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SECOND-ORDER SCHEDULES WITH FIXED-RATIO COMPONENTS: VARIATION OF COMPONENT SIZE[1]

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Key pecking by pigeons was reinforced with food under second-order schedules with fixed-ratio units. A constant total number of key pecks was required for reinforcement under each condition, but the size and, inversely, number of fixed-ratio components were varied. The total response requirement of 256 pecks was divided into fixed-ratio units of 128, 64, 32, 8, and 2 responses. A brief stimulus, which always preceded food reinforcement, was presented upon completion of each fixed-ratio unit. Under most conditions, the pattern of within-unit responding was typical of that under simple fixed-ratio schedules. Overall response rate was an inverted U-shaped function of component size. That is, response rates were highest under moderate sized units (fixed ratio 128 and 64). This relationship is consistent with previous determinations of rate as a function of fixed-ratio value for simple fixed-ratio schedules.

Several recent experiments have shown that long, orderly sequences of behavior can be maintained when brief stimuli follow the completion of response units. This type of schedule, called a "second-order" schedule, has been classified and studied by Kelleher (1966). A second-order schedule is a "schedule on a schedule", or one in which the completion of a simple schedule (such as fixed ratio or fixed interval) is considered a response unit (*i.e.*, an operant, *cf.* Findley, 1962) that produces reinforcement according to a schedule of primary reinforcement.

Findley and Brady (1965) showed that performance on a large fixed-ratio (FR) schedule was facilitated by the addition of a brief stimulus on a second-order schedule. A chimpanzee was trained to make 10 groups of 400 responses with food reinforcement. In one condition, all 4000 responses were made with no stimulus changes. In the other condition, each of the first nine groups of 400 responses was followed by a 0.5-sec illumination of the food hopper. When food was delivered the hopper was also lighted. Under the latter condition, the pause before responding and the time to complete the total ratio requirement were shorter.

Facilitation of performance has also been demonstrated under a schedule where the response unit was an FR chain. Findley (1962) found that a pigeon responded more rapidly on a schedule composed of eight three-member chains with FR 10 components than on one three-member chain where each member consisted of FR 80.

In previous studies of second-order schedules in which FR units produced the reinforcer according to an FR schedule, responding was examined under only one value of the FR unit. In the present study, the FR unit size was varied, with the total response requirement for food reinforcement held constant.

METHOD

Subjects

The experiment was performed with two adult male White Carneaux pigeons. They were housed individually and given free access to water and non-nutritive grit in the home cages. Their weights were maintained at 80% of previously determined free-feeding values. The birds had an experimental history of variable-interval chain schedules with food reinforcement.

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Apparatus

The experimental chamber was similar to that described by Ferster and Skinner (1957), with a compartment for the pigeon that was 12.5 in. high by 12 in. long by 10.75 in. wide (32 by 30 by 27 cm). A Gerbrands pigeon key 0.75 in. (1.9 cm) diameter and Gerbrands grain feeder were located on one wall of the box. The feeder was centered on the wall and was 3.25 in. (8.2 cm) from the floor. The key was 2 in. (5.1 cm) to the left of center and 9 in. (23 cm) from the floor. A small relay was installed to provide auditory response feedback for each key peck. A houselight was mounted near the top of the rear wall and a light was mounted behind the front wall to illuminate the food when it was presented. Both lights were clear 115 v ac, 7-w lamps. Colored, 115 v ac, 7-w bulbs were mounted behind the key. A fan attached to the box provided air circulation as well as a masking noise. Relay control equipment was located in a different room, separated by another room from the experimental chamber.

Procedure

The birds were trained under FR schedules of increasing size until behavior under FR 256 was maintained. Under an FR schedule, food is presented after a specified number of responses: *e.g.*, under FR 256, the two hundred fifty-sixth response produces food. After performance under FR 256 was stable, second-order schedules were introduced by dividing the total response requirement into units of varying sizes. The conditions, listed in Table 1, were presented in order of decreasing size (and increasing number) of response units. A replication was run in the reverse order, so that after the condition in which the response unit was FR 2, the FR 8 condition was instituted. All conditions were run for a minimum of 15 sessions, and conditions were not changed until rates and patterns of responding were judged stable.

Table 1

Experimental conditions. Number of sessions and size and number of FR units for each condition.

