

## RESPONDING UNDER CHAINED AND TANDEM FIXED-RATIO SCHEDULES

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The role of stimuli in chained fixed-ratio schedules of reinforcement was examined. At various ratio values, responding on schedules consisting of three or five equal components, with a different colored light in each component ("block counter") was compared with responding on tandem or simple fixed-ratio schedules having the same color present throughout the entire ratio. At all ratio values except the smallest, the chain stimuli resulted in longer pauses after reinforcement. The magnitude of this effect became greater as the size of the ratio was increased. Post-reinforcement pause durations were longer under five-component schedules than under three-component schedules. Running rates in the first component were lower on the chained schedules than on the tandem schedules; on both kinds of schedule, rates were lower in the first component than in the rest of the ratio. When the sequence of stimuli was reversed, the duration of the post-reinforcement pause dropped markedly and the running rate in the initial component increased, but these effects gradually disappeared after the first reversal session. When the final chain stimulus was substituted for the first component stimulus but continued to appear in the final chain component as well, the pause duration dropped and remained at this lower level during subsequent sessions.

The main purpose of this experiment was to study the effect of an exteroceptive "block counter" (Ferster and Skinner, 1957) on key pecking maintained by a fixed-ratio (FR) schedule of reinforcement, in which every  $n$ th response is reinforced. When external stimuli are provided that change following the completion of each fraction of the total response requirement (block counter), the resulting schedule may be classified as a chained fixed-ratio schedule. To determine the effects of the counter or chain stimuli, the performance is compared with that obtained on an equivalent "tandem" fixed-ratio schedule having the same total response requirement for reinforcement

but with no change occurring in exteroceptive stimulation.

Although two-component chained schedules have been studied by a number of investigators, relatively little work has been done with "extended" chained schedules having three or more components. Most of this type studies have used fixed-interval (FI) schedules, in which the first response after a specified period of time produces the stimulus for the next component.

Since Ferster and Skinner's (1957) initial exploratory work with block counters, very few studies have been reported of performance under extended chained schedules having FR schedules in each component. Ferster and Skinner (1957) obtained long post-reinforcement pauses under this type of schedule, and Findley (1962) obtained similar results. However, since no tandem control schedules were used in these investigations, it is not possible to separate the effects of the chained stimuli from the effects of the ratio contingency, which often results in long pauses even when no counters or chain stimuli are used.

One of the few investigators who had directly compared tandem and chained FR schedules is Thomas (1964, 1966). Thomas reported longer post-reinforcement pauses on

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chained than on tandem FR schedules, and presented sample cumulative records illustrating this effect. However, he did not actually measure pause durations, and the pause times are included in calculating the response rates in the first component. Moreover, in Thomas' studies, the chained and tandem schedules were used in alternation within the same session, in the form of multiple schedules. Since the multiple schedule provides no safeguard against possible interactions between its chained and tandem components, all comparisons in the present study are based on successive blocks of sessions.

The major question that the present research attempted to answer is what effect the stimuli in a block counter have on fixed-ratio behavior. If a fixed number of responses is required for reinforcement, how will performance be affected if a change in stimulation is provided after certain portions of the "task" have been completed? The effects of the total number of responses required, and of the number of components into which this total has been divided, were also examined. Finally, the discriminative control exerted by the stimuli in chained schedules was investigated through changes in the sequence in which the stimuli were presented.

## METHOD

### *Subjects*

Eight experimentally naive adult Carneaux barren hen pigeons were maintained at approximately 80% of their free-feeding body weights throughout the experiment.

### *Apparatus*

The basic apparatus consisted of two standard Lehigh Valley two-key pigeon chambers, Model 1519. Operation of the keys required a force of approximately 0.3 N, and effective responses produced an audible click. The visual stimuli, consisting of six different colors (red, purple, blue, green, yellow, and white), were projected on the right-hand response key by an Industrial Electronic Engineers digital display unit (Model 10052). The left key was covered with black tape throughout the experiment. Ventilation and some masking noise were provided by a blower.

All experimental events were controlled automatically by Massey Dickinson solid-state

modules located in an adjoining control room. Durations of pauses and running times were measured by solid-state timers, and responses were recorded on Harvard Type SHS (Silent High Speed) cumulative recorders (Ralph Gerbrands Co.) and electromagnetic counters.

