TIME LIMITS FOR COMPLETING FIXED RATIOS. II. STIMULUS SPECIFICITY¹

MICHAEL D. ZEILER

EMORY UNIVERSITY

Pigeons were exposed to two stimuli that were each correlated with the same fixed-ratio schedule. During one stimulus, the ratio had to be completed in more than a specified time for food to be presented. During the other, the ratio had to be completed in less than a specified time. Failures to meet the time criterion produced a timeout and reset the ratio. Treating the entire behavioral sequence generated by a fixed-ratio schedule as a unitary response and scheduling differential reinforcement with respect to the duration of the sequence produced effects comparable to those observed previously with individual responses. The times taken to complete the ratios conformed to the time criteria under both stimulus conditions. Similar effects have been observed with differential reinforcement of the duration of individual responses and in experiments specifying running speed criteria under discrete trial conditions.

Evidence has begun to accumulate indicating that entire sequences of behavior resemble individual responses in the way they are affected by reinforcement. Kelleher (1966) reinforced fixed-ratio behavior according to a fixed-interval schedule: the first group of 20 responses completed after 10 min elapsed resulted in food presentation. The time taken to emit successive ratios became shorter as the interval progressed, just as the time between individual responses becomes shorter when a single peck is reinforced according to a fixed-interval schedule. Zeiler (1970) found that differential reinforcement could be used to control the duration of the total fixed-ratio sequence: reinforcement occurred at the completion of a fixed ratio only if the time from the first opportunity to respond until the final response was as specified. Sequence duration was controlled by imposing specific values as the requirement for reinforcement, just as the duration of single responses is controlled by differential reinforcement (e.g., Skinner, 1938, pp. 328-334). The importance of these findings is that they suggest that the principles governing sequences and individual responses may be similar.

The present experiment continued the analysis of how behavioral sequences generated by fixed-ratio schedules are affected when they are treated as unitary responses. Notterman and Mintz (1962) reported that if a response of a certain force was required in the presence of one stimulus, while a response of a different force was required in the presence of another stimulus, the forces emitted differed appropriately during the two stimuli. The present experiment studied whether the duration of fixed-ratio sequences would be brought under stimulus control by correlating two stimuli with identical fixed-ratio schedules but with different duration requirements. The conformity of durations to the specific requirements would mean that a property of the sequence was brought under stimulus control, and would be further evidence for the similarity of sequences and individual responses.

METHOD

Subjects

Three White Carneaux pigeons were maintained at 80% of their free-feeding weights. Bird 71 had experience with simultaneous discriminations involving differential reinforcement under fixed-interval schedules, Bird 16 had an extensive history with a variety of schedules, the most recent being a fixed-interval schedule, and Bird 56 had been exposed to fixed-ratio schedules with time criteria.

¹This research was supported by Research Grant GB-25959 from the National Science Foundation. I wish to thank Anthony DeCasper for his assistance in the experiment and for discussions of the data. Reprints may be obtained from the author, Department of Psychology, Emory University, Atlanta, Georgia 30322.

Apparatus

The experimental chamber was a standard single-key unit (Grason-Stadler E1100PB) modified by the substitution of a Lehigh Valley Electronics 1347 grain feeder and the addition of a relay mounted on the back of the panel above the key. The relay provided auditory feedback for each response. The 0.75-in. (2-cm) diameter response key (R. Gerbrands Co.), operated by a minimum force of 0.18 N, was transilluminated by either red, green, or blue 7 w lamps. A 2 in. (5 cm) square aperture centered 3.5 in. (8 cm) below the key provided occasional access to Purina Pigeon Checkers, the birds' standard diet. During the 4-sec feeder cycles, a 1.1-w white lamp illuminated the aperture and the keylights were off. There was no houselight. Continuously present white noise masked extraneous sounds.

Procedure

The birds were exposed to fixed-ratio schedules in the presence of either a red or green key: in either color, food was presented after the number of responses specified by the ratio. The same fixed-ratio value was correlated with each color, thereby producing a multiple fixed-ratio fixed-ratio schedule (*mult FR FR*) with equal FR components. Birds 56 and 71 had a *mult FR 30 FR 30* schedule, and Bird 16 had a *mult FR 60 FR 60* schedule.

