TEMPORAL ALTERNATION IN THE WHITE RAT?

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Four white rats were reinforced after 15 then 45 then 15 then 135 (or 5) responses to a bar under a single exteroceptive stimulus condition. Three came to make long pauses before the longest ratio in the schedule but not before any of the others. Four other rats were reinforced after alternate response chains each made on two bars. The first chain was FR5FR5 for all subjects, the second FR5FR40 for two, and FR40FR5 and FR20FR5 for one subject each. Subjects reinforced on schedule *mix* (chain FR5FR5 chain FR5FR40) both paused longer after the first than after the second chain relatively early in training. Later, the subject reinforced on *mix* (chain FR5FR5 chain FR40FR5) also paused longer after the first chain, but pauses of the fourth subject were equally short after both chains. When the ratios in the second chain were reversed the two subjects now reinforced on *mix* (chain FR5FR5 chain FR40FR5) paused much longer after the first chain, but the other two paused only slightly longer after the first than after the second chain.

A number of studies (*cf.* Munn, 1950) utilizing the double alternation maze invented by Hunter (1920) have shown the white rat to be unable to make two different responses at different times to the same set of exteroceptive stimuli without special "shaping", and even then in only a limited way (Hunter and Nagge, 1931; Karn and Patton, 1941).

Hunter's double alternation temporal maze requires a series of turns of the kind right-right-left-left in an apparatus constructed so that turns are made at the same choice point. The exteroceptive stimulation is therefore the same at each choice point and a turn to the right is followed alternately by a right and a left turn. A comparable arrangement is possible in a free operant situation by appropriate choices of mixed schedules. The present study examined the performance of white rats on selected samples of these schedules.

In Exp 1 some subjects were reinforced after every 15, then 45, then 15, then 135

presses on a single bar, with the exteroceptive stimulus conditions constant. This schedule is technically repeating *mix* FR15FR45FR15FR 135. In Exp 2, other rats were reinforced on alternating chain schedules performed on two bars. For example, five presses on Bar II in SP_2 produced SP_1 in which five presses on Bar I produced reinforcement and restored SP_2 (chain FR5FR5), then five presses on Bar II in SP_2 produced SP_1 in which 40 presses on Bar I produced reinforcement and restored SP_2 , and so on. Technically this schedule is alternating *mix* (chain FR5FR5 chain FR5FR40).

The objective was to see if differential pausing occurred after the two FR 15 components of the schedule in the first experiment, and either after or within the two chains in the schedule used in the second experiment (*cf.* Keehn, 1964).

METHOD

Subjects

Eight male white rats were used, four in each experiment. All had prior experimental histories. The four used in Exp 1 (K1, K2, K3, K4) were from the colony maintained by the American University of Beirut, and had been exposed to about 100 half-hour sessions of bar pressing under reinforcement schedule alternating *mix* FR15FR45. The present ex-

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periment directly followed this history, by which time subjects were about 200 days old. The four used in Exp 2 (S1, S2, S3, S4) were from the colony maintained by the Psychology Department of Washington State University, and had been exposed to about 60 half-hour sessions of bar pressing under various *chain* FRFR reinforcement schedules. At the beginning of the present experiment, they were about 195 days old.

Apparatus

The experimental chambers used in both experiments were commercial two-bar rat boxes. Liquid reinforcers were delivered by a dipper which presented .1 cc 12% sucrose solution by weight in tap water for 2 sec when scheduled. The internal dimensions of each chamber were 11½ in. by 9¼ in. base, by 7½ in. high. The response bars were 2 in. wide and mounted so that the inside edges were ¾ in. from the centrally-placed dipper. Each bar was about 3 in. above the dipper, and protruded ⅝ in. from the chamber wall. A weight of about 22 g on the bar was sufficient to activate the automatic programming and recording equipment. Three stimulus lights were located in the same wall as the bars and the opening that allowed access to the dipper. Red and white lights were slightly above and about 1¼ in. from the outside edges of Bar I and Bar II respectively. A green light was centered above the dipper opening, mid-way between the response bars and about 1⅞ in. above them. The experimental chambers were enclosed in commercially adapted picnic chests to reduce extraneous stimuli. Ventilation was provided by a blower which also served as a masking noise. The experimental chambers were located in rooms adjacent to those containing the programming and recording equipment.

Gerbrands cumulative recorders and Grass-Stadler running time meters (.01 min) were used to collect data.