### *Acquisition Training*

On the first day of training, the birds were placed in the experimental chamber and magazine training was begun. The birds were repeatedly presented with the tray of grain until they learned to approach and eat promptly on each presentation. Then, the right key was illuminated and pecking on this key was shaped by the reinforcement of successive approximations.

Initially, each peck was reinforced by a 4-sec presentation of the grain hopper. During reinforcement, both the houselight and the keylight were turned off, and a white light above the hopper came on. After the birds were pecking at a steady rate on the FR 1 schedule, an FR 3 schedule was introduced, *i.e.*, with reinforcement of every third response. By the end of the second session, all eight birds were responding steadily on this schedule. The reinforcement duration was then reduced to 3.5 sec for the remainder of the study. After seven additional training sessions on the FR 3 schedule, the experimental procedure was introduced.

### *Procedure*

Responding on chained FR schedules of various sizes was compared with responding on tandem control schedules having identical response requirements for primary reinforcement. For the chained schedules, a different color appeared on the response key during each component; during the tandem schedules, the key color (which was different from the chain colors) remained unchanged during the entire ratio. Different sequences of chain colors and different tandem colors were used for different birds.

In order to permit within-subject comparisons, the birds were run on both chained and tandem schedules at each ratio size. The size of the ratio was increased progressively during the experiment. The total number of responses required for reinforcement ranged from 12 to 240. All eight subjects were run on ratio values of 12, 60, and 90, and higher ratio values of

120, 180, and 240 were used for some of the subjects.

At each different response requirement, half of the subjects were run on the chained schedule during the first series of sessions, and then on the tandem schedule for the next series of sessions; the other half were run first on the tandem and then on the chained schedule. The type of schedule used in the first series (*i.e.*, chain or tandem) was repeated during a third series at each ratio value, to control for sequence and temporal effects.

Transitions from one schedule to another were made only after careful inspection of the data and cumulative records indicated that the behavior on the previous condition had stabilized, which usually required from 15 to 25 experimental sessions on each schedule. Sessions were terminated after 50 reinforcers had been received.

For four of the subjects, the chained schedules consisted of three equal blocks or components. For the other four subjects, the chained schedules consisted of five components (except at the smallest ratio value, FR 12, at which all birds were run on three-component schedules). Some of the birds were run on both three-component and five-component schedules, as well as on the tandem schedule, at selected ratio values. Thus, when 120 responses were required for reinforcement, the three-component chain consisted of three blocks each having 40 responses [chain FR 40 FR 40 FR 40, sometimes designated FR 3 (FR 40)]; the five-component chain consisted of five components each having 24 responses [chain FR 24 FR 24 FR 24 FR 24 FR 24, sometimes designated FR 5 (FR 24)].

When birds were run on both three-component and five-component chains, the stimuli used for the three-component chain were those used in Components 1, 3, and 5 of the five-component chain. Otherwise, the colors used for an individual bird remained constant throughout the experiment, except during the final stimulus reversal and stimulus substitution procedures.

The dependent variables were the post-reinforcement pause duration, measured from the end of the reinforcement period to the next response; the running rate in each component; and the interreinforcement time, *i.e.*, the total length of time taken to complete the ratio, including pause time. For each of these

dependent variables, the mean value on each of the last five sessions under every schedule condition was determined for each subject. The median of these five values was used in the analysis.

Special procedures involving changes in the sequence of the chain stimuli were utilized during the final phase of the experiment in order to examine the amount of discriminative control over responding that had been acquired by the various chain stimuli.

## RESULTS<sup>2</sup>

### *Pause Duration*

On both chained and tandem schedules, the size of the post-reinforcement pause increased as the size of the ratio was increased, in almost all cases. Figure 1 shows pause durations obtained at various ratio values for three of the eight subjects.

When equivalent chained and tandem schedules were compared, it was found that the post-reinforcement pause duration was almost always longer under the chained schedules than under the corresponding tandem schedules. The only exception was at the smallest ratio value used, FR 12, at which the chain stimuli had no consistent effect on the birds' performance.

Not only was the pause duration longer under the chained schedules, but the difference between the two kinds of schedule was greater at higher ratio values, indicating an interaction between ratio size and block counter effects. This is shown by the increasing separation between the two curves for each of the subjects in Figure 1.

