EXTINCTION OF A HETEROGENEOUS CHAIN AFTER SEVERAL REINFORCEMENT SCHEDULES¹

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Rats were conditioned to emit the following two-member chain of responses on two different operanda always available: responses on a vertical bar produced a discriminative stimulus for food-reinforced responding on a horizontal bar. Responses on the vertical bar produced a discriminative stimulus on a variable-interval 1-min schedule, and the horizontal bar produced food on a variable ratio of 10 responses. Control conditions were included in which vertical bar responses were also food-reinforced simultaneously with the onset of the discriminative stimulus for the horizontal bar response and a tandem schedule which had the same response requirements but without different exteroceptive stimuli associated with the separate components of the response chain. The latter condition greatly retarded acquisition of the response chain compared to the other schedules studied here and compared to reports in the literature on homogeneous (single operandum) response chains. Intermittent reinforcement of the chain led to greater resistance to extinction of both members and the chain remained intact longer in the sense that stimulus control was maintained.

A number of studies have reported on the properties of serially ordered behavior and the variables which control sequences of responses (*e.g.*, Dews, 1962; Ferster and Skinner, 1957; Schlosberg and Katz, 1943). Psychologists have referred to ordered sequences of responses as response chains and have shown a long history of interest in chained behavior (Kelleher, 1966). Kelleher and Gollub (1962) distinguished between homogeneous response chains, in which all responses in the sequence are topographically similar, and heterogeneous chains, made up of responses of different topographies. Most recent work has focused on homogeneous response chains. There are strong methodological reasons for restricting work to homogeneous chains, especially if the investigation is concerned with the relative strength of successive members of the sequence. Nevertheless, heterogeneous response chains are of some theoretical and practical interest and more information is needed about them. The present experiment examined acquisition and extinction of a hetero-

geneous response chain under several schedules of reinforcement.

METHOD

Subjects and Apparatus

Twelve male albino rats of the Sprague-Dawley strain, about 120 days old at the start of training, were maintained at 85% of free-feeding weight on a 24-hr deprivation regimen. Water was freely available in the individual home cages.

Three Foringer experimental chambers were used. A standard horizontal bar of stainless steel (Foringer) was mounted on the front panel 7.6 cm to the right of center and 7.6 cm above the floor. Downward excursion of this horizontal bar operated a telegraph key behind the panel. A vertical bar of black Bakelite, the same dimensions as the steel bar, was mounted 7.6 cm to the left of center at the same height. Excursion of the vertical bar sideways toward the center of the front panel closed a microswitch behind the panel. Excursion distance of all bars was 5 ± 0.5 mm and a force of 15 to 20 g was required to operate them. Food reinforcement (45-mg Noyes pellets) was delivered to a foodcup midway between the bars and 2.5 cm above the floor. Presence or absence of houselights in the chambers served as stimuli in the schedule components. A white masking noise was pres-

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ent at all times and blowers provided ventilation of the chambers.

Procedure

After adaptation, operant level, and magazine training sessions, one 60-min acquisition session was given with the vertical bar removed from the chamber. The first 20 responses on the horizontal bar were food-reinforced, followed by an intermittent schedule in which reinforcement was presented when a variable number of responses, with a mean of 10, had been emitted (VR 10). For the next four days (Sessions 8 to 11), the animals were given discrimination training. Responses on the horizontal bar were reinforced on a VR 10 schedule during one stimulus condition (houselight on or off) but never in the other. A 20-sec delay contingency was imposed between responses in the nonreinforced stimulus condition and onset of the stimulus associated with the VR 10 schedule. The vertical bar was replaced for Sessions 8 to 11 but responses on it were never reinforced, although the 20-sec delay contingency also held for responses on this bar in the nonreinforced stimulus condition. For half the animals, the houselights were on in the VR 10 component and off in the delay component; for the other half these conditions were reversed. The three animals in any schedule to be used in the main phase of the experiment did not have the same stimulus associated with the VR 10 component. No differences in behavior were observed as a function of the counterbalancing of stimulus conditions. Beginning with Session 10, to the end of the experiment, session length was 90 min.