After 30 sessions, time criteria were intro-

duced. In the presence of the green key (maximum time stimulus), to obtain food the birds had to complete the ratio in less than the time specified; the time spent in pausing and responding had to total less than the criterion value. In the presence of the red key (minimum time stimulus), to obtain food the birds had to take longer than the time specified. Whenever the bird failed to meet a criterion, the last response of the ratio resulted in a timeout: the key color changed to blue for 4 sec and responses had no scheduled effect. The same component stimulus repeated after a timeout. After food presentations, the color alternated between green and red, according to an irregular sequence arranged so that each color could not appear for more than three successive food presentations but did occur five times in each block of 10 food presentations.

Table 1 shows the sequence and the number of sessions with each condition. Time criteria were made progressively more stringent. The criteria correlated with green were selected (by experimenter intuition) to maintain an approximately equal number of timeouts in red and green; the selection of values was effective in this respect. Each pair of values was maintained at least until the rate of responding in the presence of each color for each of three successive sessions was within 5% of the median rate of the three days. Criteria were changed on the same sessions

Table 1
Sequence of Criteria

Bird 16		Bird 56		Bird 71		Sessions
Maximum Time (Green)	Minimum Time (Red)	Maximum Time (Green)	Minimum Time (Red)	Maximum Time (Green)	Minimum Time (Red)	
<i>Mult FR 60 FR 60</i>		<i>Mult FR 30 FR 30</i>		<i>Mult FR 30 FR 30</i>		
1. Infinite	1. 0 sec	1. Infinite	1. 0 sec	1. Infinite	1. 0 sec	30
2. 60 sec	2. 12 sec	2. 60 sec	2. 12 sec	2. 60 sec	2. 12 sec	4
3. 30 sec	3. 16 sec	3. 30 sec	3. 16 sec	3. 30 sec	3. 16 sec	46
4. 24 sec	4. 24 sec	4. 20 sec	4. 20 sec	4. 20 sec	4. 20 sec	6
5. 30 sec	5. 30 sec	5. 16 sec	5. 20 sec	5. 16 sec	5. 20 sec	29
6. 26 sec	6. 32 sec	6. 14 sec	6. 24 sec	6. 14 sec	6. 24 sec	23
7. 24 sec	7. 40 sec	7. 14 sec	7. 30 sec	7. Infinite	7. 30 sec	10
8. 30 sec	8. 40 sec	8. Infinite	8. 0 sec	8. Infinite	8. 0 sec	10
9. Infinite	9. 40 sec	9. Infinite	9. 16 sec			21
<i>Mult FR 15 FR 15</i>						
10. Infinite	10. 0 sec	10. Infinite	10. 32 sec			13
11. Infinite	11. 6 sec	11. Infinite	11. 40 sec			31
12. Infinite	12. 12 sec					16
13. Infinite	13. 16 sec					12

for all of the birds, so that a given pair of values was maintained until the last bird stabilized, even if the birds had different criteria.

As the final conditions, Birds 56 and 71 were continued on a *mult* FR 30 FR 30 schedule, and Bird 16 was changed to a *mult* FR 15 FR 15 schedule. When the key was green, there was no time criterion. When the key was red, to obtain food the birds had to take longer than the specified time to complete the ratio. These conditions investigated if a time criterion correlated with one stimulus would be effective when the other stimulus did not involve a temporal requirement.

Sessions lasted for 25 or 30 food presentations for Birds 16 and 56 and for 15 or 20 food

presentations for Bird 71. Variations in session length were necessary to limit weight gain. Sessions occurred Mondays through Fridays.

RESULTS

Figure 1 shows the ratio time—the time taken to complete fixed ratios—for each criterion; the required ratio times appear adjacent to each point. For each session, the average ratio time was computed by dividing the total time the stimulus was on by the number of ratios completed in that time. Time and responses before the first food presentation obtained during the stimulus were excluded to attenuate warmup effects. The data shown are the means of the average ratio times of the last three sessions.

Fig. 1. Time taken to complete ratios under each condition. The numerals next to each point indicate the time criterion.

Under the time criteria, differential responding developed with respect to the stimuli. Before the criteria were introduced, ratio times either were equal during the two stimuli or were shorter during red. With criteria imposed, ratio times increased during red and decreased during green. In the minimum time condition (red key), food presentation required that the birds take longer than the time specified to complete the ratio. No timeouts occurred for Birds 56 and 71 until the criterion was increased to 16 sec. For Bird 16, timeouts first occurred with the 16-sec criterion under the FR 60 schedule and with the 6-sec criterion under the FR 15 schedule. The maximum time condition (green key) provided a smaller range of effective time criteria. The 30-sec criterion produced the first timeouts for Bird 16, the 20-sec value did so for Birds 56 and 71. Under both the minimum and maximum time conditions, the number of timeouts decreased with sustained exposure to a particular criterion value.