To investigate the effects of switching back and forth between chained and tandem schedules in successive blocks of sessions, the type of schedule used in the first series was repeated in a third series at each ratio value. Thus, half of the birds had the sequence chain-tandem-chain, and the other half had the sequence tandem-chain-tandem. For all birds and at all ratio values, pause durations changed in the expected direction. If the change was from a chained to a tandem schedule, the pause decreased; if the change was from a tandem to a chained schedule, the pause increased. In most cases, however, the

<sup>2</sup>For further details, see Jwaideh (1968).

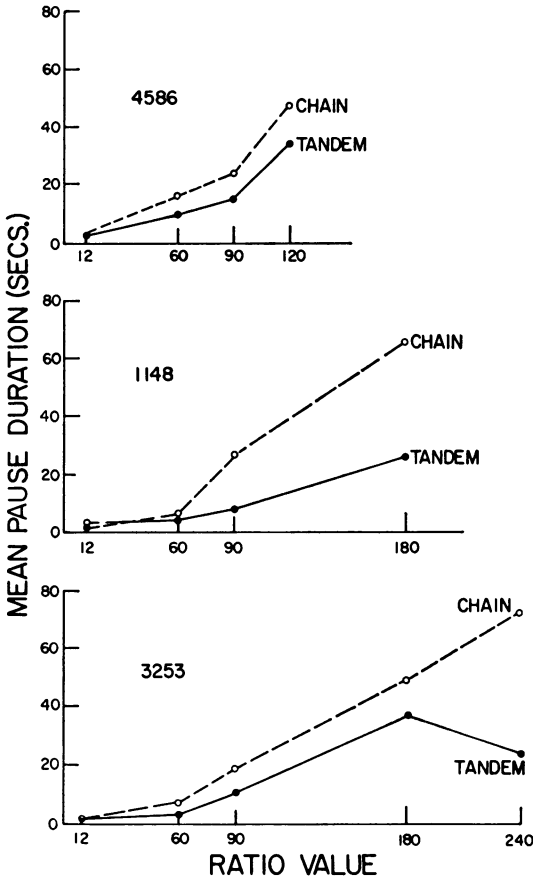


Fig. 1. Mean post-reinforcement pause duration for three birds on chained and tandem schedules as a function of ratio size.

pause duration during the third series never returned completely to its value on the original schedule.

To find out whether the difference in pause duration between the chained and tandem schedules would be recoverable at lower ratios after experience on higher ratios, three of the birds were run again on the FR 90 value after being run on higher ratios. Again, pause durations under the chained schedules were substantially longer than under the corresponding tandem schedules.

For four birds, comparisons were made between three-component and five-component chained schedules having the same total response requirement for reinforcement. It was found that the post-reinforcement pause duration was in all cases longer under the five-component chains than under the three-component chains. The positive relationship

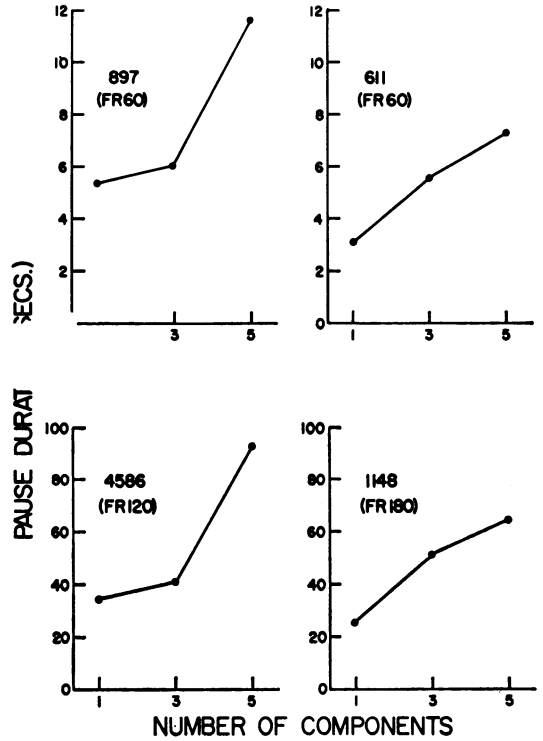


Fig. 2. Mean post-reinforcement pause duration as a function of number of components.

between pause duration and number of chain components is shown in Figure 2. It was interesting to note, incidentally, that when the number of chain components was decreased, the change in pause duration occurred quite rapidly, often in a single session. When the number of components was increased, however, the adjustment in pause level occurred much more gradually over a number of sessions.