Training on the two-member chain was begun in Session 12. In the first component, the animal was required to push the vertical bar sideways, to produce the VR 10 stimulus, on a variable-interval 1-min schedule (VI 1-min) in which onset of the stimulus was contingent upon emission of a vertical bar response and the passage of a variable interval of time (with a mean of 1 min). In the second component, downward presses on the horizontal bar terminated the VR 10 stimulus and reinstated the first component when the VR 10 requirement was completed. One of the following four reinforcement schedules was randomly assigned to each of the 12 animals with the restrictions that every schedule must be as-

signed to three animals and that each animal within a schedule must be tested in a different experimental chamber: (1) A chained schedule, *chain* VI 1-min VR 10, in which food reinforcement was presented each time the ratio requirement of the second member of the chain was completed. (2) An intermittent chained schedule in which randomly one-half the exposures to the VR 10 component resulted in food reinforcement when the VR 10 requirement was completed; on the other half of the exposures, the VR 10 component terminated after 7 sec, independent of the animal's behavior. This schedule is abbreviated *int chain* VI 1-min VR 10. (3) A multiple schedule, *mult* VI 1-min VR 10, in which the component schedules alternated after food reinforcement in each component. (4) A tandem schedule, *tand* VI 1-min VR 10, where the response requirements were the same as in the *chain* VI 1-min VR 10 schedule but no stimulus changes occurred to signal the changes in schedule components. The stimulus present during the VR 10 component in Sessions 8 to 11 was continuously in effect for the remainder of the experiment for animals in the *tand* condition. In Session 12, animals on the *int chain* schedule were permitted to complete the VR 10 requirement for food reinforcement on every exposure to the final (VR 10) component. After 30 min of Session 13 had elapsed, the food reinforcer was intermittently omitted. The stimulus correlated with the VR 10 component remained on for 7 sec on these nonreinforced exposures to the VR 10 component and terminated automatically, reinstating the VI 1-min component. The 7-sec value was chosen because it was the average time required by the animals to complete a VR 10 requirement during the first 30 min of Session 13. Food was gradually withheld more and more frequently until it accompanied only one-half of the exposures to the VR 10 component.

After 30 min of Session 28 had elapsed, extinction was in effect for the final 60 min of the session. All schedule contingencies were the same as those during training, except that no food pellets were delivered; instead, the VR 10 component automatically terminated after 7 sec had elapsed. Three prolonged exposures to the VR 10 component were programmed during extinction. These lasted for 30 sec and occurred as a consequence of the

first vertical bar response in the VI 1-min component after approximately 40, 60, and 80 min had elapsed. The purpose of the prolonged exposures was to assess stimulus control during extinction.

The entire twenty-ninth and thirtieth sessions were run on extinction with 7-sec exposures to the VR 10 component except for four 30-sec exposures programmed to occur at the first vertical bar response in the VI 1-min component after 10, 30, 50, and 70 min of the session had elapsed. The animals were not tested for two days between Sessions 29 and 30 but were weighed and fed at their regularly assigned times.

Cumulative records of vertical bar responses were taken. Readings of response frequency on both bars in both components were taken at 10-min intervals.

RESULTS

Acquisition

All animals showed similar response patterns on the horizontal bar during discrimination training in Sessions 8 to 11. Response rate on the vertical bar decreased virtually to zero. Four sessions of discrimination training were not enough to achieve clear and consistent differences in response rates on the horizontal bar in the two conditions.