Stimulus control over ratio time was strongest when the shortest criterion correlated with green was combined with the longest criterion correlated with red. The cumulative records for the last session of these conditions (Figure 2) indicate that the pattern of responding during green was a brief or no pause followed by an abrupt shift to either steady, positively accelerated, or negatively accelerated responding. During red there was a definite pause. After the pause, sometimes response rate increased gradually, sometimes it changed abruptly and then was constant, sometimes pauses intervened during the ratio, and sometimes responding was negatively accelerated.

When the time criterion during green was abandoned, minimum time criteria during red once again generated a correspondence between required and observed ratio times. The stable response rates in green during these conditions (Conditions 10 to 13 for Bird 16 and 8 to 11 for Bird 56) showed that the ratio times during green were not affected by the progressive slowing of responding when the key was red.

After exposure to the ascending series of minimum time criteria, Bird 71 continued to respond slowly even with the criterion removed (Condition 8), while Bird 56 recovered the behavior observed previously when there

had been no criterion. With the criterion removed during green (Conditions 8 to 11 for Bird 56 and Conditions 7 to 8 for Bird 71), both birds responded more rapidly than before exposure to minimum time criteria (Condition 1). Bird 16 responded at about the same rate in green before and after maximum time criteria were imposed.

Relation Between Ratio Time, Pause Time, and Run Time

To determine how the criteria asserted their effects, ratio time was divided into (1) the time from the first opportunity to respond until the first response (pause time), and (2) the time from the first response until the completion of the ratio (run time). Figures 3 and 4 show the mean ratio times, pause times, and run times for the last three sessions of the first exposure to each maximum and minimum time criterion respectively. Since the abscissas are arranged with the shortest criteria to the left and the longest criteria to the right, progressively more stringent criteria occur from right to left in Figure 3 and from left to right in Figure 4.

Figure 3 shows that for Bird 56, the changes in ratio time under the maximum time criteria occurred primarily due to decreases in the duration of the initial pause. In contrast, for Bird 71 the changes were mainly in run time. For Bird 16, the different ratio times arose from changes in both pause and run time, although both did not change together under all criteria. At the 26-sec criterion, the shortened ratio time was due to a shortened pause time, but at 24 sec pause time was like that at 26 sec, while run time decreased.

Figure 4 indicates that both pause and run time were implicated in the changes in ratio time under the minimum time criteria. Although for Bird 56 the major effect was on pausing, run time increased as well. For Bird 71, slower run times were largely responsible for the slower ratio times with criteria up to 20 sec, but both run and pause time changed nearly equally with longer criteria. With the FR 60 schedule, Bird 16 increased both the pause and run time with longer criteria; with the FR 15 schedule, the major changes were in run time.

Considering all of the birds, changes in pause duration and in the time from the end of the pause to the completion of the ratio

were not as systematic as were changes in ratio time. Criterion changes often affected both pause and run time, but sometimes af-

fected only one. Ratio time, which is the combination of pause time and the time spent responding, varied consistently with the cri-

Fig. 2. Cumulative records for the final session with the most extreme criteria. The records were collected for each stimulus condition. The time criteria appear adjacent to each record. The response pen reset at the end of each ratio. Offsets of the response marker indicate ratios in which the criterion was not met.

Fig. 3. Ratio time, pause time, and run time for each value of the maximum time criterion condition.

teria, but the components of ratio time showed less systematic effects both within and between birds.

Not only was ratio time the measure most consistently related to the independent variable under either the minimum or maximum time conditions, but under the minimum time condition it was also more stable than either pause time or run time. To ascertain stability, it was necessary to analyze daily variability about a measure of central tendency, and it was necessary to compare conditions, even though the independent variable (required times) produced different absolute ratio, pause, and run times depending upon its value. The

mean of the average ratio time, pause time, and run time of the last three sessions with every criterion provided the measure of central tendency; the absolute amount by which the three daily scores deviated from the mean provided the measure of variability. The mean difference scores and standard deviations shown in Table 2 were obtained by averaging all of the daily difference scores for the minimum and maximum time conditions. Under minimum time criteria, ratio time had a smaller difference score than did either pause time or run time in the four comparisons (Bird 16 appears twice because of exposures to two

Fig. 4. Ratio time, pause time, and run time for each value of the minimum time criterion condition.

