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CONTINGENCY AND STIMULUS CHANGE IN CHAINED SCHEDULES OF REINFORCEMENT

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Higher rates of pecking were maintained by pigeons in the middle component of three-component chained fixed-interval schedules than in that component of corresponding multiple schedules (two extinction components followed by a fixed-interval component). This rate difference did not occur in equivalent tandem and mixed schedules, in which a single stimulus was correlated with the three components. The higher rates in components of chained schedules demonstrate a reinforcing effect of the stimulus correlated with the next component; the acquired functions of this stimulus make the vocabulary of conditioned reinforcement appropriate. Problems in defining conditioned reinforcement arise not from difficulties in demonstrating reinforcing effects but from disagreements about which experimental operations allow such reinforcing effects to be called conditioned.

Key words: chained schedule, tandem schedule, multiple schedule, mixed schedule, fixed-interval schedule, conditioned reinforcement, contingency, key peck, pigeons

The concept of conditioned reinforcement was implicit in the original definition of chained schedules: "A schedule in which responding under one stimulus on a given schedule is reinforced by the production of a second stimulus in the presence of which a response is reinforced on a second schedule . . ." (Ferster & Skinner, 1957, p. 724). Including reinforcement in this definition made the maintenance of responding in one component by the onset of the next component a defining property of chained schedules. The definition followed from demonstrations of higher response rates in the initial components of two-component chained schedules than in corresponding extinction (EXT) components of two-component multiple schedules (e.g., with chained variable-interval or VI schedules, chained VI VI versus multiple EXT VI: Ferster & Skinner, 1957, Chapter 12). These schedules began to be defined more strictly in terms of procedure rather than behavioral outcome with the finding that responding was not well maintained in early components of extended chained schedules (e.g., Gollub, 1958; Kelleher & Fry, 1962).

Chained schedules include both contingency, in that the production of one component depends on responding in the preceding component, and stimulus changes, in that each component is correlated with a different stimulus. Demonstrating the reinforcing effects of successive chained components requires comparisons among chained, multiple, tandem, and mixed schedules (cf. Silverman, 1971). The progression of components depends on responding in chained and tandem but not in multiple and mixed schedules; successive components are correlated with different stimuli in chained and multiple but not in tandem and mixed schedules.

Consider three-component chained fixed-interval (FI) schedules. At the end of the initial component, a response produces the stimulus correlated with the middle component; at the end of that component, a response produces the stimulus correlated with the final component; and at the end of that component, a response produces the primary reinforcer. If the contingency between responding and stimulus changes is eliminated in the first two components, the chained FI FI FI schedule becomes a multiple EXT EXT FI schedule. (The

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implicit stimulus functions in the vocabulary of chained schedules are emphasized by noting that this multiple schedule can also be regarded as a chained FT FT FI schedule, where FT schedules deliver the reinforcer independently of responding at the end of a fixed time.)

If stimulus changes are eliminated instead of the contingency, by substituting a single stimulus for the three different component stimuli, the chained schedule becomes a tandem FI FI FI schedule. Finally, if both the contingency and stimulus changes are eliminated, the schedule becomes a mixed EXT EXT FI schedule (equivalent to a simple FI schedule with a duration equal to the sum of the durations of the three successive components).

The present experiments compared the performances maintained by three-component chained, multiple, tandem, and mixed schedules. The schedules differed in contingency in that the primary reinforcer depended on at least three responses in the chained and tandem schedules (one at the end of each fixed interval) but on only a single response in the multiple and mixed schedules (at the end of the fixed interval in the last component). The schedules differed in stimuli in that the three components were each correlated with a different stimulus in the chained and multiple schedules but with only a single stimulus in the tandem and mixed schedules. Actual rather than scheduled durations of the first two FI components of the chained and tandem schedules were used to determine the durations of the corresponding EXT components of the multiple and mixed schedules.

METHOD

Subjects

Fifteen adult male White Carneaux pigeons were maintained at about 80% of free-feeding body weights. Their histories included interval and ratio schedules of reinforcement, and an experiment on generalization and discrimination of line orientation.

Apparatus

Five standard pigeon chambers each included a 2.0-cm translucent Gerbrands key centered above a Gerbrands feeder. Each key could be lit from behind with blue, red, green, or white light by a digital display unit (Grason-Stadler E4580 Multiple Stimulus Projector with No. 170 stimulus patterns).