Cumulative records of horizontal bar re-

sponses on the first day of training on the experimental schedules (Session 12) are shown in Fig. 1. All animals, except No. 43 on the *chain* schedule and those on the *tand* schedule, acquired the sequence of behavior on the first day of training. In the *mult* condition, each animal collected 100 or more food pellets in Session 12. Animal No. 43 in the *chain* condition began emitting vertical bar responses immediately in Session 13. Each animal on the *chain* schedule collected over 50 food pellets in Session 13. The additional contingency of intermittently nonreinforced exposures to the VR 10 component was begun in Session 13 for the *int chain* group. Very little disruption was noted when intermittency was introduced. In Session 14, the first session in which the full 50% intermittency was in effect for the *int chain* group, each animal collected 25 or more pellets. On all of the above schedules, the number of pellets collected per session increased rather smoothly to stable terminal levels. In the final training session, the *mult* animals collected an average of 130.3 pellets, the *chain* animals averaged 62.3, and the *int chain* group averaged 30.7. In contrast to the above, acquisition of the response sequence on the *tand* schedule was very slow. Animal No. 42 in the *tand* condition first collected over 50 pellets in Session 14, but dropped below 50 in some later sessions. The other two, No. 11 and No. 23, first collected more than

Fig. 1. Cumulative records of vertical bar responses in the first session on the two-member response chain (Session 12). Pips indicate changes in stimulus conditions. Periods in which no responses occurred were deleted from some of the records and the length of the deletions is indicated by time in minutes.

50 pellets in Sessions 15 and 18, respectively, and exceeded 50 per session from then on. The average number collected by the *tand* group in the final training session was 57.7. All animals except those in the *tand* condition showed a gradual decrease in out-of-sequence behavior (vertical bar responses in the VR 10 component and horizontal bar responses in the VI 1-min component) as training progressed until Session 22, when animal No. 32 began emitting horizontal bar responses in the VI 1-min component at an increasingly higher rate. The animal was seen to be gnawing on the horizontal bar, thus pro-

ducing the high response rate. The unusual behavior of this animal did not affect in any noticeable way its performance on the horizontal bar in the VR 10 component, although response rate on the vertical bar in the VI 1-min component varied inversely with rate on the horizontal bar in this component. Average response rates on the two bars in both components for the final training session (Session 27) were computed for all four conditions. These average response rates are plotted as the lone points on the left of each graph in Fig. 2 and labeled terminal acquisition rates (T.A.).

Fig. 2. Average response rates in the terminal acquisition session (T.A.) and extinction sessions (28, 29, 30). The lone points at the left of each graph represent average rate over the entire last training session. The points connected by lines indicate the rates for each 10-min interval in extinction (A and C) or for the 30-sec exposures to the VR 10 component in extinction (B and D). Each data point represents the average of the rates of the three animals in each condition. A. Response rates on the vertical bar in the VI 1-min, or first, component (in-sequence responses). B. Response rates on the vertical bar in the VR 10, or second, component (out-of-sequence responses). C. Response rate on the horizontal bar in the VI 1-min, or first, component (out-of-sequence responses). D. Response rate on the horizontal bar in the VR 10, or second, component (in-sequence responses).

Stimulus Control

The extent to which the schedule components controlled different response rates on a particular operandum can be assessed by comparing the in-sequence terminal acquisition rates (vertical bar in VI 1-min and horizontal bar in VR 10, Fig. 2A and 2D respectively) with the corresponding out-of-sequence rates shown in Fig. 2B and 2C. Except for the *tand* condition, where it makes little sense to speak of exteroceptive stimulus control, the other nine animals each exhibited much higher rates in-sequence than out-of-sequence. The smallest intra-individual difference between components was shown by animal No. 32 on the *chain* schedule, where in-sequence rates were about five times the corresponding out-of-sequence rates on both bars. This was the animal that developed a very high response rate by gnawing on the horizontal bar. Only one of the other eight animals, No. 22 in the *mult* condition, had a ratio of in-sequence to out-of-sequence rate on the vertical bar less than 10 (5.9). These eight animals each maintained rates on the horizontal bar in the VR 10 component which were greater than 20 times the out-of-sequence rate on this bar.

