SCALING OF STIMULUS DURATION BY PIGEONS¹

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Pigeons were presented with a series of key-illumination time periods. During these periods two response keys were lit, one by white light and the other by red or green. White-key responses changed the color on the other key and green- and red-key responses intermittently produced food. Choice responses were reinforced at either of two intervals timed from the onset of the stimulus period. Food was scheduled for green responses during the shorter interval in some stimulus periods and food was scheduled for red-key responses at the longer interval during alternate stimulus periods. The temporal location of food in the stimulus periods was varied across conditions. Across conditions, the pigeons responded on the green key until the time at which green-key responses might be reinforced had passed; then, the probability of red-key responses increased as the time approached at which red-key responses might be reinforced. In all conditions, the pigeons, changed from green-key to red-key responses at the time that was an equal relative temporal distance from the two intervals where these responses were reinforced.

Key words: stimulus duration, animal psychophysics, scaling, temporal discrimination, fixed interval, schedule of reinforcement, choice procedure, pigeons

Explanations of schedule performance have often included discussions of the role of the temporal properties of stimuli (*e.g.*, Catania, 1970; Staddon, 1972, 1974). Due to the interest in temporal stimulus control, various experiments have studied the discrimination of stimulus duration by animals (*e.g.*, Catania, 1970; Snapper, Ramsay, and Schoenfeld, 1969; Stubbs, 1968). For example, Stubbs trained pigeons on a psychophysical task. A keylight was presented on different trials for durations ranging from 1 sec to 10 sec; following the stimulus duration a choice response was made. One choice response was reinforced if the stimulus duration had been 1 to 5 sec; a second response was reinforced if the duration had been 6 to 10 sec. The results showed that the probability of a "long" response increased as an ogival function of stimulus duration.

Like previous research, the present study was designed to study the effects of stimulus duration on behavior. However, this study was not directly concerned with discrimination of duration, but rather with scaling per-

formance along a temporal dimension. (See Zuriff, 1972, for a general discussion of scaling in animals.) In discrimination tasks such as that of Stubbs (1968), different durations have been presented, with different responses being reinforced depending on those durations. In contrast, the present subjects were given long time periods but responses were reinforced only at two durations. The question was how responding would be affected at other times where reinforcement never occurred. Specifically, what if one response was reinforced at a short duration and a second response was reinforced at a long duration; what would happen to choice responses at intermediate durations? At what duration would the animals change from responding "short" to responding "long"?

Previous research on the discrimination of stimulus duration (Behar, 1963; Catania, 1970; Stubbs, 1968), as well as research on schedules of reinforcement (*e.g.*, Gibbon 1972; Jenkins, 1970; Killeen, 1970), suggests that animals respond to relative, rather than absolute, differences between stimuli in time. For example, Stubbs (1968), as part of the discrimination of duration tasks, trained some pigeons the following way. One response was reinforced if the prior stimulus duration had been 1 sec; the alternate response was reinforced if the

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duration had been 10 sec. Following this training, durations between 1 and 10 sec were introduced. The probability of a "long" response increased as stimulus duration increased. More important, the probability of a "long" response was 0.50 at approximately 3 sec, suggesting that choice behavior was a function of the relative temporal relations among stimuli (*i.e.*, $\frac{1}{3}$ approximates $\frac{3}{10}$).

The major purpose of the present study was a more complete examination of pigeons' behavior along a temporal dimension to provide psychophysical evidence bearing on these suggestions.

METHOD

Subjects

Three adult male White Carneaux pigeons were maintained at 80% of their free-feeding weights throughout the experiment. All three had experimental histories.

Apparatus

The experimental chamber was similar in design to that described by Ferster and Skinner (1957). Two response keys (Ralph Gerbrands Co.) were mounted 50.8 mm apart, center to center. A force of 0.15 N (15 g) was required to operate each key. The keys were transilluminated by different lights from display units (Industrial Electronics Engineer). Food was delivered by an automatic feeder (Lehigh Valley Electronics).