Response Rates and Patterns

No consistent relationship was found between running rates (excluding the post-reinforcement pause) and ratio size in the present investigation. At larger ratio values, the rates of responding were sometimes higher and sometimes lower than at smaller ratio values. Moreover, the rate data were characterized by considerable variability, both within and between subjects.

Despite the general variability in the rate data, some consistent patterns appeared when equivalent portions of chained and tandem schedules were compared. Rates in the first

component were lower on the chained schedules than on the corresponding tandem schedules in 21 of the 25 schedule comparisons that were made for the eight birds. Rates in the final component were lower under the chained schedules in 16 cases. Although there was less consistency in the rate data for the middle components, in the majority of cases these rates were higher under the chained schedules. A comparison of three-component and five-component chained schedules showed that the five-component schedules had lower rates in the first component and higher rates toward the middle and end of the ratio run than the three-component schedules.

When the pattern of responding within the ratio run was examined, it was found that the running rates were almost always lower in the first component than in subsequent portions of the ratio, on both chained and tandem schedules. In a large number of cases, the response rate was higher in the middle than in the final component of the schedule. Although this pattern was more common under the chained schedules, occurring in about three-fourths of the total cases, it also occurred in about half of the tandem schedules as well. It occurred about equally often under the three-component and five-component schedules. In those cases where no such maximum rate occurred in the middle of the ratio, the usual pattern on both chained and tandem schedules was a progressive increase in rate from the beginning to the end of the ratio run.

The response rates for Bird 3253 at four different ratio values are shown in Figure 3. As

this figure shows, rates in the first and last components were in all cases lower under the chained schedule than under the equivalent tandem schedule. The difference between the rates on the two kinds of schedule was greater at higher ratio values, mainly as a result of higher rates on the tandem schedule. On the chained schedule, the increase in ratio size had little effect on the bird's rates. As in the case of the other seven subjects, this bird's running rates in the first component were lower than the rates in the second and third components, on both the chained and tandem schedules. Figure 3 also shows the peak in rate during the middle component, which occurred under all of the chained schedules as well as under two of the tandem schedules on which this bird was run.

*Total Time for Ratio Completion*

In almost all cases, it took the subjects longer to complete the ratio requirement on the chained schedules than on the equivalent tandem schedules. This was due mainly to the greater duration of the post-reinforcement pause under the chained schedules. However,



Fig. 3. Response rates of Bird 3253 in each component of chained and tandem schedules at different ratio values.

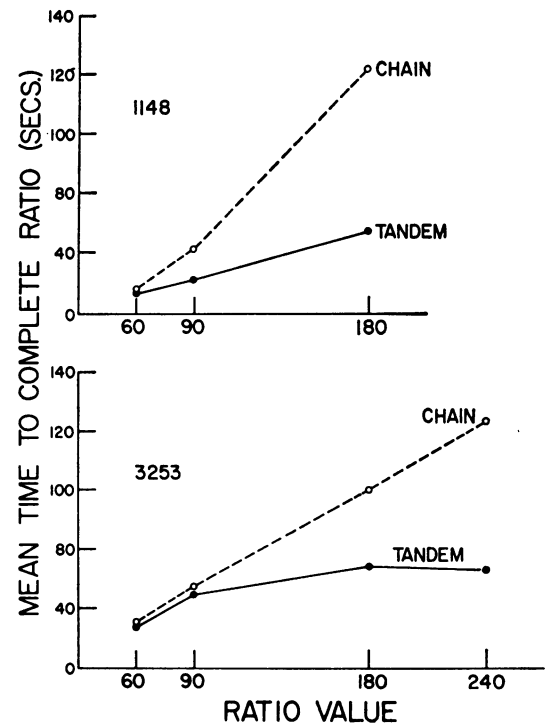


Fig. 4. Mean time to complete ratio (including pause time) at different ratio values.