A second aspect of stimulus control is the extent to which terminal acquisition rates on the two operanda differ within a component of the chain. This can be seen by comparing Fig. 2A with Fig. 2C and Fig. 2B with Fig. 2D. In the VI 1-min component, only the *mult* schedule (again ignoring the question of stimulus control for the *tand* condition) produced dramatically higher rates on the vertical bar than on the horizontal bar. The high rate on the horizontal bar in the VI 1-min component for the *chain* condition was due solely to animal No. 32. The other two animals in the *chain* condition had rates of 3.8 and 1.9 responses per minute on the horizontal bar in the VI 1-min component. Most of the out-of-sequence responses on the horizontal bar were extra responses after the VR 10 stimulus terminated and before the animal approached the foodcup or switched to the vertical bar. Control by the VR 10 stimulus over rates on the two bars was extremely strong, as can be seen by comparing the terminal acquisition rates in Fig. 2B and 2D.

The *tand* schedule did not control response patterns in any way similar to those main-

tained by the other schedules. During the final training sessions, animals on the *tand* schedule were emitting one or two responses on the vertical bar followed by a long, rapid run of responses on the horizontal bar. The animals emitted this sequence throughout the session at a very high rate. Stimulus control by the food reinforcer was evident in the *tand* schedule. In the final training sessions, the animals rarely returned to the horizontal bar after delivery of a food pellet.

Extinction

A within-sessions analysis of extinction is presented first.

Vertical bar in VI 1-min (in-sequence responses). Analyses of variance (Lindquist Type I; Lindquist, 1953) of the response rates graphed in Fig. 2A, with schedules and intervals as main effects, were computed for each extinction session. All main effects and interaction effects are significant beyond the 0.001 level with the single exception of the schedule effect for the second extinction session, which is significant beyond the 0.01 level. In other words, there is a significant decrease in response rate within each extinction session, the training schedules result in different performances in extinction, and there is a differential decrease in response rate in extinction as a function of the training schedule. It is evident from Fig. 2A that response rate in the *int chain* group decreased at a lower rate than rates in the other three conditions.

Vertical bar in VR 10 (out-of-sequence responses). Vertical bar response rates during the prolonged exposures to the VR 10 component are plotted in Fig. 2B. The onset of extinction produced a large and immediate increase in out-of-sequence vertical bar response rate for all conditions except the *int chain*. Examination of the cumulative records of these rates shows that the average response rates plotted in Fig. 2 are representative of the individual subjects and that the *int chain* animals showed considerably fewer response bursts or other disruptive effects of extinction.

Horizontal bar in VR 10 (in-sequence responses). Figure 2D shows average response rates on the horizontal bar in VR 10 during the prolonged exposures to that component. Extinction of the horizontal bar response was rapid for the *mult* and *chain* groups in the

first extinction session. The *tand* and *int chain* groups did not show the effects of extinction until Session 29.

Horizontal bar in VI 1-min (out-of-sequence responses). Fairly orderly decreases in horizontal bar response rate in the VI 1-min component are evident in Fig. 2C for the *tand* and *chain* groups. In the first 10-min intervals of Sessions 29 and 30, all animals on the *mult* and *int chain* schedules manifested spontaneous recovery of the horizontal bar response in the VI 1-min component at rates higher than their respective terminal acquisition rates.

The extinction data may also be examined in terms of the total number of responses emitted by the different groups. For this purpose, the mean and standard deviation of the number of responses emitted by each group, tabulated separately by operandum and component, are compiled in Table 1 for the last training session and the three extinction sessions. The *mult* group emitted the most vertical bar responses in extinction, followed by the *int chain*, *chain*, and *tand* groups, in that order. With respect to the number of horizontal bar responses emitted during extinction, the groups arrange themselves in the following order, from most responses to least respectively, *tand*, *int chain*, *chain*, and *mult*. It is interesting to note that the *int chain* group emitted almost twice as many horizontal bar responses in extinction as the *mult* group and that over 75% of these responses were in-sequence, compared to only about 45% for the *mult* group.

