CONCURRENT SCHEDULES OF PRIMARY AND CONDITIONED REINFORCEMENT IN RATS¹

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Rats responded on a fixed-interval schedule during which a 3-sec stimulus preceded each water reinforcement. The stimulus was then scheduled concurrently for responses on the same lever according to either a variable interval or a variable ratio. Although water reinforcement continued on a fixed-interval schedule, the pattern of responding became typical of a variable-interval or variable-ratio schedule. When the 3-sec stimulus was presented on a variable-interval or variable-ratio schedule, but was omitted on the fixed-interval schedule, the response rate decreased. When the stimulus occurred after the same time periods as those of the variable-interval schedule, but at least 7-sec after the last response, the rate decreased. The rate became higher when the fixed-interval schedule was discontinued and each presentation of the 3-sec stimulus was followed by water on a variable-interval schedule. When both water and the 3-sec stimulus were discontinued for a period of time, resulting in extinction of the lever response, and the 3-sec stimulus alone then presented on a variable-interval or variable-ratio schedule after lever responses, rate increased and then gradually decreased.

Methods of maintaining responding over extended periods of time by conditioned reinforcement have been reported by Kelleher (1966), Zimmerman (1963, 1966, 1967), Findley and Brady (1965), and others. In the second-order schedules studied by Kelleher (1966), behavior specified by a schedule contingency was treated as a unitary response that was itself reinforced on a schedule. Patterns of positively accelerated responding were engendered when a 0.7-sec light was response-produced under fixed-interval schedule components in the second-order schedule. Findley and Brady (1965) and Thomas and Stubbs (1966) found similar effects with second-order schedules consisting of individual fixed-ratio schedules.

In a procedure used by Zimmerman and Hanford (1966) and Zimmerman, Hanford, and Brown (1967), the grain magazine operated as a consequence of key-pecking by a pigeon, but the cycle was so brief that the bird did not have access to grain. Operation of the magazine acted as a conditioned reinforcer, since responding continued indefinitely even though it did not produce grain. The reinforcing capability of the stimulus was

maintained by association with grain presented in the situation regularly, but not immediately after a response. In another procedure studied by Zimmerman (1963) and Zimmerman and Hanford (1967), responses on one key produced food, while responses on a different key produced a stimulus that had been associated with food. Responding that produced the stimulus was maintained indefinitely.

These experiments indicate conditioned reinforcement effects under what Zimmerman *et al.* (1967) called stable chronic conditions. They may be contrasted with what Kelleher and Gollub (1962) referred to as "extinction" procedures, in which the conditioned reinforcer is tested at the same time its power is undergoing extinction. In the studies cited above, a stimulus was associated regularly with primary reinforcement, and the stimulus maintained responding over long periods.

The present paper describes a method of studying conditioned reinforcement over long periods of time by the use of concurrent schedules. As in the techniques used by Kelleher and by Zimmerman, the stimulus was associated regularly with primary reinforcement. Initially, lever responses produced primary reinforcement, accompanied by a 3-sec stimulus, on a fixed-interval schedule. Later, responses produced the 3-sec stimulus on a second schedule, and primary reinforcement,

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accompanied by the stimulus, continued concurrently on a fixed-interval schedule. If primary reinforcement alone maintained responding, the pattern would remain characteristic of the original fixed-interval schedule. The extent to which the pattern changed to that typical of the second schedule was an indication of the conditioned reinforcing properties of the stimulus.

METHOD

Subjects

Twenty-three Sprague-Dawley male albino rats, approximately 90 days old at the beginning of the experiment, were given daily 1-hr sessions under 22-hr water deprivation. Food was continuously available in the home cages.

Apparatus

Four units, each a Gerbrands model C-3 chamber with a liquid feeder and a lever 3.5 in. from the floor, were enclosed in ventilated ice chests. Stimuli in each unit consisted of a 750-cps tone and a 7.5-v lamp with a white crystal. The lever and the opening of the liquid feeder were on opposite walls of the chamber, 8 in. apart. Responses were recorded on Gerbrands cumulative recorders.

Procedure

Rats were conditioned to press a lever for water reinforcement. Preceding operation of the liquid feeder by 3-sec throughout the training period was a stimulus consisting of a white light and tone. It was terminated at the moment the liquid feeder operated, and the rat then had access to 0.1 cc of water for 6 sec.