Response Unit	*No. of Units*	*No. of Sessions*	
		Initial Run	*Replication*
FR 256	1	27	15
FR 128	2	32	22
FR 64	4	20	26
FR 32	8	15	23
FR 8	32	31	21
FR 2	128	19	

Each session began and ended with a blackout (all lights in the chamber were turned off). During the session, the light transilluminating the key was red, except for a 0.5-sec presentation of a green light at the end of each response unit. Five-sec access to grain followed the 0.5-sec presentation of the green light after the last response unit. During food presentation, the houselight and keylights were off, and the food hopper was illuminated with white light. The session ended after 30 reinforcements or after the first reinforcement after 3.5 hr, whichever occurred first.

Key-pecking responses produced no feedback clicks during the brief stimulus presentation (green keylight) or the magazine presentation. Also, although responses were recorded on the cumulative recorder, responses were not effective in reducing the response requirement during the presentation of either the green light or the food hopper.

RESULTS

Median overall rates for the last five sessions under each condition are presented in Fig. 1. The order in which the conditions were run is indicated by arrows. Both birds showed an increase in rate with the decrease in response-unit size, followed by a decrease in rate as the response unit was further decreased. The highest overall rate on the first run was achieved with the FR 64 response unit for both birds.

The overall rates for the conditions replicated with decreasing FR size showed a peak at an intermediate value of the FR response unit. The peak of the replication function occurred at FR 64 for Bird 80, but for bird 82 the peak shifted to FR 128. For both birds, the rates for the replication of conditions FR 128 and FR 256 were higher than in the initial run.

Response patterns within the FR units are illustrated by representative cumulative response records in Fig. 2 and 3. Several features of responding were markedly affected by the brief stimulus. Under the first condition, where the brief stimulus appeared only immediately

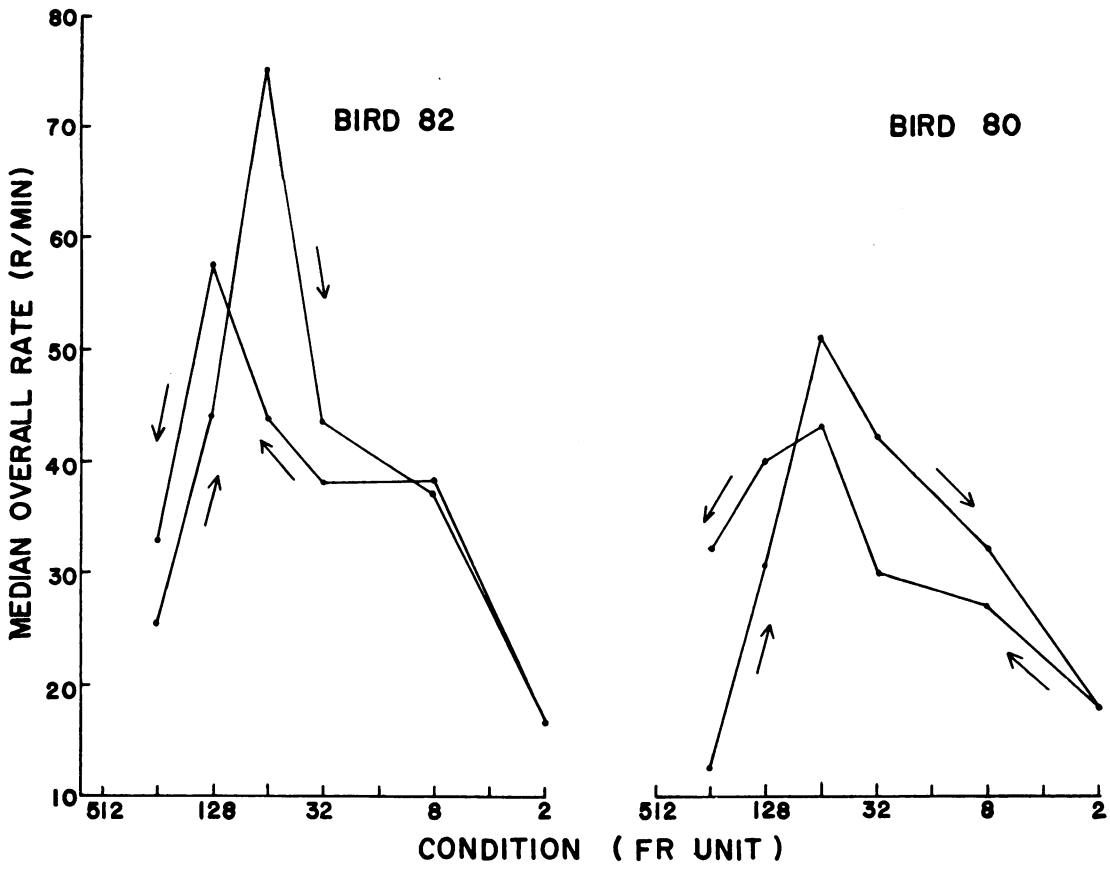

Fig. 1. Median overall response rates under each condition for Birds 82 and 80. The values shown are medians of the median rate in the last five sessions. Median rates within each session were calculated from a printed record of the time elapsing between food reinforcements. Arrows indicate the order in which the conditions were varied.