DISCUSSION

The striking difference among the schedules in rate of acquisition of the response sequence (Fig. 1), particularly acquisition of the first-component response, points to a clear difference between heterogeneous and homogeneous response chains. A search of the literature reveals little on the acquisition of heterogeneous chains, although some experiments have been reported on sequences of responses of different topographies (Ferster, 1958; Hurwitz, 1962). Ferster and Skinner (1957, p. 416 ff.) report data on transitions from simple reinforcement schedules to tandem schedules with two components for the homogeneous case. Essentially, their animals continued responding on the single operandum, and per-

formances appropriate to the new schedule often emerged rather quickly. In the homogeneous chain there is no problem of switching from one operandum to another. The present study shows that in the heterogeneous chain, where the animal is required to respond on two operandum, the absence of exteroceptive stimuli in the *tand* schedule seriously hinders acquisition of the response sequence, compared with acquisition under the *chain* and *mult* schedules. The effect is most notable in the slow acquisition of the first-component response for the *tand* schedule. Animals on the *tand* schedule took at least three and up to seven sessions to reach a level of performance, indexed by number of reinforcements collected in a session, achieved by all other animals by the second session on their respective schedules.

The behavior maintained by the *tand* schedule in the last phases of training also produced fewer reinforcements per session than did the behavior maintained by the *chain* schedule, in which the reinforcement contingencies were identical to those of the *tand* schedule. The literature indicates that for homogeneous sequences of two components, tandem and chained reinforcement schedules are roughly comparable in terms of frequency of reinforcement and response rates (Gollub, 1958). For homogeneous sequences of more than two components, tandem schedules generate higher frequencies of reinforcement than chained schedules, due to the development of prolonged pausing in early components of the chained schedules (Kelleher and Fry, 1962). In the present study, the response patterns generated by the *tand* and *chain* schedules in heterogeneous sequences are markedly different from each other and from behaviors maintained by comparable schedules on homogeneous chains.

As Fig. 2A shows, training on the *int chain* schedule resulted in greater resistance to extinction of the vertical bar response than training on the *chain* schedule. Because of the high rate on the horizontal bar in the VI 1-min component for the *chain* group (Fig. 2C), the extent to which these out-of-sequence responses attenuated the in-sequence rate on the vertical bar must be determined before accepting this conclusion. The high average rate for the *chain* condition shown in Fig. 2C was due solely to animal No. 32, which gnawed

Table 1

Mean ($\bar{X}$) and standard deviation (SD) of the number of responses emitted in the VI 1-min and VR 10 components by each experimental group in the last acquisition session and the three extinction sessions. All sessions were 90-min long, but data are reported for 60 min of extinction only: for the first extinction session.

Sessions	mult				int chain				chain				tand			
	V		H		V		H		V		H		V		H	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
VI 1-min	2932.3	1001.2	483.7	235.8	588.7	3.1	240.3	127.4	598.3	184.4	1299.0	1838.5	526.7	54.2	4761.7	1365.2
Terminal Acquisition																
VR 10	14.0	11.8	681.0	9.8	2.7	1.2	764.3	123.5	2.7	1.2	629.0	11.2	40.3	22.2	601.7	62.4
VI 1-min	598.7	110.4	166.0	46.0	281.7	40.1	130.0	30.6	256.7	17.6	352.3	366.1	205.7	43.6	1129.3	384.7
Extinction ₁																
VR 10	65.0	16.0	174.7	13.3	1.7	2.1	697.3	160.6	25.7	12.5	251.3	57.7	26.0	19.2	483.0	50.7
VI 1-min	275.7	96.2	157.7	40.1	300.7	45.5	118.3	22.5	162.3	27.8	329.7	419.4	92.3	29.3	514.0	133.3
Extinction ₂																
VR 10	51.0	26.2	138.7	12.7	15.0	7.5	377.7	155.0	19.3	16.5	146.3	50.5	21.7	6.8	249.7	195.8
VI 1-min	153.7	40.5	130.3	64.1	198.0	10.6	117.0	32.9	106.7	4.2	167.0	229.4	52.7	5.5	236.0	116.0
Extinction ₃																
VR 10	20.1	3.5	67.7	15.5	17.3	11.0	168.0	36.0	11.3	10.0	67.0	28.6	12.7	4.2	83.0	41.3
VI 1-min	1028.0	235.0	454.0	131.7	780.3	69.1	365.3	56.4	525.7	33.8	850.0	1018.5	350.7	45.8	1879.3	507.2
Total in Extinction																
VR 10	136.0	41.6	381.0	20.1	34.0	15.6	1243.0	280.8	56.3	36.7	464.7	124.4	60.3	29.8	815.7	276.9