Table 2
Difference Scores

		Maximum Time Criterion			Minimum Time Criterion		
		Ratio Time	Pause Time	Run Time	Ratio Time	Pause Time	Run Time
Bird 16	Mean	0.13	0.07	0.13	0.23	0.24	0.45
(FR 15)	σ	0.07	0.08	0.08	0.17	0.20	0.45
Bird 16	Mean	0.53	0.36	0.46	0.60	0.76	0.86
(FR 60)	σ	0.38	0.32	0.38	0.40	0.53	0.63
Bird 56	Mean	0.33	0.38	0.31	0.61	1.06	1.05
(FR 30)	σ	0.23	0.30	0.20	0.45	0.80	0.81
Bird 71	Mean	0.34	0.26	0.37	0.45	0.54	0.57
(FR 30)	σ	0.23	0.25	0.36	0.30	0.51	0.48

different ratio values), and was, on this basis, the least variable measure. The source of the lesser variability was that there tended to be a trade-off relation between pause time and run time such that run time increased when pause time decreased. Therefore, the sum of run time and pause time was more stable than either considered separately. In contrast, under the maximum time conditions pause time had the smallest difference score in three of the four cases, and run time had the smallest score in the remaining case. To determine stability only under time criteria that affected behavior, the mean difference scores were recomputed with those criteria that did not make contact with behavior excluded. For the maximum time criteria the difference scores of ratio time, pause time, and run time did not change consistently from those shown in Table 2. For the minimum time criteria, all of the difference scores for ratio time decreased while those for pause time and run time either decreased less or did not change. The relative ordering of variability among the three measures was the same as when all criteria were included.

DISCUSSION

Logan's (1960, chapter 6) distinction between operational and theoretical definitions of the response is important in understanding what the present data do and do not show. The operationally defined response is the class of events that the experimenter treats as equivalent with respect to some rule, commonly a rule involving the scheduling of reinforcement. In the present experiment, there were two response classes, one followed by food delivery and the other followed by time-out presentation. The classes were differentiated by the duration of the total fixed-ratio

sequence. The basic finding was that differential reinforcement of sequence duration determined the duration emitted. The theoretical response, on the other hand, refers to what the subject has learned; in contrast to the operationally defined response class, the theoretical response is not observed but is inferred. The present results have little to offer with respect to theoretical responses because they provide no clear basis for deciding whether the pigeons learned to emit unified sequences of certain durations, learned to emit certain combinations of pause time and run time, learned to space individual pecks in some way, or emitted some combination of these and other possible responses. In terms of Platt and Johnson's (1971) dichotomy between studies concerned with demonstrating analogous effects of variables on sequences and individual responses and studies concerned with the processes by which sequences become integrated, this experiment falls into the first category.

Time criteria added to fixed-ratio schedules established differential responding with respect to stimuli. The data replicated Zeiler's (1970) finding that the times taken to complete fixed ratios were controlled by the imposition of time requirements, and duplicated the major phenomena observed in that research, although now, minimum and maximum time criteria were studied simultaneously and previously they were studied separately. These phenomena are (1) a systematic relation between required time and the time taken to complete fixed ratios, (2) an effect of time criteria on the duration of the pause at the outset of each ratio, (3) an effect of time criteria on the time spent responding after the pause, and (4) the persistence of longer-than-required ratio times in some birds after minimum time criteria

were removed. The new information provided is that the effects of time criteria were specific to the prevailing stimulus, *i.e.*, two fixed-ratio performances having different temporal dimensions were brought under stimulus control.