Sessions were arranged by relay circuitry. Data were recorded by counters, a cumulative recorder, and a print-out counter.

Procedure

Experimental sessions, conducted daily, lasted until a pigeon received 50, 3-sec presentations of food. Each session contained a series of stimulus time periods during which both response keys were transilluminated. At the beginning of each stimulus period, the left key was transilluminated by green light, the right key by white. A right-key (changeover key) response changed the color on the left key from green to red; additional responses would alternate the color. Left-key (main key) responses produced food according to the following restrictions. Left-key responses in the presence of green could produce food at one interval after keylight onset and responses in

the presence of red could produce food at a second interval. During each stimulus period, food was scheduled to be available either at the short interval or at the long, but not both. Whether responses could produce food at the short or long interval was scheduled by a 33-position stepping switch that stepped from stimulus period to stimulus period. Food was scheduled to occur equally for green-key (short) and red-key (long) responses. The first appropriate response during an interval of food availability would produce food. If, for example, food was scheduled at the short interval of 2 to 4 sec, the first green-key response between 2 and 4 sec after the onset of stimuli would produce food. If food was produced, the keylights went off and the magazine light was turned on for the 3-sec food cycle; following food, a new stimulus period began. If food was not produced during either the short or long interval, the keylights were turned off automatically for 10 sec at the end of the long interval and then a new stimulus period began. Food would not be produced if a pigeon failed to emit an appropriate response during the period of reinforcer availability.

The length of the stimulus periods and the particular intervals at which food was available were varied across conditions. Table 1 shows the experimental conditions in order of occurrence. In Conditions 1 to 3, the keylights were on for a maximum of 64 sec; in Conditions 4 to 7, for a maximum of 48 sec, and in Condition 8 for a maximum of 160 sec. For purposes of recording and scheduling reinforcement intervals, the stimulus periods were divided into 16 time classes. Thus, the first three conditions were divided into 16, 4-sec time classes, the next four into 16, 3-sec time classes, and the last condition into 16, 10-sec time classes. In each condition, food was scheduled during one time class for green-key responses and during a second for red-key responses. Table 1 shows both the time in seconds and the time class at which food was available. For example, green-key responses could produce food between 8 and 12 sec and red-key responses could produce food between 60 and 64 sec. The 8 to 12-sec interval is the third time class, the 60 to 64-sec interval is the sixteenth. Across conditions, green-key responses produced food in time classes between one and nine; red-key responses always produced food in the sixteenth time class. If food

Table 1

Summary of experimental conditions (in order) for Pigeons 57, 86, and 60, and the number of sessions under each condition. Time in seconds and time class (in parentheses) following onset of stimuli when food was potentially available.

Conditions	Green-Key (Short)	Red-Key (Long)	Number of Sessions
1	2- 4 sec (1)	60- 64 sec (16)	39
2	8-12 sec (3)	60- 64 sec (16)	30
3	16-20 sec (5)	60- 64 sec (16)	22
4	12-15 sec (5)	45- 48 sec (16)	15
5	9-12 sec (4)	45- 48 sec (16)	28
6	6- 9 sec (3)	45- 48 sec (16)	22
7	24-27 sec (9)	45- 48 sec (16)	31
8	30-40 sec (4)	150-160 sec (16)	18

Note: The numbers in parenthesis are the time classes (1 to 16) at which reinforcement is available; under Condition 1, a reinforcement was available only for the second half of the time class of 0 to 4 sec.

was not produced during either interval, the stimulus period ended at the end of the sixteenth time class.

The criterion for change of conditions was visual: conditions were changed when no systematic trends appeared in the data for at least five sessions. The one exception was the last condition, which terminated automatically the day I moved from Maryland to New York.

RESULTS

Figure 1 shows the probability of a red-key (long) response as a function of time class across the various conditions. The time-class scale is ordered logarithmically. The data are medians of the last three sessions for each condition. Probability data were calculated by dividing the number of red-key responses by the total number of responses (red-key plus green-key) at each time class. All responses were used for the daily calculations, including those responses in stimulus periods that ended "early" due to reinforcement of green-key responses, and those during stimulus periods where food was "missed". The total responses differed across time classes because of these factors and because of response-rate changes during the stimulus periods.