After two sessions, during which every response produced a stimulus and water, a 3-, 5-, 6-, or 10-min fixed-interval schedule (FI 3-min, FI 5-min, FI 6-min, or FI 10-min) was begun. The 3-sec stimulus, followed by water, was produced by the first response occurring after a fixed period of time. Throughout the experiment, lever presses during the 3-sec light and tone had no scheduled consequences and were not recorded. Observations indicated that, after the initial training, rats almost invariably moved away from the lever toward the opening to the water device during this period.

Establishment of concurrent schedule. After 12 to 18 sessions on the fixed-interval sched-

ule, the concurrent schedule was begun. The 3-sec stimulus and water were produced on a fixed-interval schedule, and, concurrently, the 3-sec stimulus was produced on either a variable-interval or variable-ratio schedule. On the variable-interval schedule, the 3-sec stimulus was produced by the first response after a designated period of time since the last presentation of the stimulus, with the periods varying from one presentation to another. On the variable-ratio schedule, the 3-sec stimulus was produced by a designated number of responses after the last presentation of the stimulus, with the number of responses varying from one presentation to another. The variable-interval schedule was an arithmetic series with a mean interval of 2-min (VI 2-min), and the variable-ratio schedule was an arithmetic series with a mean ratio of 12 (VR 12). Therefore, on both of these schedules, 3-sec stimulus presentations occurred frequently between water reinforcements.

That a transition in performance from one characteristic of a fixed-interval schedule to one characteristic of either a variable-interval or variable-ratio schedule could be attributed to reinforcing properties of the 3-sec stimulus was established by the following control procedures.

Extinction procedure. Enhancing effects of the 3-sec stimulus were tested using a conventional extinction procedure. After performance on the concurrent schedule, an 80-min extinction period, during which lever presses had no scheduled consequences, occurred. Then, the 3-sec stimulus alone was presented on a variable-interval or variable-ratio schedule as a consequence of lever-presses.

Elimination of association of stimulus and primary reinforcement. This procedure determined if there would be a transition of performance back to that typical of a fixed-interval schedule when association of the stimulus with water no longer occurred. The stimulus was presented on the variable-interval or variable-ratio schedules described above, but was omitted in association with water reinforcement.

Presentation of stimulus on DRO schedule. This procedure determined whether the 3-sec stimulus could facilitate lever pressing even when it did not immediately follow a response. After variable time periods, which were the same as those of the variable-interval schedule

Table 1
Summary of Procedures

Schedule	Number of Sessions				
	Rats C1-C6	Rats L1-L6	Rats G1-G4	Rats G5-G8	Rats K1-K3
Fixed interval	12	12	18	18	12
Concurrent, stimulus on variable interval	26	—	8	—	3
Concurrent, stimulus on variable ratio	—	26	—	8	—
DRO	3	—	—	—	3
Concurrent, stimulus on variable interval	3	—	—	—	—
Fixed interval	3	3	—	—	—
Variable interval	3	—	—	—	3
Extinction procedure	3	3	—	—	3
Concurrent, stimulus on variable interval	—	—	—	—	3
Fixed interval	—	—	—	—	3
Concurrent, stimulus on variable interval, no association of stimulus and water	—	—	8	—	—
Concurrent, stimulus on variable ratio, no as- sociation of stimulus and water	—	9	—	8	—

described above, the 3-sec stimulus was presented when at least 7-sec had elapsed since the last response [differential reinforcement of other behavior (DRO) contingency]. The fixed-interval schedule of water remained in effect concurrently, and association of stimulus and water continued.

Comparison to variable-interval schedule of primary reinforcement. Performance was examined when the fixed-interval schedule was discontinued and water followed each presentation of the 3-sec stimulus on the variable-interval schedule.

The procedures are summarized in Table 1. Groups of rats designated as C, L, G, and K were run one after the other in that order. Within the C, L, G, and K groups the order of experimental sessions was from top to bottom in the table.

RESULTS

A transition occurred within a single session after the variable-interval or variable-ratio schedule of 3-sec stimulus presentations was superimposed upon the ongoing fixed-interval schedule. The most prominent change was an increase in mean rate of responding, occurring immediately after the new schedule was in

effect. Patterns of positively accelerated responding under the fixed-interval schedule were disrupted. Generally, changes in mean rate of response were more marked and more consistent than changes in positively accelerated responding. Quantitative measures of positively accelerated responding under this and other procedures are presented below.