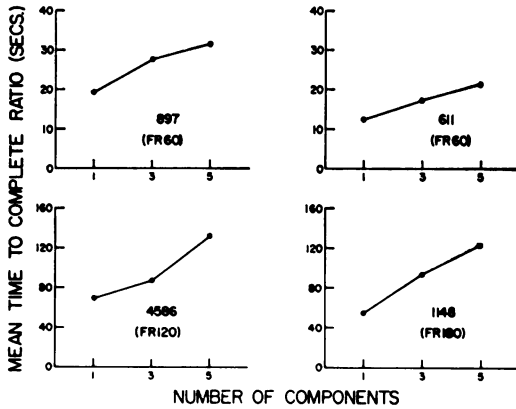


Fig. 5. Mean time to complete ratio as a function of number of components.

the lower running rates in the first component under the chained schedules also contributed to this result. The total time taken to complete the ratio, including both pause time and run time, is shown as a function of ratio size for two of the birds in Figure 4.

In the four cases where comparisons were made between three- and five-component chained schedules having the same total response requirement, the overall amount of time it took to complete the ratio was greater under the five-component schedules. This is shown graphically in Figure 5. Again, this was due to the longer pause and the lower first-component rates in the five-component schedules.

#### Effects of Changes in Stimulus Sequence

For three birds, the order of the chain stimuli was reversed at the FR 90 value, in order to determine the amount of discriminative control over responding that had been acquired by the individual stimuli. During the first session on this procedure, there was an immediate drop in the post-reinforcement pause duration for all three subjects. As Figure 6 shows, the pause for Birds 3253 and 7799 dropped to less than half its value in the previous session. A new discrimination soon formed, however, and during the second reversal session the pause duration went back up, almost to its level under the regular chain sequence. The effects of the reversed sequence were much less marked for Bird 611, perhaps because of a "ceiling" effect, since this bird's pause duration was already very short.

For all three birds, the mean running rate

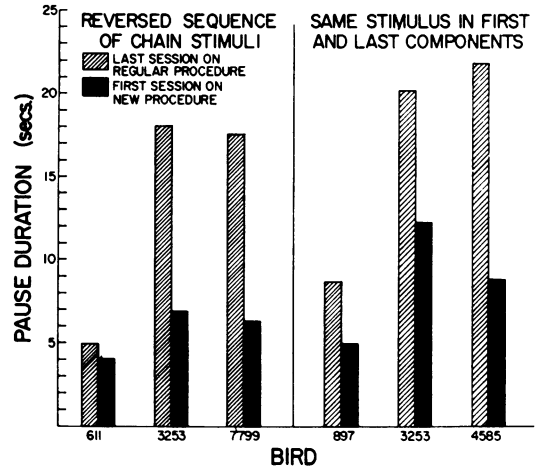


Fig. 6. Pause duration before and after change in stimulus sequence.

in Component 1 increased during the first reversal session, but decreased during the subsequent session. All three of these subjects showed a brief pause after the onset of the Component 2 stimulus during the first session with the reversed sequence. It was of particular interest to note that the reversal of the color sequence had no effect on the birds' latencies or response rates in the final chain component.

Three birds were then run on a procedure in which the previously final stimulus in the chain was used in both the first and last components, with the intermediate stimulus remaining the same. For all three birds, a large reduction (ranging from about 40 to 60%) occurred in the post-reinforcement pause duration during the initial session on this procedure (see Figure 6). Moreover, in subsequent sessions under this procedure, the pause remained much shorter than it had been under the regular chain sequence. One of the birds also showed a higher running rate during Component 1, and this increased rate was maintained throughout all 13 sessions on this procedure.

## DISCUSSION

### Pause Duration

The positive relationship between ratio size and post-reinforcement pause duration found in this study agrees with results obtained by several other investigators (*e.g.*, Ferster and Skinner, 1957; Felton and Lyon, 1966; Powell, 1968).

With regard to the effect of FR chain stimuli on ratio performance, the present data showed conclusively that such a procedure increases the duration of the post-reinforcement pause and thus delays the completion of the ratio. This was suggested by Ferster and Skinner's early work with block counters; however, it had not previously been systematically investigated using direct comparisons of chained and tandem procedures in alternating blocks of sessions. Data for all subjects in the present study, at five different ratio values ranging from FR 60 to FR 240, demonstrated that the block counter, by increasing the pause time, impairs ratio performance and decreases the rate at which the organism receives reinforcement.