The probability data are shown as a function of time classes, rather than time in seconds, for ease of comparison across conditions. Green-key (short) responses were reinforced at the time classes indicated by arrows, classes 1,

3, 4, 5, and 9. Red-key responses were reinforced in all conditions at class 16. Probability data at class 16 are not shown because so few responses occurred: whenever the sixteenth time class occurred, typically only one response was emitted, the response that produced food.

Figure 1 shows that the probability of a red-key (long) response increased from zero to or close to 1.0 across all conditions. The probability remained near zero until the time at which green-key responses were reinforced had elapsed, and then the probability increased. Comparisons of conditions in which time-class intervals differed (3 sec *versus* 4 sec, 3 sec *versus* 10 sec) show that the pattern of responding generally was similar. There was, however, less similarity when the time-class interval was 10 sec than when it was 3 sec or 4 sec. The similarity indicates that the relative, rather than absolute, difference in time was the more important determinant of choice responding. When, for example, responses were reinforced at classes 5 (short) and 16 (long), performance was similar despite the fact that responses were reinforced at 16 to 20 sec and 60 to 64 sec in one condition (a difference of 44 sec) but reinforced between 12 to 15 sec and 45 to 48 sec in the other (a difference of 33 sec).

The probability data were used to calculate the point at which the probability of a red-key (long) response was 0.50. The measure describes the point at which red-key and green-key responses occurred equally. Since the probability often was less than 0.50 in one time class but higher than 0.50 in the adjacent class, the points had to be estimated. The data were calculated by the linear interpolation method (Guilford, 1954). Figure 2 shows the data across conditions.

Figure 2 shows the time at which the red-key probability was 0.50 as a function of the geometric mean of the two time classes where food occurred. The geometric mean was calculated by the formula

$$\sqrt[n]{(X_1)(X_2)},$$

where n equals the number of intervals, in this case two, and X_1 and X_2 equal the short and long intervals (specifically the lower bounds). When, for example, responses were reinforced at 2 sec (green-key) and 60 sec (red-key), the geometric mean approximated 11 sec; when responses were reinforced at 6 and

45 sec, the geometric mean approximated 16 sec.

The three points for each condition show data for each of the last three sessions. Figure 2 shows that the points tended to lie along the lines for each subject. The lines are drawn through those points at which the 0.5 probability would equal the geometric mean. That the obtained points approximated the lines

indicates that the 0.5 probabilities tended to occur at or near the geometric means. The data show that the subjects tended to respond equally to the two choice stimuli at the time that was an equal relative distance from the two classes where food was presented. Equal choices did not occur at times that were an equal distance in linear time. For example, the time that was equally different in linear

Fig. 1. Probability of a red-key (long) response as a function of time class across conditions. The data are medians of the last three sessions under each condition. The arrows indicate the class at which green-key responses were reinforced. The abscissa is ordered along a logarithmic scale.

Fig. 2. Time in seconds at which the probability of a red-key response equalled 0.50 across conditions. The numbers in the abscissa indicate the geometric means of times at which green-key and red-key responses were reinforced. The lines indicate the locus of points when the 0.50 probability equalled the geometric means. The points are for each of the last three sessions under each condition. Both the ordinate and abscissa are ordered logarithmically.

time from 2 sec and 60 sec was 29 sec. Since the observed points approximated 11 sec, the data are 18 sec shorter than would be expected if choice responding was a function of the linear difference.

The present experiment employed a free-operant procedure. Accordingly, measures other than the probability data were available, and are instructive for demonstrating how the temporal location of food controlled the rate and pattern of responding. Figures 3, 4, and 5 show these data.