Figures 1, 2, and 3 show typical performances in which the 3-sec stimulus was produced on a variable-interval schedule. In record *A* of Fig. 1 and 2, both 3-sec stimulus and water were on FI 5-min, while in record *B* of Fig. 1 and records *B* and *C* of Fig. 2, the 3-sec stimulus was on VI 2-min and water was on FI 5-min.

The DRO schedule brought about a decline in response rate. Typical performances are shown in record *C* of Fig. 1 and record *D* of Fig. 2. On the DRO schedule, rats continued to move to the water device during presentation of the 3-sec stimulus. On the variable-interval schedule, with each presentation of the 3-sec stimulus followed by water, a consistently high rate occurred. Record *A* of Fig. 3 shows a typical performance.

The extinction procedure had a result similar to those found in previous experiments using this technique (see Kelleher and Gollub,

Fig. 1. Representative cumulative records (Rat C2) showing fixed-interval schedule (record A), concurrent fixed-interval schedule of water and variable-interval schedule of 3-sec stimulus (record B), concurrent schedule with 3-sec stimulus presented at least 7-sec after last response (record C), and transition back to fixed-interval schedule of water (record D). In records A and D, presentation of both 3-sec stimulus and water is indicated by downward movement of the recorder pen. In records B and C, presentation of 3-sec stimulus is indicated by downward movement of the recorder pen, and water is indicated by heavy vertical marks below the record.

Fig. 2. Representative cumulative records (Rat K2) showing fixed-interval schedule (record A), concurrent fixed-interval schedule of water and variable-interval schedule of 3-sec stimulus (records B and C), and concurrent schedule with 3-sec stimulus presented at least 7-sec after last response (record D). In record A, presentation of both 3-sec stimulus and water is indicated by downward movement of the recorder pen. In records B, C, and D, presentation of 3-sec stimulus is indicated by downward movement of the recorder pen, and water is indicated by heavy vertical marks below the record.

1962). In the initial extinction period, when responses were no longer followed by either the 3-sec stimulus or by water, rate of lever-pressing gradually declined. The performance was characteristic of extinction following a variable-interval schedule (Ferster and Skinner, 1957). When the 3-sec stimulus was then presented on VI 2-min, there was a marked increase in rate, followed by a gradual decrease. A similar result was found when the stimulus was presented on VR 12. An extinction procedure is shown in records B and C of Fig. 3. After a period during which no responses were reinforced, the 3-sec stimulus was presented on VI 2-min, beginning at the arrow. Record D of Fig. 3 shows a return to the concurrent schedule.

Response rates under the concurrent schedule similar to those in Fig. 1, 2, and 3 were

maintained over as many as 26 sessions. A transition from a pattern of positively accelerated responding to one of a constant rate of responding occurred within a single 1-hr session, and the pattern remained characteristic of the new schedule over many sessions.

Figure 4 summarizes the performance of three rats (K1, K2, and K3) under the above procedures in the following order: (1) initial fixed-interval schedule of water, (2) concurrent schedule with 3-sec stimulus on VI 2-min and water on FI 6-min, (3) DRO schedule, and (4) variable-interval schedule of water. Each point in the figure represents the mean number of responses made by one rat in a given quarter of the interval between water presentations throughout three 1-hr sessions under each procedure. The left-hand point in each section is the earliest quarter of the

Fig. 3. Representative cumulative records (Rat K2) showing variable-interval schedule with each 3-sec stimulus presentation followed by water (record A), extinction procedure (records B and C), and return to concurrent fixed-interval schedule of water and variable-interval schedule of 3-sec stimulus (record D). In record A, presentation of both 3-sec stimulus and water is indicated by downward movement of recorder pen. In records B, C, and D, presentation of 3-sec stimulus is indicated by downward movement of recorder pen, and water is indicated by heavy vertical marks below the record.

interval, and the right-hand point is the quarter just preceding water reinforcement.