A similar effect has been found with chained fixed-interval schedules. Gollub (1958) and Kelleher and Fry (1962) showed that the use of chained schedules containing several FI components results in long pauses after reinforcement, as compared with equivalent tandem schedules. Ferster and Skinner (1957) suggested an explanation for the effects of chain stimuli on responding, which would apply equally to the long post-reinforcement pauses obtained under both chained FI and chained FR schedules. They point out that the correlation between the stimuli and reinforcement in a chained schedule produces a "least favorable color". Since food reinforcement never occurs in its presence, the initial chain stimulus becomes a negative discriminative stimulus, or  $S_A$ , for responding. Similarly, Skinner (1938) and Boren (1953) pointed out that through stimulus generalization, the probability of responding depends on how closely the stimulus conditions of the pause resemble the conditions prevailing at reinforcement. From this point of view, there would be more stimulus generalization and thus a greater tendency to respond in the presence of the tandem stimulus, which is also present at the time of reinforcement, than in the presence of the first chain stimulus, which differs from that present at the time of reinforcement.

No previous research has investigated the combined effects of the initial chain stimulus and ratio size on post-reinforcement pause duration under chained FR schedules. The present study found that an interaction occurred between block counter effects and the effects of ratio size. That is, the difference in pause duration between the chained and tan-

dem schedules became greater as the size of the ratio was increased.

The difference in pause duration between chained and tandem schedules was maintained even when the two kinds of schedules were alternated several times in successive blocks of sessions. However, it was found that the difference was reduced to some extent as a result of the alternation, *i.e.*, the magnitude of the difference between the two types of schedules became somewhat smaller. Thus, it seems that some kind of sequential interaction occurred between the chained and tandem schedules. Although the difference between the two kinds of schedule was not eliminated by repeated alternations, experience on the chained schedule appeared to produce a lasting increase in the tandem pause, and experience on the tandem schedule produced a decrease in the chain pause. Some kind of generalization effect may have been responsible for this phenomenon.

One of the major findings of the present study was the effect of the number of blocks or FR chain components into which the total response requirement was divided, a question that had not previously been investigated systematically with chained FR schedules. The data showed conclusively that with the total response requirement held constant, schedules having a larger number of components result in longer pauses after reinforcement than schedules having fewer components.

#### *Response Rates and Patterns*

Previous studies have shown little agreement as to the effects of ratio size on rate of responding. Although the relationship between response rates and ratio size was of secondary importance in the present study, it was hoped that the results might help to shed some light on this question. If a systematic relationship does indeed exist between these two variables, it was believed that this relationship should become apparent in the present research, which obtained quantitative data over a larger range of ratio values than many previous studies, and with a larger number of sessions at each ratio value. The data obtained indicated that the FR running rate is insensitive to the parameter of ratio size. This same insensitivity of FR rates has been found with respect to several other variables, including deprivation

and extinction (Ferster and Skinner, 1957), prefeeding (Dews, 1956; Sidman and Stebbins, 1954) punishment (Azrin, 1959), and shock frequency and escape duration is escape studies (Azrin, Holz, Hake, and Ayllon, 1963). It has been suggested that this insensitivity may be due to the chaining of responses, *i.e.*, to the fact that each response is to a large extent under the control of the preceding response rather than the external parameters.

The present study found that response rates during the first component were lower on chains having five components than in chains having three components. The lower rates toward the beginning of the chains with more components could have been due to the fact that in such schedules the initial chain stimulus is a weaker discriminative stimulus for responding. Another possible explanation is that the stimulus for the second component may be a weaker conditioned reinforcer in chains having more components. The present data, however, do not provide a basis for distinguishing between these interpretations.

It has often been maintained that once an organism begins to respond on an FR schedule, after the initial pause, it runs off the ratio at a constant rate. In the present study, however, it was found that the running rates were lower toward the beginning of the ratio run, under all of the schedules. On the tandem schedules, which are simple FR schedules, there was often a progressive increase in rate from the first to the last component. A similar finding was reported by Thomas (1964). Suboski (1965), working with simple FR schedules, also found positive acceleration within the ratio run.

The finding that the rates usually dropped in the final component of the chained schedules was rather surprising. It might be expected that rates would be highest in the last component because this component was followed by food delivery, and because of the resulting discriminative power of the final chain stimulus, which was followed by food. If the decreased rate in the final component had occurred with equal frequency on chained and tandem schedules, it might be attributed to the operation of some kind of fatigue factor, especially since it seemed to be more pronounced at higher ratio values. However, such an explanation cannot account for the fact that this pattern occurred with considerably

greater frequency on the chained schedules than on the tandem schedules.