Figure 3 shows representative cumulative records for Pigeon 57. The records were taken from the first, fourth, seventh, and eighth conditions. Each response on the left (main) key stepped the response pen whether the key color was green or red. Responses on the changeover key controlled the event pen: the event pen was up when the left key was green, down when the key was red. The occurrence of food is indicated by downward deflections of the response pen. The response pen reset after a food presentation or a timeout.

The upper record shows the following pattern of responding. The pigeon would begin a time period by responding at a high rate in the presence of green. Green-key responses produced food during some time periods but not others. When green-key responses did not produce food, the pigeon continued to respond for some time and then a pause occurred. Once the pause had occurred, the subject would then emit one response on the changeover key, changing the main-key color from green to red. Then, the animal would begin responding on the now red-key until either food or a timeout occurred. The second record shows a similar pattern of responding with two differences. First, following the onset of the keylights, there generally was a slight pause before responding began. Second, when green-key responses were not reinforced, the pause during the interval (correlated with the changeover response) became less pronounced. In the third record, pauses at the beginning of a time period became more pronounced, while pauses in the middle of an interval were no longer evident. The changes in performance in the top three records undoubtedly resulted from the placement of food in the intervals. In the top record, food was available 2 sec after keylight onset, in the second record 12 sec, and in the third record 24 sec. Locating

food further in time from the keylight onset would be expected to produce greater pausing. Also, this change in time of food availability made the short and long reinforcement intervals closer in time, which would tend to eliminate pausing near the end of an interval.

The bottom record shows performance when

the time periods lasted a maximum of 160 sec. The performance was similar to that shown in the other records, though less regular. The most striking change in performance was that now multiple changeover responses occurred during a stimulus period, rather than just one as in the other conditions.

PIGEON 57

FOOD AT 2-4 SEC OR 60-64 SEC

FOOD AT 12-15 SEC OR 45-48 SEC

200 RESPONSES

FIVE MINUTES

FOOD AT 24-27 SEC OR 45-48 SEC

FOOD AT 30-40 SEC OR 150-160 SEC

Fig. 3. Cumulative records for Pigeon 57. Each response on the left key stepped the response pen. The event pen indicates the color in the left key, up for green, down for red. Deflections of the response pen indicate food presentations. The response pen reset following food or a timeout. The recorder motor operated except during food cycles and timeout periods.

The performance of Pigeon 57 was representative of the other two subjects. The patterns of pausing and the pattern of changeover responses were quite similar. The records show that most intervals ended in reinforcement (downward deflections of the pen). Timeouts (indicating the pigeon had "missed" a reinforcer) occurred infrequently for all three pigeons across all conditions: averaged across the last sessions of all conditions the average numbers of timeouts were 4.2, 3.3, and 2.4 respectively for Pigeons 57, 86, and 60.

Since the records showed that typically only one changeover response occurred during a time period, the time class at which changeovers occurred was recorded on a print-out counter for the last session of the fifth condition. Figure 4 shows the distribution of changeover responses for the three pigeons. For all three, the changeover responses were distributed around the seventh time class. In this condition, responses were reinforced at 9 to 12 sec and 45 to 48 sec. The geometric mean for this condition was 20 sec, which occurred during the seventh time class. Thus, the changeover data, as well as the choice data, indicate that performance was controlled by relative relations of reinforcing events.

The cumulative records showed variations in response rates across intervals and across conditions. Figure 5 shows response rates as a function of time class across conditions. Response rates were calculated by dividing the total number of responses (red-key plus green-key) by the time spent in that class. Time was calculated simply by knowing the number of exposures of a time class per session (*e.g.*, 30 exposures of a 3-sec time class would mean a 90-sec total). Use of this method did not allow computation of response rates at time classes where food was produced, since the production of food would terminate the interval and time spent was not known.