When the 3-sec stimulus was presented on a variable-ratio schedule, the results were similar to those described above. There was an immediate change in response rate and a disruption of positively accelerated responding. High rates of response, typical of variable-ratio schedules (Ferster and Skinner, 1957) were generated. Figures 5 and 6 show typical performances. The initial fixed-interval schedule (record A in both figures) was FI 10-min, and the 3-sec stimulus was presented on VR 12 (records B and C in both figures).

Omitting the association between the 3-sec stimulus and water brought about a return to a pattern of positively accelerated responding. Figures 7 and 8 show this procedure. In

both figures, record A begins with an extinction period. At the arrow in record A, the 3-sec stimulus was presented on a variable-ratio schedule. Beginning at the arrow in record B, a concurrent schedule was in effect, except that the 3-sec stimulus was omitted before water. The water schedule was FI 10-min as before. Beginning at the arrow in record D, association of stimulus and water was resumed.

Fig. 4. Mean response rates of three rats (K1-K3) in each quarter of 6-min intervals between presentation of water. Each point is the mean number of responses made by one rat in a given quarter of the interval over all intervals throughout three 1-hr sessions. The open circles represent the performance during sessions in which the 3-sec stimulus occurred only before water on a 6-min fixed-interval schedule. The open squares represent the performance during sessions in which the 3-sec stimulus was presented on a variable-interval schedule as a consequence of responses throughout the interval and also continued to occur before water. The solid squares represent the performance during sessions in which the 3-sec stimulus was presented at variable time periods throughout the interval, but at least 7-sec after the last response. The solid circles represent the performance during sessions in which the 3-sec stimulus was presented on a variable-interval schedule and each presentation was followed by water.

Figure 9 presents the mean number of responses in each quarter of the fixed interval between water presentations under three conditions: (1) original fixed-interval schedule, (2) concurrent schedule, and (3) concurrent schedule without association of 3-sec stimulus and water. The eight rats whose records are shown in this figure were on a 10-min fixed-interval schedule of water. Each point in the figure represents the mean number of responses made by one rat in a given quarter of the interval over all intervals throughout the last four 1-hr sessions under each procedure. The left-hand point in each section is the earliest quarter of the interval, and the right-hand point is the quarter just preceding water reinforcement.

Fig. 5. Representative cumulative records (Rat L2) showing fixed-interval schedule of water (record A), concurrent fixed-interval schedule of water and variable-ratio schedule of 3-sec stimulus (records B and C), and transition back to fixed-interval schedule of water (record D). In records A and D, presentation of both 3-sec stimulus and water is indicated by downward movement of the recorder pen. In records B and C, presentation of 3-sec stimulus is indicated by downward movement of the recorder pen, and water is indicated by heavy vertical marks below the record.

DISCUSSION

This experiment provided further evidence that a stimulus that is temporally contiguous with a primary reinforcer can become a conditioned reinforcer and maintain responding over extended periods of time. A fixed-interval performance was first established by primary reinforcement. Then, a stimulus that had been associated with primary reinforcement, and which continued to be associated with primary reinforcement, was presented as a consequence of responses on the same lever on a different schedule. Conditioned reinforcing effects were indicated by a transition of the performance to that characteristic of the new schedule. Once the concurrent schedule was in effect, the typical performance continued for as many as 26 sessions. When the 3-sec stimulus no longer occurred as a consequence of responding throughout the in-

Fig. 6. Representative cumulative records (Rat L3) showing fixed-interval schedule of water (record A), concurrent fixed-interval schedule of water and variable-ratio schedule of 3-sec stimulus (records B and C), and transition back to fixed-interval schedule of water (record D). In records A and D, presentation of both 3-sec stimulus and water is indicated by downward movement of the recorder pen. In records B and C, presentation of 3-sec stimulus is indicated by downward movement of the recorder pen, and water is indicated by heavy vertical marks below the record.

terval between water reinforcements, the performance returned to that of the original fixed-interval schedule.

Previous experiments have shown that conditioned reinforcers can establish typical fixed-interval performance (Kelleher, 1961, 1966; de Lorge, 1967) and fixed-ratio performance (Kelleher, 1961; Findley and Brady, 1965; Thomas and Stubbs, 1966). The present experiment showed that concurrently scheduled conditioned reinforcement can disrupt patterns of positively accelerated responding on fixed-interval schedules of water presentation and generate the patterns of variable-interval and variable-ratio schedules.