before food presentation, responding occurred in short bursts followed by pauses of varying lengths, producing irregular patterns in the record, especially in the early portion of the ratio. With the introduction of the brief stimulus within the response sequence, there was less irregular responding at the beginning of the ratio and the post-reinforcement pause (time until the first response after food reinforcement) decreased. This trend toward an increasingly abrupt transition between the post-reinforcement pause and the initiation of steady responding continued until condition FR 64 or FR 32 for both birds. Under conditions FR 8 and FR 2, with a greater number of presentations of the brief stimulus and smaller response units, irregular response patterns again appeared in the early portions of the ratios.

Responding within the response units (indicated by the short diagonal marks within each excursion on the record) showed patterns typical of responding under fixed-ratio schedules maintained by food reinforcement. That is, there was often a brief pause following the stimulus presentation and then an increase in response rate. Modifications in the behavior patterns within the response units are most apparent in the records of Bird 80, which had the lower response rate. For Bird 82 there is only slight indication of pauses following the brief stimulus. The pauses following the brief stimulus in the later components were too small to appear on the cumulative records. They were shown, however, by a subsidiary analysis of average response rates in successive groups of 32 responses between food reinforcements. Under this analysis, median response rates were lower in the fifth such block with the FR 128 unit, *i.e.*, where the second unit