Procedure

The general design of the experiment evolved as a unit in an undergraduate course in operant behavior. Details of general laboratory procedure and equipment are described in Catania, Matthews, Silverman, & Yohalem (1977). The reliability and rapidity of their development make the performances generated by chained schedules particularly suitable for an undergraduate laboratory course. The data here were selected for presentation because during these semesters the relevant schedule comparisons were combined within a single laboratory unit. In preceding semesters, overall design and such parameters of chained schedules as number of components were explored. By the time of the present studies, the conduct of this laboratory unit was routine, and staff could concentrate on the accuracy with which students arranged procedures and recorded data. To reduce the likelihood of undetected recording errors, redundancies were built into data to be recorded from counters, and spot checks were made of recorded data and of their consistency with cumulative records.

Pairs of three-component chained and multiple or tandem and mixed schedules of reinforcement were arranged. The chained schedule consisted of three FI 30-sec components. Within each session this schedule alternated with a multiple schedule in which two EXT components were followed by an FI 30-sec component. Each of the three chained and three multiple components was correlated with a different stimulus. The durations of the two EXT components of the multiple schedule were yoked to the nearest second to those of the corresponding components of the preceding chained schedule. For example, if the initial FI 30-sec component of the chained schedule was terminated by a response after 40 sec, the initial EXT component of the next multiple schedule was also presented for 40 sec. In practice, the middle component of the chained schedule was usually terminated promptly by a response at the end of the 30-sec fixed interval, so that only durations of initial components were affected by the yoking.

Pairs of tandem and mixed schedules were equivalent to the chained and multiple sched-

ules, except that only one stimulus was correlated with the three components of the tandem schedule, and a different stimulus was correlated with the three components of the mixed schedule. These two schedules alternated within each session, with the durations of the two EXT components of the mixed schedule yoked to those of the corresponding FI components of the preceding tandem schedule. Rates of responding were sufficiently high in the tandem schedule that yoking had little effect on either initial- or middle-component durations.

In the Fall semester, alternating chained and multiple schedules were arranged for one group of five pigeons, and alternating tandem and mixed schedules were arranged for a second group of five pigeons. Each daily session consisted of 24 reinforcers (12 presentations of each schedule). Two four-day blocks of sessions were separated by a three-day interruption. In the Spring semester, alternating chained and multiple schedules were arranged for five pigeons for four sessions of 40 reinforcers each (20 presentations of each schedule). After a three-day interruption, four sessions of alternating tandem and mixed schedules were arranged for the same pigeons.

Reinforcement duration was 4 sec, during which the feeder was lit and keylights and houselight were off. The colors correlated with the various schedule components were partially counterbalanced, as summarized in Table 1. Because only four colors were available in the display units, orange was produced by lighting both the red and green lamps, and violet by lighting both the red and the blue lamps. Although the appearance of the key varied with angle of view with these stimuli, the data from these and preceding semesters provided no evidence of differences in discriminability among the six stimuli.

Table 1

Sequences of stimuli for each pigeon in the three components of chained, multiple, tandem, and mixed schedules.

Pigeons (12/69)	*143, 145, 147*	*144, 146*
Chained	R V G	O W B
Multiple	O W B	R V G
Pigeons (12/69)	*148, 150, 152*	*149, 151*
Tandem	R R R	G G G
Mixed	G G G	R R R
Pigeons (4/70)	*338, 343, 345*	*339, 344*
Chained	R V G	O W B
Multiple	O W B	R V G
Tandem	B B B	G G G
Mixed	G G G	B B B

Note: R = red; V = violet; G = green; O = orange; W = white; B = blue.

RESULTS

As shown in Figure 1, the results in the two semesters were similar despite differences in the number of sessions and the allocation of pigeons to procedures. Rates of responding tended to be lower in the initial and higher in the final components of the chained and multiple schedules (first and third rows) than in the corresponding components of the tandem and mixed schedules (second and fourth rows).

In the chained and multiple schedules, response rates were not systematically different in the initial and final components (−3 and −1), but for all 10 pigeons higher rates were maintained in the middle component of the chained schedule than in the middle component of the multiple schedule (−2). In the tandem and mixed schedules, however, response rates were not systematically different in any of the three components; in terms of absolute rate, in no case did any direction of difference occur for more than seven of the ten pigeons. The right column of Figure 1 summarizes these findings, showing mean relative rates in each component; for each component, response rates were expressed relative to that pigeon's rate in the final component (−1) and were then averaged across the five pigeons.

