over the various ranges (Fig. 3) a number of cases of response bias were observed; these cases were both shifts in relative proportion of long responses over all durations and for durations near the cutoff. Shifts in relative proportion of long responses are not surprising since the observed response biases were not correlated with changes in overall accuracy level. For example, an increase in proportion of long responses for all stimulus durations lowers accuracy for durations of the short class but correspondingly raises accuracy for durations of the long class.

A result correlated with shifts in response bias was that the transition of 50% long responses shifted away from expected transition which lies between 5 and 6 sec. In all cases the observed shift was a shift in the transition below the 5-sec stimulus duration. Such shifts were correlated with either a relative bias over all durations or just the durations near the cutoff. It will be recalled that accuracy was a function of relative difference of a duration and the cutoff. Given that choice responses were a function of relative duration, one effect of the linear array of stimuli was to make the long durations relatively closer to the cutoff, or stated otherwise, to make the long duration relatively more "difficult". Thus, if discriminations were strictly a function of the logarithmic difference from the cutoff one would expect accuracy of responding for the long durations combined to be lower than accuracy for the short durations combined. But the observed combined accuracies for responses to long as compared with short durations were approximately equal. In effect, responding as a function of relative difference from the cutoff tended to give way to a tendency to respond long near the cutoff, and thereby equalize the total number of short and long responses. Equalization of different classes of responses was noted by Treisman (1963) in a study involving humans discriminating duration under the method of single stimuli.

Shifts in response bias were observed as a result of contingency manipulations under both FR and VR schedules (Fig. 8). By proper manipulations, the proportion of long re-

sponses was shifted and to a greater or lesser degree. Although accuracy was higher on the VR schedule, it was possible to manipulate the contingencies in such a manner that the observed increase in short responses was so great that total accuracy level fell below the total accuracy level obtained under the FR schedule. The present findings parallel the findings of signal detection research that asymmetrically arranging the reinforcement contingencies or payoff matrix result in changes in response factors rather than sensitivity (Green and Swets, 1966). Contingency manipulations resulted in corresponding increases or decreases in the proportion of FA and CD responses, while sensitivity as measured by accuracy (in a Weber fraction or d') remained constant. However, severe shifts in bias, as were observed under the VR schedule, were correlated with a decrease in measures of sensitivity (*cf.* Miller, 1966).

The results of two aspects of behavior were presented in order to study the possible relation to choice behavior.

First, key pecking and other behaviors during the stimulus duration to be discriminated were analyzed, but no systematic modes of behavior that could be related to choice behavior were observed. This result differs in one sense from the results of a study by Rilling (1967). Rilling based a conditional discrimination on the duration of one of two fixed-interval (FI) schedules and found that choice responding was correlated with the number of responses emitted in the presence of the FI schedules to be discriminated. That Rilling's birds did use number of responses as a mediating cue, but the present birds did not, probably is a function of the different procedures. The birds in Rilling's study emitted responses to terminate the FI and present the two-choice stimuli. In the present study the birds had no response requirement to end the stimulus duration and present the choice stimuli.

Second, latency of responding to start a problem was examined. The cumulative records (Fig. 7) are similar to those for animals on single FR schedules (Ferster and Skinner, 1957) and for birds matching-to-sample on an FR schedule (Ferster, 1960). The long pause at the beginning of the FR was correlated with lower accuracy at the beginning, which replicate matching-to-sample results (Cumming and Berryman, 1965). When mean duration of the

stimuli to be discriminated was increased, pausing before starting a problem increased considerably; but, with one exception, the increased pausing was not correlated with an increase in errors of discriminative responding. As can be inferred from the cumulative records (Fig. 7) pausing led to a marked reduction in frequency of reinforcement, yet accuracy was maintained. However, the breakdown in accuracy of Bird 12 on the 4 to 40 tasks suggests that if the durations are sufficiently long and pausing becomes extreme, accuracy level might decrease (Ferster, 1960).

The present choice procedure of assessing temporal discrimination offers several advantages over procedures employing time-based measures. Rate and patterns of responding under temporally defined schedules of reinforcement have been used to infer temporal discrimination. As Morse (1966) has argued, the greatest difficulty in relating behavior under such schedules to temporal discrimination is that many other variables interact and that the interactions are of such complexity and so little understood that the use of the concept of temporal discrimination is premature. Frequency and amount of reinforcement, stimulus control, prior responding, punishment, and schedule of reinforcement may interact. The effects of other factors have been considered so great that Dews (1962, 1966) has assigned temporal discrimination a negligible role in FI performance. The dangers of premature use of the concept of temporal discrimination are exemplified by the contradictory findings that pigeons' characteristic performance is "poor" on DRL schedules yet "good" on interval schedules (Reynolds, 1964). The difference in performances must be considered the result of number of factors. In contrast, the present procedure isolated the effects of interacting variables to be found in procedures employing time-based measures. Thus, in the present situation the effects of schedules of reinforcement, sequential effects, and contingency manipulations on the discrimination could be assessed and isolated.

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Received 20 July 1967.