Figure 5 shows that there tended to be two peaks of responding, peaks that approximated the times at which food was presented. Response rates generally were higher at the short interval than at the long, and the peaks were more pronounced. Following the time at which green-key responses were reinforced, response rates dropped to a minimum and then increased again. The lowering of rates is correlated with the pausing shown in the cumulative records (Figure 3). Similarly, from left to

Fig. 4. Frequency of changeover responses as a function of time class under the fifth condition: green-key responses were reinforced at 9 to 12 sec and red-key responses were reinforced at 45 to 48 sec. The data are from the last session.

right, there was a lowering of response rates in the shortest time classes (1 to 4); the lowering of response rates is correlated with the increased pausing following keylight onset shown in Figure 3.

Observation of the lowering of response rates between reinforcement intervals suggested another relation between performance and the relative temporal relation of reinforcing stimuli. Response rates at all classes intervening between reinforcements were inspected and the class having the lowest rate was found. Across conditions, lowest response rates occurred at the time class that was an equal relative distance from the two time classes where food was available. The response-rate data

Fig. 5. Response rates as a function of time class across conditions. The data are medians of the last three sessions under each condition. The arrows indicate the class at which green-key responses were reinforced. The abscissa is ordered along a logarithmic scale.

suggest that response rates as well as choice responses (Figure 2) were controlled by relative, rather than absolute, temporal relations between stimuli.

DISCUSSION

Performance in the present experiment was a function of the relative, rather than abso-

lute, temporal difference between stimuli. The relative temporal difference controlled behavior in spite of changes in absolute time between keylight onset and food presentations and changes between food presentations. The results are in accord with previous research involving temporal stimulus dimensions (Behar, 1963; Catania, 1970; Reynolds and Catania, 1962; Stubbs, 1968). The various experiments

all produced similar results using different procedures. For example, Stubbs trained pigeons on a conditional discrimination procedure to make one response, given a prior 1-sec duration, and a second response, given a prior 10-sec duration. When intermediate stimuli were then presented, the pigeons tended to make both responses equally at 3 sec, approximating the geometric mean of the training durations. Reynolds and Catania (1962) used a different procedure, exposing pigeons to a dark key for durations of 3 to 30 sec followed by a lit key for 30 sec. Food was scheduled according to a variable-interval schedule when the key was lit only after the 3-sec dark stimulus in one condition and only after the 30-sec dark duration in another. In both conditions, response rates on the lit key were highest following the "appropriate" dark stimulus and declined the greater the temporal difference of the other dark durations. The decreasing rate functions for the two conditions crossed around 9 sec, approximating the geometric mean of 3 and 30 sec. The similar findings of several different procedures support the conclusion that pigeons respond to the relative temporal relations between stimuli. The results of the various experiments indicate that the present results are not an artifact of the procedure used. This experiment extends past findings through the use of a wider range of stimulus values and by comparison of performance with a variety of relative differences among stimuli.

The present experiment bears a procedural resemblance to the two-valued interval schedules of Catania and Reynolds (1968). (See also Ferster and Skinner, 1957.) Under the two-valued interval schedules in the Catania and Reynolds experiment, responses were reinforced either at a long interval (240 sec) or at a short interval (30, 90, or 210 sec across conditions). The procedure was the same as the present one, except for the use of different intervals and, more importantly, their animals could respond on only one key; their procedure did not have the choice features of the present experiment. Even with the differences in procedure, their results were similar. When responses were reinforced at 30 and 240 sec, response rates increased to an asymptote near 30 sec, then declined, and then increased again as 240 sec approached. Response rates tended to be lowest at the time (80 to 90 sec)

that was an equal relative temporal distance from the two reinforcement intervals. Additionally, cumulative records were similar to those observed here: a high rate, followed by a pause, followed then by a second period of high responding. The pattern of high to low to high response rates was not evident when the intervals were 90 and 240 sec or 210 and 240 sec. Then, however, the two intervals were relatively close and performance was most comparable to the present condition in which responses were reinforced at 24 to 27 sec and 45 to 48 sec. The similarities in performance in the two experiments indicates that the two-valued interval features controlled rates and patterns of responding in both experiments while the choice features controlled the distribution of responses into two classes.