The dashed lines (Figure 1) show mean component durations for each pair of schedules for each pigeon. The durations of the first two components of the multiple and mixed schedules were set equal to those of the corresponding components of the chained and tandem schedules with which they were respectively paired. In the initial component, pauses that lengthened component duration were frequent in the chained schedule but infrequent in the tandem schedule. In neither schedule did pauses appreciably affect the durations of the middle components.

Sample cumulative records for each pair of schedules are shown for Pigeon 343 in Figure 2. The top record illustrates how a long pause (and therefore a long component duration) in an initial component of the chained schedule was sometimes followed by an extended period of low-rate responding in the initial

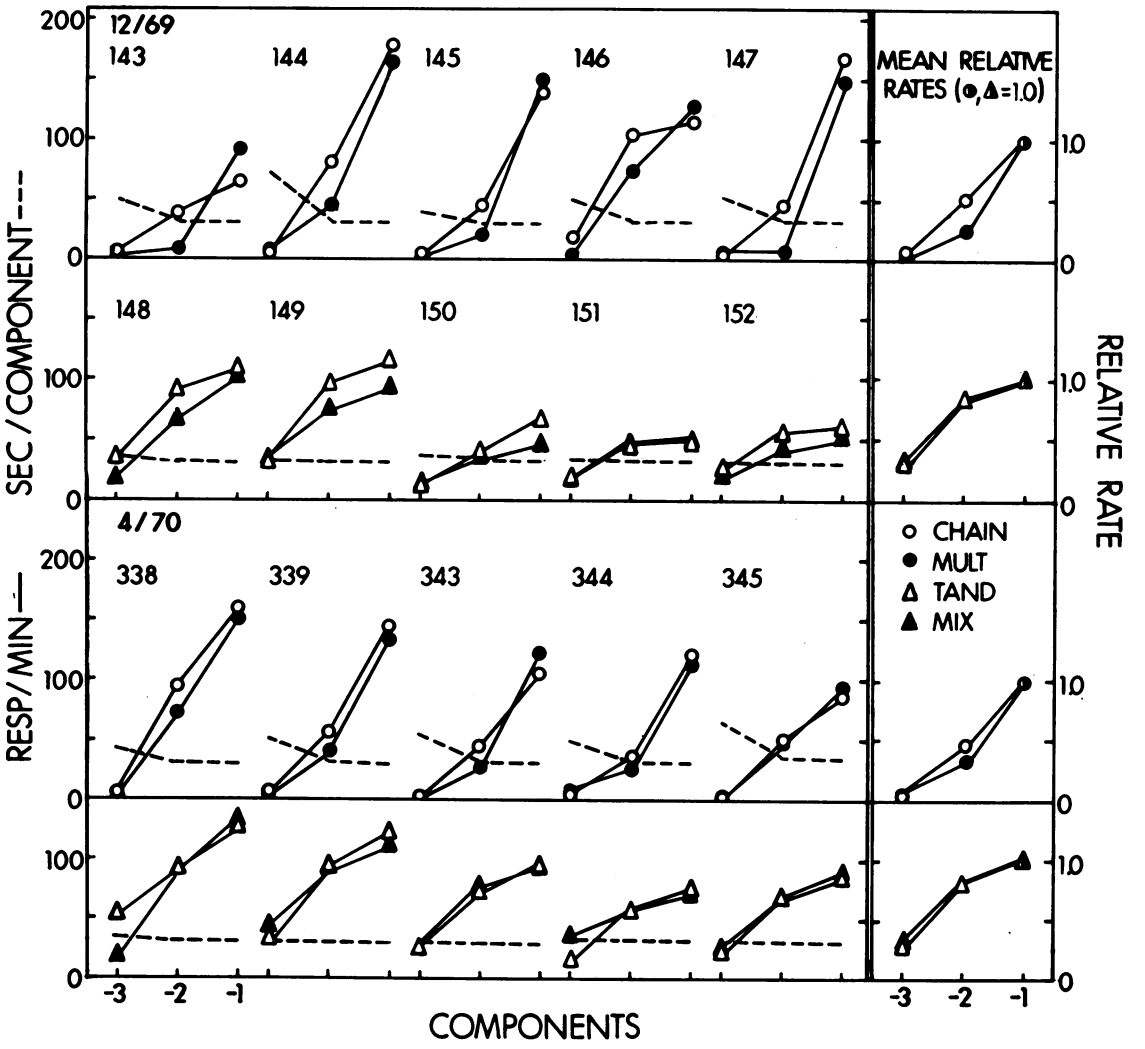

Fig. 1. Response rates and component durations in three-component chained (CHAIN), multiple (MULT), tandem (TAND), and mixed (MIX) schedules of reinforcement. The components are labeled backwards from reinforcement (−3 is the initial component, and −1 the final component). The data in the top two rows are means over the last two of eight 24-reinforcement sessions, and the data in the bottom two rows are from the last of four 40-reinforcement sessions. The right frames show arithmetic means across pigeons of the relative response rates in each component, where rate in the last component (−1) is taken as unity.