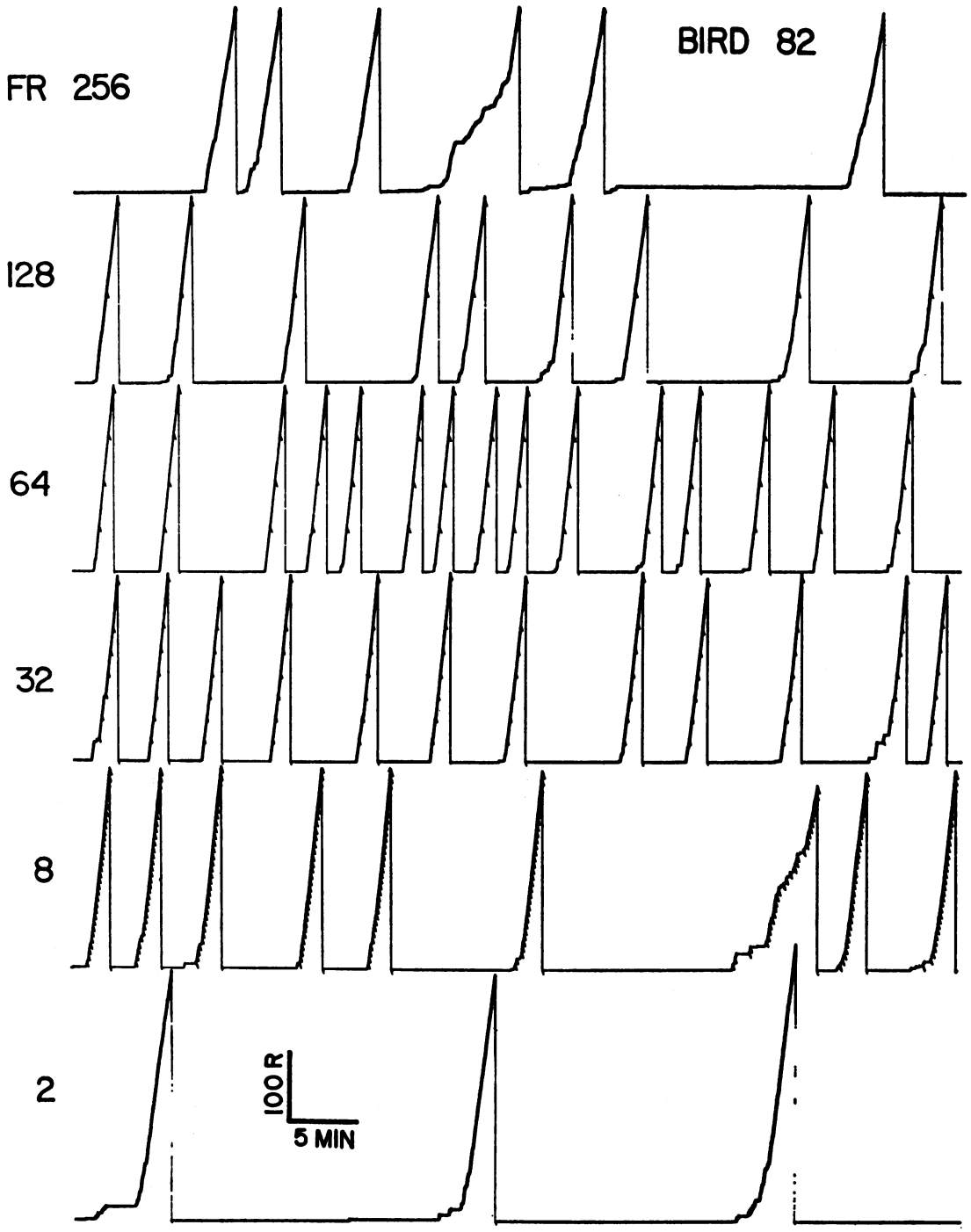

Fig. 2. Representative cumulative response records for Bird 82. The samples are taken from the sessions in which the median overall rates were obtained during the series of increasing ratio values. The pen was reset upon food presentation, and a short diagonal mark to the right of the record indicates the brief stimulus presentation, except on FR 2, where no marks were recorded because their high frequency would have made an illegible record.