That animals respond to the relative spacing of events in time is not a conclusion unique to the scaling research. Rather, such a conclusion is consistent with the findings of a wide variety of time-based schedules. The control of performance by relative time dimensions appears to be a general conclusion or, as Catania (1970) spoke of it, a temporal invariance. Catania has reviewed the schedule literature, and a detailed review is unnecessary here. Three examples, however, will serve to illustrate the variety of ways in which the relative spacing of events in time affects behavior.

First, the data on fixed-interval performance are consistent with the view that behavior is a function of the relative spacing of events in time. The rate or probability of responding under fixed-interval schedules is a function more of relative than absolute time to the reinforcer. For example, Schneider and Neuringer (1972) used a discrete-trial fixed-interval procedure exposing pigeons to a variety of fixed intervals. They found two-state performance across all intervals in which there was an abrupt transition from a zero probability of responding to a high probability of responding. The mean breakpoint or change from low to high probability of responding occurred 45% of the way through the interval at all fixed intervals except the longest. A similar, though less regular, finding was observed by Schneider (1969) under free operant fixed-interval schedules. (See also Catania and Reynolds, 1968; Jenkins, 1970; Nevin, 1973).

Second are the data on free-operant (or Sidman) avoidance schedules. Under these schedules, shocks are delivered at regular intervals, but each response postpones shock delivery for a fixed time. These schedules generate responding that is characterized by a low probability followed by an increasing probability as the time of shock nears (*e.g.*, Anger 1963). Behavior is a function of the relative, not absolute, difference in time between the occurrence of shocks or behavior and shock. The "scalar timing process" has been proposed by Gibbon (1972) as a basic process for explaining asymptotic avoidance behaviors.

Third, the data from various concurrent-chains procedures suggest that a scaling process might contribute to choice behavior. Under the concurrent chains, responses are assessed under a concurrent schedule that forms the initial link of the chain; responses in the initial link produce one or the other of two terminal-link schedules. Responding in the initial link may be used as a measure of preference for the different schedules associated with the terminal links. Under this procedure, pigeons show a preference for variable-interval schedules over fixed-interval schedules when the average rate of reinforcement is the same in both schedules (Killeen, 1968). Similarly, pigeons show a preference for mixed-interval *versus* fixed-interval schedules of reinforcement (Davison, 1969, 1972). And when preference is measured for one fixed-interval schedule *versus* another (Davison and Temple, 1973; Duncan and Fantino, 1970; Killeen, 1970) or one delay of reinforcement *versus* another (Chung and Herrnstein, 1967), relative response rate does not match relative reinforcement rate in the terminal links. There is, instead, a deviation in matching, with relatively more responses on the initial-links schedule producing the shorter terminal-link schedule or delay. Precise statements that unify these divergent experiments are difficult to make. Different authors have proposed different quantitative statements, and the data seemingly resist unification into a precise and simple framework. In a general way, however, the data are consistent with an analysis in terms of relative time measures. For example, the preference for a VI 60-sec schedule over an FI 60-sec schedule would be expected, since the geometric mean, the harmonic mean, and other related measures are smaller for the VI

schedule. Similarly for the other cases, the relative means favor mixed FI schedules over FI, *etc.* Thinking in terms of such relative measures might be one step toward clarifying certain preferences for some schedules over others.

One important consideration stems from the discussion of the consistency of the schedule data and the scaling data. A scaling process presumably contributes to schedule performance, but this process should not be viewed as the "basic" or most important factor affecting behavior. Many researchers have pointed out the dangers of overemphasizing the effects of temporal processes on schedule behavior (Catania, 1970; Morse, 1966). Each of the schedules discussed here is exceedingly complex and many factors influence fixed-interval performance (*e.g.*, Dews, 1970; Jenkins, 1970), Sidman avoidance responding (*e.g.*, Gibbon, 1972; Herrnstein and Hineline, 1966; Hineline and Herrnstein, 1970; Sidman, 1966), and concurrent-chain performance (*e.g.*, Davison and Temple, 1973). In view of the many complexities, it is somewhat surprising that a temporal scaling process appears as clearly as it does.

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