component of the subsequent multiple schedule (e.g., at *a* and *b*, and at *c* and *d*). As illustrated in the bottom record, pausing at the beginning of the tandem schedule (e.g., at *e* and *f*) rarely was long enough to extend the duration of the initial component appreciably.

DISCUSSION

In order to call a stimulus a reinforcer, it is not enough to show that a response produced that stimulus and then responding increased. It is also necessary to show that the increased responding occurred because the response produced the stimulus and not for some other reason (e.g., an eliciting effect following the first production of the stimulus). By these criteria, responding in the middle component of the chained schedule was reinforced by the onset of the stimulus correlated with the final component. Higher rates of responding were maintained by the contingency between responding and stimulus changes (chained schedule) than by the stimulus changes alone (multiple schedule); furthermore, in the absence of stimulus changes, the

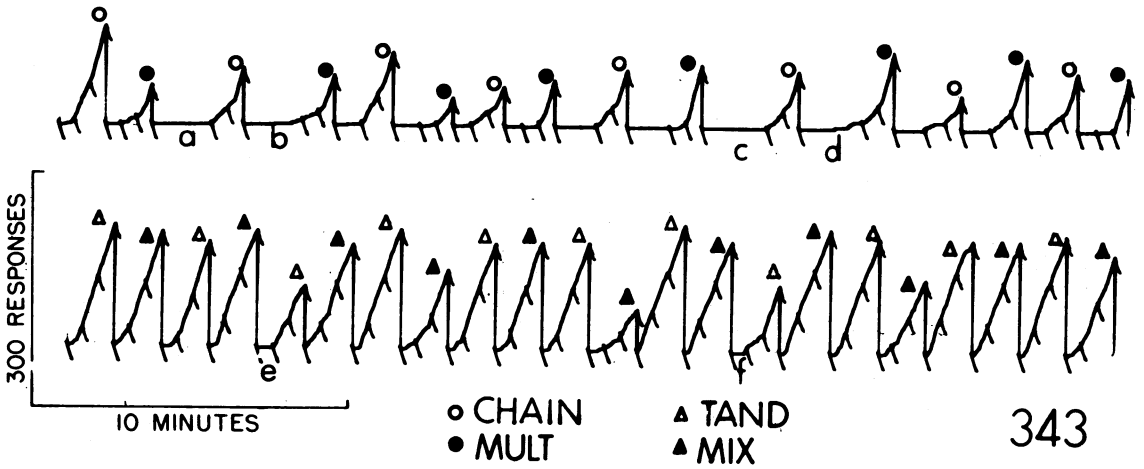

Fig. 2. Cumultative records of Pigeon 343's performance on chained (CHAIN), multiple (MULT), tandem (TAND), and mixed (MIX) schedules of reinforcement. Component changes are indicated by pip marks, and reinforcement by pip marks and reset to baseline.

contingency alone did not produce a rate difference (tandem and mixed schedules).

Stimulus Functions

The stimuli in chained schedules can have discriminative as well as reinforcing functions. It therefore could be argued that the contingency difference between the tandem and mixed schedules would have had an effect with continued exposure to those schedules, or might have varied as a function of the absolute rate of responding or some other property of those performances. Paradoxically, analogous objections would probably not be raised with respect to primary reinforcers. For example, when a particular response is reinforced with food, the conclusion that the food is a reinforcer would not wait upon manipulations of the discriminability of the food (e.g., by comparing oral ingestion, stomach loading, and intravenous feeding) or upon demonstrations that the food can function as an antecedent discriminative stimulus (e.g., Reid, 1958). To say that when food serves as a reinforcer the organism must discriminate the presence of food from its absence is to speak plausibly but imprecisely of discrimination (i.e., in the colloquial sense of "telling the difference"). It is an empirical question whether the discriminative functions of an antecedent stimulus are correlated with its reinforcing functions when the stimulus is consequent. For example, it is conceivable, given an organism unable to discriminate between electrical stimulation at two brain sites, that stimulation at one of those sites but not the other would be effective as a reinforcer.