The data are relevant to conceptual integrations of free-operant and discrete-trial procedures. Platt (1971) elaborated Logan's (1960) suggestion that the discrete trial alley situation is like the free operant fixed-ratio schedule in that both involve chains of constant length. In an alley, the distance from start to end is constant; with a fixed-ratio schedule, the number of responses per reinforcement is constant. Platt has reported experiments showing that the behavior found in the alley and with fixed-ratio schedules is similar, if care is taken to have the stimulus consequences of completing the chains be similar. For example, both reveal increases in response speed early in the chain and decreases just before the end, and the resistance-to-extinction of both shows quite comparable effects. Logan's (1960) research and the present data provide additional evidence for similarity. When Logan (chapter 8) differentially reinforced slow running speeds, that is, long sequence durations, the speeds emitted corresponded closely with those required. The similarity to the minimum time conditions of the present and Zeiler's (1970) experiments shows that the sequence involved in running an alley and in completing a fixed ratio can be controlled in a virtually identical manner. Also, Logan (p. 171) found a negative correlation between the time rats took to start running and the subsequent running speed when reinforcement required slow speeds, a result that was mirrored in the minimum time conditions of the present study when ratio time was more stable than either pause or run time. Logan's contention that it is likely that in his experiments this variability was maintained because the reinforced response class did not differentiate how the specified duration was attained seems equally applicable to the present results with minimum time criteria, although it does not explain why ratio time was not also the most stable measure with maximum time criteria. The question of explaining the results, however, is separate from the fact that as of this time, behavior in the alley has demonstrated a substantial degree of similarity to behavior under fixed-ratio schedules.

The present results correspond with those of other experiments studying differential reinforcement of response properties. Skinner's (1938) procedures and results are representative of later research: when a response was reinforced only if its duration or intensity exceeded a specified value, the durations or intensities emitted changed accordingly. Notterman and Mintz (1962) found that the intensity of responses could be brought under stimulus control. Since Zeiler's (1970) data involving the duration of sequences also showed the same relationships as did Skinner, and the present study found results equivalent (with duration rather than intensity) to those of Notterman and Mintz, it seems that sequences and individual responses are affected analogously. But the generality extends to another response class as well. Findley (1962) and Kelleher, Fry, and Cook (1964) showed that differential reinforcement of the duration of the pause before the first response emitted on fixed-ratio schedules operated in the same way. Differential reinforcement of a property appears to control whatever response is specified independent of the size of the response or whether it involves emitting or withholding a specified response.

Kelleher (1966) and Lee and Gollub (1971) found that sequences and individual responses were affected similarly by another variable, namely, the schedule of reinforcement. When sequences generated by a fixed-ratio schedule were reinforced according to a fixed-interval schedule or a fixed-ratio schedule, the temporal relations among successive sequences were much like those among successive individual responses reinforced on a fixed-interval or fixed-ratio schedule. Thus, differential reinforcement of a property of the response and schedules reveal the same lawful relations whether the response class be an individual response or a sequence. A hypothesis that integrates the various data is that the laws of behavior are independent of whether the class is the individual response or a sequence of these responses. In terms of this hypothesis, differential reinforcement of duration has similar effects independent of the size of the segment into which behavior is divided, because it is an instance of the more general rule that the laws are independent of the size of the unit of behavior treated as the response class.

REFERENCES

- Findley, J. D. An experimental outline for building and exploring multi-operant behavior repertoires. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 113-166.
- Kelleher, R. T. Chaining and conditioned reinforcement. In W. K. Honig (Ed.), *Operant behavior: areas of research and application*. New York: Appleton-Century-Crofts, 1966. Pp. 160-212.
- Kelleher, R. T., Fry, W., and Cook, L. Adjusting fixed-ratio schedules in the squirrel monkey. *Journal of the Experimental Analysis of Behavior*, 1964, 7, 69-77.
- Lee, J. K. and Gollub, L. R. Second-order schedules with fixed-ratio components: variation of component size. *Journal of the Experimental Analysis of Behavior*, 1971, 15, 303-310.
- Logan, F. A. *Incentive*. New Haven: Yale Univ. Press, 1960.
- Notterman, J. M. and Mintz, D. E. Exteroceptive cueing of response force. *Science*, 1962, 135, 1070-1071.
- Platt, J. R. Discrete trials and their relation to free behavior situations. In H. H. Kendler and J. T. Spence (Eds.), *Essays in neobehaviorism*. New York: Appleton-Century-Crofts, 1971. Pp. 137-160.
- Platt, J. R. and Johnson, D. M. Localization of position within a homogeneous behavior chain: effects of error contingencies. *Learning and Motivation*, 1971, 2, 386-414.
- Skinner, B. F. *The behavior of organisms*. New York: Appleton-Century-Crofts, 1938.
- Zeiler, M. D. Time limits for completing fixed ratios. *Journal of the Experimental Analysis of Behavior*, 1970, 14, 275-286.

Received: 31 August 1971.

(Final acceptance: 30 May 1972.)