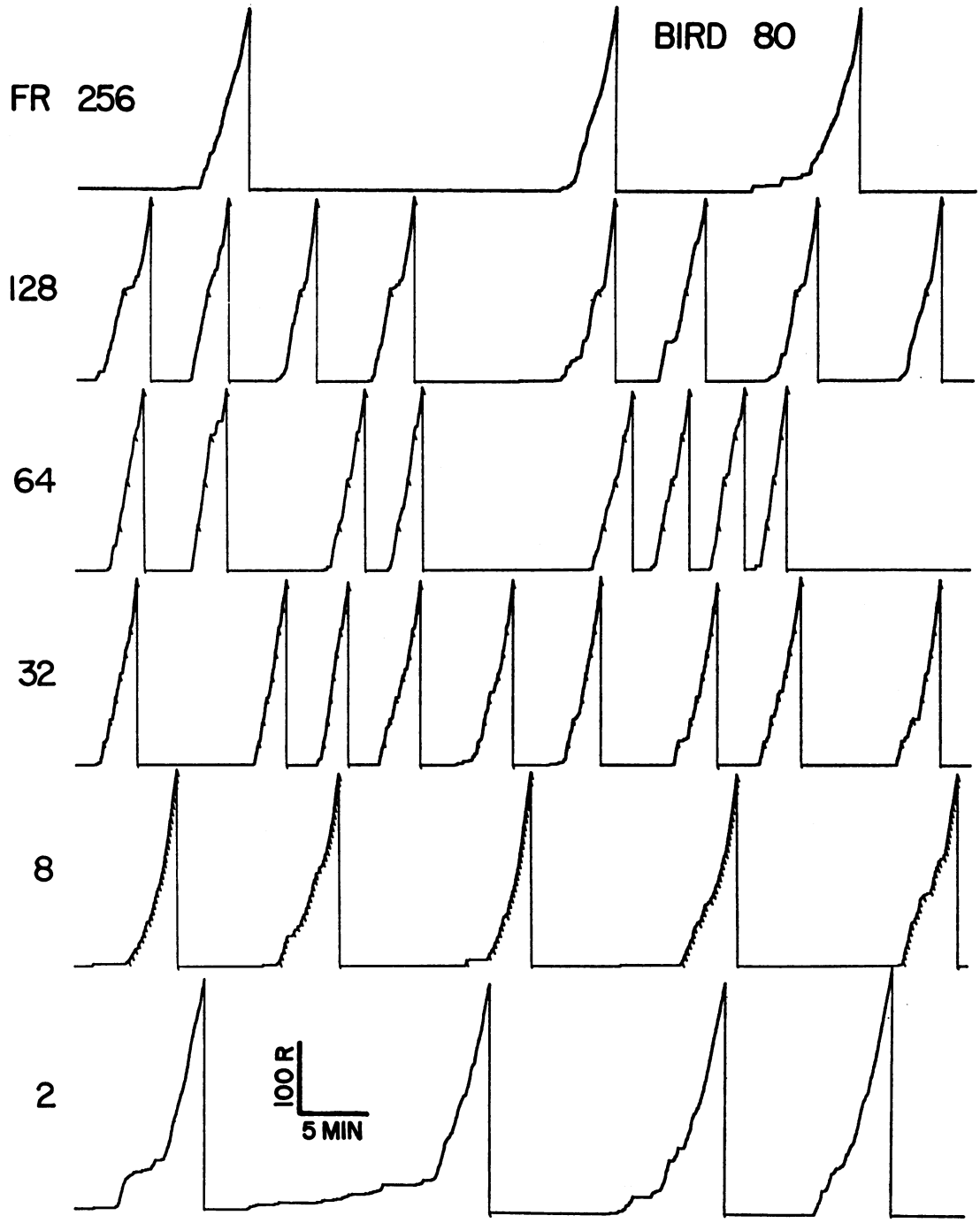

Fig. 3. Representative cumulative response records for Bird 80. The samples are taken from the sessions in which the median overall rates were obtained during the series of increasing ratio values. The pen was reset upon food presentation, and a short diagonal mark to the right of the record indicates the brief stimulus presentation, except on FR 2, where no marks were recorded because their high frequency would have made an illegible record.

began, compared to the fourth and sixth blocks, and in the fifth and seventh blocks, with the FR 64 unit, compared to the adjacent blocks. Further analysis of within-ratio responding is presented in Lee (1968).

Under conditions FR 128, FR 64, and FR 32, responding within the units showed fairly uniform patterns so that the overall performance appeared to be composed of smaller fixed ratios, which were emitted at increasingly higher rates. Responding under conditions FR 8 and FR 2, however, often showed variations in rate that were not regularly associated with successive response units. Under these values, the birds often began responding at a high rate early in the ratio, and then paused before resuming a high rate. This type of responding resulted in a characteristic of the cumulative record described as a "knee" (Ferster and Skinner, 1957). An example of such a very pronounced pattern is seen in the first excursion for Bird 80 under condition FR 2 (Fig. 3). Further analysis of the occurrence of this pronounced response pattern is reported in Lee (1968).

Changes in the overall rate or patterns of responding immediately after a new condition was introduced did not show any consistent relation to the conditions, either within or between subjects. The cumulative records showed very few transition effects. Where the FR unit size was decreased, the patterns of responding on the first day of each condition were not very different from those of the terminal sessions, although for certain conditions of the replication, there were some indications of initial disruption of responding. Both birds showed the most marked disruption on the transition from FR 2 to FR 8. The responding was characterized by very short bursts and long pauses at the beginning of the overall ratio. The rest of the ratio showed the frequent changes in rate that were typical of responding under this condition for final sessions. Instances of short bursts of responding and long pauses at the beginning of ratios persisted under this condition for at least three sessions after the change. During the first several sessions following the other schedule changes for the replication, Bird 80 showed the most marked variations from later responding. There were fewer indications of pausing after the brief stimulus presentations and more frequent rate decreases within the schedule components.

DISCUSSION

In this experiment, patterns of responding within fixed-ratio response units were similar to those found under simple fixed-ratio schedules. These results are consistent with the findings of other studies of fixed-ratio second-order schedules (Findley, 1962; Findley and Brady, 1965; Kelleher, 1963; Thomas and Stubbs, 1966). In addition, the overall rate first increased and then decreased (an inverted U-shaped function) as the total fixed ratio was divided into progressively smaller response units. Highest overall rates occurred for response units FR 64 and FR 128.

Two major factors are proposed to account for these effects: changes in the reinforcing properties of the brief stimulus, and the size of the fixed-ratio requirement of each schedule unit.

Functions of Brief Stimuli

The non-monotonic relationship of median overall rate and response-unit size may reflect several functions of the brief stimulus. The increase in response rate at intermediate values of the FR response unit can be accounted for by assuming that the brief stimulus was a conditioned reinforcer (Kelleher and Gollub, 1962; Hendry, 1969). The stimulus occurred for 0.5 sec before food delivery, a value with which conditioned reinforcers have successfully been established (Kelleher, 1966). Another sign that the brief stimulus acted as a conditioned reinforcer is that the response patterns within the units were usually similar to those for FR schedules involving primary reinforcers.