on the horizontal bar. Time spent gnawing could result in a lower rate on the vertical bar in that component. This animal did, however, emit vertical bar responses in the VI 1-min component at a higher rate than the other two animals on this schedule in some sessions. Although its behavior distorts Fig. 2C, over the three extinction sessions this animal showed orderly trends in response rates, perfectly consistent with the behavior of the other two animals in this condition except for absolute level of response rate on the horizontal bar in the VI 1-min component. The *int chain* schedule also generated greater resistance to extinction of the horizontal bar response in the second component than did the *chain* schedule (Fig. 2D).

Intermittent food reinforcement of the entire two-member sequence keeps the chain intact longer. The *mult* and *chain* groups showed large and immediate increases in out-of-sequence responses on the vertical bar with the onset of extinction (Fig. 2B). In the case of the *mult* schedule, omission of the food reinforcer associated with the change from the VI 1-min to the VR 10 component during extinction could account for the breakdown in stimulus control, but this will not explain the increase in out-of-sequence responses on the vertical bar for the *chain* group. There is no evidence of increase in out-of-sequence vertical bar responses for the *int chain* group until the second extinction session. In terms of the proportion of the total responses on either bar emitted in the appropriate stimulus condition, the *int chain* group was last to show any disruptive effects of extinction. These data suggest that intermittent reinforcement of the response sequence results in greater resistance to extinction of the sequence as a unit; the integrity of the entire chain is maintained longer in extinction. Incidental support for this is found in the behavior of the *tand* animals. As stated above, animals in the *tand* condition emitted a response or two on the vertical bar followed by a long, rapid run on the horizontal bar (average about nine). This pattern was sustained at a high rate throughout the training session and occasionally terminated in reinforcement. The high horizontal bar rates for the *tand* schedule in Fig. 2D for the first extinction session would seem to indicate that the sequence, vertical bar response followed by a burst of horizontal bar

responses, was maintained longer as a result of the intermittent reinforcement of this sequence during training.

This report stresses the speed with which response rate decreases as the index of resistance to extinction. The *mult* group clearly showed the most rapid decrease in rate on the vertical bar in the VI 1-min component as extinction progressed, but the level of responding maintained by this schedule during training was much higher than any other schedule investigated here and the decrease in rate may simply be a function of response rate during training. The usual measure of resistance to extinction in studies on this problem is number of responses in extinction (see, e.g., Miles, 1956). As Table 1 shows, the *mult* group was clearly superior in terms of the number of vertical bar responses in the VI 1-min component emitted during extinction, but this measure also fails to take account of level of performance during training. A possible correction for this is to transform the number of responses in extinction into per cent of terminal acquisition responses, or alternatively, transform the rate in extinction into per cent of terminal acquisition rate (Nevin, 1964). Table 1 shows that the *mult* group would be well below the *int chain* group using such a proportion. This, too, is unsatisfactory because all groups approach the same lower limit despite different initial levels. Nevertheless, as Fig. 2A shows, the *mult* group dropped below the *int chain* rate by the end of the first extinction session and was higher than the *int chain* group only in the first 10-min interval of each of the last two extinction sessions. Further, Table 1 shows that in the last extinction session, the *int chain* group emitted more vertical bar responses in VI 1-min than did the *mult* group. The interesting hint in the comparison between the *int chain* and *mult* schedules is that intermittent food reinforcement of the terminal component of a response sequence may generate greater resistance to extinction of earlier components than if these components each result in food reinforcement. Much more work on this problem is needed to substantiate this last suggestion.

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