Consider again the argument that a difference between response rates might have emerged with continued exposure to the tandem and mixed schedules. A difference in overall rates would have been of little relevance because the phenomenon of concern involves relative as well as absolute rates across components (Figure 1, right column). Suppose, however, that the contingency difference between tandem and mixed schedules eventually produced a rate difference restricted to the middle component and comparable to that in the chained and multiple schedules. There is no evidence that such a difference was developing in the present experiments. Nevertheless, it is not appropriate simply to observe that this outcome is unlikely. Rather, the issue is how a phenomenon that develops slowly (the hypothetical tandem-mixed difference with extended exposure) might bear on one that develops rapidly (the observed chained-multiple difference). Compared with the slow emergence of temporal discrimination within the successive components of the tandem and mixed schedules, the rapidly demonstrable stimulus functions within the chained and multiple schedules would continue to justify the language of reinforcement. In other words, it would still be appropriate to say that the relatively higher response rate in the middle component of the chained schedule than in the multiple schedule occurred because responding in that component produced a stim-

ulus change. In general, to account for a behavior change that develops rapidly, it is inappropriate to appeal to another that develops slowly.

In summary, then, had the contingency difference between tandem and mixed schedules produced a rate difference in the middle component as quickly as, and comparable in magnitude to, that in the chained and multiple schedules, this would have demonstrated that the rate difference did not depend on stimulus changes and therefore that the final-component stimulus of the chained schedule was not a conditioned reinforcer. The absence of such a difference illustrates the interaction of contingency and stimulus change: in the definition of reinforcement, both criteria are essential.

Effects of Yoking

Discriminative functions of the chained stimuli are demonstrated by the response rates in the initial component, which were typically lower than those in the initial component of the tandem schedule (cf. Jwaideh, 1973). Responding in this component of the chained schedule produced the middle-component stimulus but never the primary reinforcer. The similar response rates in the initial components of the chained and multiple schedules might simply imply that the middle-component stimulus is not effective as a reinforcer. The yoking of component durations, however, may have influenced this outcome.

Consider those cases in which only a single response occurred in the initial chained-schedule component, after the end of the fixed interval. Responding was recorded in the initial component of the next multiple schedule whenever responding began earlier than it had in the chained component, but the yoking terminated the component without a response whenever it would have begun later (cf. Figure 2). Thus, large differences in rate were possible whenever multiple-schedule responding began earlier in the component than chained-schedule responding, whereas only the difference between one and zero responses over a duration of at least thirty sec was possible whenever it would have begun later. The larger possible rate difference in one direction than in the other is a source of potentially substantial bias; the argument in this specific case corresponds to that made more extensively by Church (1964) for yoking procedures in general. In fact, the roughly equivalent response rates in the initial components of the chained and multiple schedules instead of a consistent difference in the direction of the bias might even be taken as evidence for a reinforcing effect of the middle-component stimulus. Because of the low rates and small differences, however, it is more appropriate to leave the question open.

The Language of Conditioned Reinforcement

The present experiments demonstrated reinforcement of responding by an arbitrary stimulus. Whether the functions of this stimulus arose through its temporal relation to the primary reinforcer or through other types of contingencies, these functions were produced in the context of these schedules, and it is therefore appropriate to say that the final-component stimulus was a conditioned reinforcer. Accounts of conditioned reinforcement have a long and controversial history (e.g., Gollub, 1977; Hendry, 1969; Kelleher, 1966; Kelleher & Gollub, 1962). Sometimes the issue is whether the acquired reinforcing functions of a stimulus can be demonstrated. Although the scope and implications of the concept of conditioned reinforcement can be affected by the success of such demonstrations, its definition is independent of its ubiquity as a behavioral process. At other times, the issue is not whether the acquired reinforcing functions can be demonstrated, but rather whether these functions are acquired through operant or respondent contingencies (cf. Rescorla, 1967), through informative functions of the stimuli (cf. Nevin & Mandell, 1978), through temporal contiguity (e.g., Stubbs, 1971), or through some other means. It seems reasonable to define conditioned reinforcement in such a way that it does not exclude some acquired reinforcers while including others. Just as the original definition of chained schedules was improved when the implication of reinforcement was removed, so that it depended only on procedure and not on procedure plus behavioral outcome, so also the definition of conditioned reinforcers is likely to be more useful if it does not prejudge the behavioral processes that can establish them.

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