The decrease in overall response rate with still smaller FR components may reflect a weakening of the reinforcing effectiveness of the brief stimulus. Under the conditions with larger numbers of smaller FR units, the stimulus occurred more frequently, and was therefore paired with food delivery proportionately less frequently. Thus, the stimulus could have become a weaker conditioned reinforcer. However, even when overall rates decreased, there was still an indication that the stimulus was an effective conditioned reinforcer in that patterns of responding within the units were typical of behavior on food-reinforced schedules. The stimulus may have been a less potent reinforcer, since even a less effective reinforcer

would be capable of maintaining a smaller FR, or a given FR at a lower rate.

Perhaps the overall decrease in rate on the schedules with the smaller response units was due to a breakdown in the discriminative function of the stimulus. This breakdown may be explained as follows. Kelleher (1966) suggested that brief stimuli in second-order schedules might help "hold the schedule together", by functioning as indicators of the completion of a unit. The stimulus also indicates a certain probability that reinforcement will follow immediately. Brief stimuli early in the ratio are associated with a low probability of reinforcement, while those later in the ratio are associated with a higher probability of reinforcement. This function of the stimuli, as signals of reinforcement probability, supposedly influences the patterning of response units appropriate to the schedule on which the response units are reinforced (Kelleher, 1966; *cf.* Marr, 1969). When the stimulus is not consistently associated with a particular reinforcement probability, the pattern of response units may become inappropriate to the schedule. With the FR 8 unit, there was a disruption in the characteristic FR pattern of responding where the rate was high at the beginning of the ratio, then slowed, and finally increased again. A similar disruption was often apparent under the FR 2 condition. These patterns resemble the behavior of pigeons under an FR schedule with an added counter (Ferster and Skinner, 1957, p. 91). In Ferster and Skinner's experiment, while the birds responded, a slit on the key gradually increased as the ratio was completed. When the direction of the counter was reversed, so that the slit was long at the beginning of the ratio, the birds began responding at a high rate, which changed abruptly to a lower rate, and then increased again. Thus, under the schedule with the high density of brief stimuli in the present study, there was the appearance of inappropriate stimulus control concerning the proximity of reinforcement throughout the ratio.

Effects of FR Unit Size

The FR unit size is an important parameter of the second-order schedule. Since the number of responses required for food was constant in the present experiment, as one FR value was decreased, the other was increased. That is, when the response unit is FR 128, it is reinforced according to an FR 2; when the response unit is FR 32, it is under an FR 8 schedule, and so forth. Therefore, the result that FR rate increased and then decreased as the FR unit value was raised can be interpreted as due to an interaction of the effects of two related controlling variables: the size of each response unit and the number of units.

Barofsky and Hurwitz (1968) reported an inverted U-shaped curve for response rate as a function of FR size. They studied the performance of rats on fixed-ratio schedules varying from six to 160 responses. Maximum overall response rates were found at FR 40 to FR 80. This result confirms the implications of studies by Boren (1961) and Weissman and Crossman (1966). In both of the latter experiments it was found that as FR size increased, rate increased according to a negatively accelerated function. Boren studied ratios as high as FR 20 (with rats), and Weissman and Crossman studied ratios as high as FR 64. Although in the present study the FR units were followed by a conditioned reinforcer, the results for simple fixed-ratio schedules are remarkably similar. It may thus be a basic property of responding under FR schedules that rate is an inverted U-shaped function of FR size, whether the FR unit is reinforced with food, or with a conditioned reinforcer.

The way in which the component fixed-ratio schedules combine thus involves two major factors controlling responding under these second-order schedules. The individual component ratios may be the major contributors to the overall response rate, when the ratio requirement is large or moderate in size. Responding is governed by the ratio performance usually occurring under fixed ratios of that size, with a function similar to that shown by Barofsky and Hurwitz (1968). The patterns of responding demonstrate that the ratio units are, in fact, acting as units, in terms of showing pause-and-run changes in rate for ratio units from FR 128 to FR 32. For smaller unit sizes there is less evidence that the fixed ratio functions as a behavioral unit. Perhaps with small units the decreased frequency of pairing the second-order stimulus with food lowers its reinforcing value, as discussed above. The weakened reinforcing or discriminative effect of the second-order stimulus results in lower overall response rates as the individual units

become less well defined, and the condition approaches a single large ratio.

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