The data also appear to indicate that the function of the stimulus is dependent upon its association with primary reinforcement. When the stimulus was presented on a variable-interval or variable-ratio schedule, but no longer associated with water, the re-

Fig. 7. Representative cumulative records (L2) showing effect of omitting association between 3-sec stimulus and water. Beginning at the arrow in record A, after extinction of the lever response, the 3-sec stimulus was presented on a variable-ratio schedule. Beginning at the arrow in record B, and continuing in records B and C, the 3-sec stimulus was presented on a variable-ratio schedule at the downward movements of the recorder pen, while water, not accompanied by the 3-sec stimulus, was presented on a fixed-interval schedule at the heavy vertical marks. Beginning at the arrow in record D, the 3-sec stimulus was presented on a variable-ratio schedule at the downward movements of the recorder pen, and both the 3-sec stimulus and water were presented on a fixed-interval schedule at the heavy vertical marks.

Fig. 8. Representative cumulative records (Rat L3) showing effect of omitting association between 3-sec stimulus and water. Beginning at the arrow in record A, after extinction of the lever response, the 3-sec stimulus was presented on a variable-ratio schedule. Beginning at the arrow in record B, and continuing in records B and C, the 3-sec stimulus was presented on a variable-ratio schedule at the downward movements of the recorder pen, while water, not accompanied by the 3-sec stimulus, was presented on a fixed-interval schedule at the heavy vertical marks. Beginning at the arrow in record D, the 3-sec stimulus was presented on a variable-ratio schedule at the downward movements of the recorder pen, and both the 3-sec stimulus and water were presented on a fixed-interval schedule at the heavy vertical marks.

sponse rate decreased. This result is similar to those obtained by Kelleher (1966) and de Lorge (1967). Kelleher found that when a brief exteroceptive stimulus that had enhanced performance on a second-order schedule was replaced by a different stimulus not associated with food after the terminal segment, the effect decreased. It was found by de Lorge that when a stimulus that had enhanced performance in the earlier segments of a second-order schedule was no longer associated with food after the terminal segment, its effect decreased.

In the present study, when the 3-sec stimulus occurred after the same time periods as those of the variable-interval schedule described above, but at least 7-sec after the last response, the rate declined. This suggests that

the results obtained with the concurrent schedule cannot be attributed to effects of the stimulus other than reinforcing ones. The decline in rate of lever pressing may have resulted from reinforcement of other behavior by the stimulus when presented with the 7-sec no-response requirement.

Additional evidence of the conditioned reinforcing properties of the 3-sec stimulus is provided by the result of an extinction procedure. When the stimulus alone was presented as a consequence of responses on a variable-interval or variable-ratio schedule after the lever-pressing response had first been extinguished, rate increased, then declined. This result seems to indicate that the stimulus acted temporarily as a conditioned reinforcer,

Fig. 9. Mean response rates of eight rats (G1-G8) in each quarter of interval between presentations of water on 10-min fixed-interval schedule. Each point is the mean number of responses made by one rat in a given quarter of the interval over all intervals throughout four 1-hr sessions. The open circles represent the performance during sessions in which the 3-sec stimulus occurred only before water. The solid circles represent the performance during sessions in which the 3-sec stimulus was presented on a variable-interval or variable-ratio schedule as a consequence of responses throughout the interval, and also continued to occur before water. The squares represent the performance during sessions in which the 3-sec stimulus was presented on a variable-interval or variable-ratio schedule as a consequence of responses throughout the interval, but did not occur before water. The concurrent schedule of 3-sec stimulus presentations was variable-interval for Rats G1-G4 and variable-ratio for Rats G5-G8.

but gradually lost its power to reinforce, since association with water no longer occurred.

The response rate on a variable-interval schedule in which all reinforcements were primary was higher than the rate on the concurrent schedule, in which some reinforcements were primary and some were conditioned. This may be an indication of the weaker effects of conditioned reinforcers relative to primary reinforcers. The fact that the concurrent schedule did not invariably eliminate positively accelerated responding between reinforcements on the fixed-interval

schedule leads to the same conclusion. These results are consistent with the findings of many other investigators (see Kelleher and Gollub, 1962) who have found conditioned reinforcers to be less effective than primary reinforcers.

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