A possible explanation is that the bird slowed down toward the end of the ratio run in order to get ready to begin eating. Since the grain was available for only 3.5 sec, any delay due to the bird's "overshooting" the ratio requirement reduced its eating time. It was observed that toward the end of the ratio, rapid bursts of responding tended to be replaced by discrete pecks, sometimes accompanied by head movements toward the hopper, as if the bird were watching for cues indicating that grain had become available (*e.g.*, keylight going off or hopperlight going on). The greater frequency of this pattern under the chained schedules may have been due to the fact that the final chain stimulus provided an added cue that reinforcement was near.

#### *Changes in Stimulus Sequence*

One of the most interesting findings of the present study was the marked and immediate reduction that occurred in the duration of the post-reinforcement pause when the initial chain stimulus was replaced by the final chain stimulus, which previously had been most closely associated with food. When the first and last chain stimuli were simply reversed, the post-reinforcement pause duration soon increased again. However, when the final chain stimulus was used in both the first and last components, the pause duration dropped and remained at a lower level.

Apparently the strong discriminative power of the final chain stimulus overcame to some extent the bird's tendency to pause after reinforcement. If this stimulus was no longer used in the final component, the drop in the pause duration was only temporary, and a new discrimination soon formed. However, when the final chain stimulus was used in the first component and was also retained for the final component, its close association with food apparently caused the shorter pause duration to be maintained.

It was interesting to note that the use of the initial chain stimulus in the final chain component had no effect on performance in that component. The stimulus control exerted by natural stimuli toward the end of the ratio run appeared to be stronger than that exerted by the block counter stimuli provided by the experimenter.



## REFERENCES

- Azrin, N. H. Punishment and recovery during fixed-ratio performance. *Journal of the Experimental Analysis of Behavior*, 1959, 2, 301-305.
- Azrin, N. H., Holz, W. C., Hake, D. F., and Ayllon, T. Fixed-ratio escape reinforcement. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 449-456.
- Boren, J. J. *Response rate and resistance to extinction as functions of the fixed ratio*. Unpublished doctoral dissertation, Columbia University, 1953.
- Dews, P. B. Modification by drugs of performance on simple schedules of positive reinforcement. *Annals of the New York Academy of Science*, 1956, 65, 268-281.
- Felton, M. and Lyon, D. O. The post-reinforcement pause. *Journal of the Experimental Analysis of Behavior*, 1966, 9, 131-134.
- Ferster, C. B. and Skinner, B. F. *Schedules of reinforcement*. New York: Appleton-Century-Crofts, 1957.
- Findley, J. D. An experimental outline for building and exploring multioperant behavior repertoires. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 113-166.
- Gollub, L. R. *The chaining of fixed-interval schedules*. Unpublished doctoral dissertation, Harvard University, 1958.
- Jwaideh, A. R. *Stimulus functions in chained fixed-ratio schedules of reinforcement*. Unpublished doctoral dissertation, Indiana University, 1968.
- Kelleher, R. T. and Fry, W. T. Stimulus functions in chained fixed-interval schedules. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 167-173.
- Powell, R. W. The effect of small sequential changes in fixed-ratio size upon the post-reinforcement pause. *Journal of the Experimental Analysis of Behavior*, 1968, 11, 589-593.
- Sidman, M. and Stebbins, W. C. Satiation effects under fixed-ratio schedules of reinforcement. *Journal of Comparative and Physiological Psychology*, 1954, 47, 114-116.
- Skinner, B. F. *The behavior of organisms*. New York: Appleton-Century-Crofts, 1938.
- Suboski, M. D. Comparison of fixed and variable-ratio schedules of reinforcement. *Journal of Comparative and Physiological Psychology*, 1965, 59, 152-154.
- Thomas, J. R. Differential effects of two phenothiazines on chain and tandem schedule performance. *Journal of Pharmacology and Experimental Therapeutics*, 1966, 152, (2), 354-361.
- Thomas, J. R. Multiple baseline investigation of stimulus functions in an FR chained schedule. *Journal of the Experimental Analysis of Behavior*, 1964, 7, 241-245.

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