Procedure

Experiment 1. While 23-hr food and water deprived, the subjects were reinforced with 12% sucrose solution on schedules repeating *mix* FR15FR45FR15FR5 (K1 and K2) or repeating *mix* FR15FR45FR15FR135 (K3 and K4) for 26 or 27 half-hour sessions. All reinforcements were scheduled for Bar I responses,

Bar II being available but non-functional. Subjects were fed 4 cc 12% sucrose solution immediately before each experimental session; this had been shown to produce long post-reinforcement pauses sooner in a session than when subjects were not pre-fed (Patrikiou and Keehn, 1964).

Each subject was allowed free access to food and water in its home cage for 30 min after each experimental session.

Experiment 2. While 23-hr food and water deprived, subjects were reinforced with 12% sucrose solution on alternating *mix* (chain chain) schedules. The schedule of reinforcement for S1 and S3 was alternating *mix* (chain FR5FR5 chain FR5FR40). That is, five presses on Bar II in dim green illumination (SP_2) turned on the red and white lights (SP_1), then five presses on Bar I produced sucrose reinforcement and reinstated SP_2 , then five presses on Bar II produced SP_1 , then 40 presses on Bar I produced sucrose reinforcement and SP_2 . During sucrose reinforcement cycles all lights were off; SP_2 came on at the end of the cycle.

This schedule was approached in eight or nine sessions over which the longest ratio was increased in steps of 10 responses every few days, and was then maintained for 26 sessions. Over the same period, S2 was stabilized on reinforcement schedule alternating *mix* (chain FR5FR5 chain FR20FR5) and S4 on schedule alternating *mix* (chain FR5FR5 chain FR40FR5). The important difference between the reinforcement schedules of S1 and S3, and S2 and S4, was whether the longest ratio in the chain with unequal components was the first or second ratio.

After 26 sessions on the above schedules, those of S1 and S3 were changed to alternating *mix* (chain FR5FR5 chain FR40FR5); and those of S2 and S4 to alternating *mix* (chain FR5FR5 chain FR5FR20) and alternating *mix* (chain FR5FR5 chain FR5FR40) respectively, *i.e.*, the ratios in the unequal chains were reversed. These schedules were maintained for 11 or 12 sessions. Each subject was allowed free access to food and water in its home cage for 30 min after each experimental session.

In both experiments, pauses were measured after every primary reinforcement and in Exp 2 post-secondary reinforcement pauses (SP_1 to the first response on Bar I) were also recorded.

RESULTS

Experiment 1. Figure 1 shows the accumulated pauses after the separate ratios on the 26th or 27th half-hour session of training on the schedules repeating *mix* FR15FR45FR15FR5 (K1 and K2) and repeating *mix* FR15FR45FR15FR135 (K3 and K4). Each of the four curves shown for individual subjects was constructed by accumulating the pauses from the end of the reinforcement cycle to the first response in the relevant ratio. That is, when reinforcements were delivered after FR 45, for example, there was a pause before responding resumed, and these pauses were accumulated to produce the post-FR 45 pause curves in the figure. The other curves were similarly constructed.

Fig. 1. Cumulative records of post-reinforcement pauses after the respective ratio segments of the reinforcement schedules repeating *mix* FR15FR45FR15FR5 (K1 and K2) and *mix* FR15FR45FR15FR135 (K3 and K4).

All four subjects exhibited longer pauses before the longest ratio in the total mixed schedule, all but K1 markedly so. Typical behavior, sooner or later in the session, was for a subject to run off its three shorter ratios while pausing only briefly between them, and then to make a longer pause before beginning its longest ratio. More reinforcements were obtained by K1 and K2 in the available time because they were required to make fewer responses per reinforcement, on the average, than were K3 and K4. Animals K2 and K3 stopped responding before the scheduled end of the sessions, and the final long pauses after FR 15 (before FR 45) and after FR 15 (before FR 135) made by K2 and K3 actually extend beyond the records. Had K1's session been prolonged, its record would probably have more closely resembled those of the other subjects: by the end of the session, pauses before FR 45 do show signs of lengthening relative to those before the other ratios.

Data of three subjects, even if not the fourth, show that they discriminated their positions within the overall mixed schedules. After reinforcement on FR 15, animal K2 made longer pauses before resuming responding when the following ratio was FR45 than when it was FR 5. Similarly K3 and K4 paused longer after the FR 15 preceding FR 135 than after the FR 15 preceding FR 45.

Experiment 2. Differential pausing after the two chains in the *mix* (chain chain) schedule was relatively quickly established by S1 and S3 compared to S2 and S4. Figure 2 shows the accumulated pauses of S1 and S3 following *chain* FR5FR5 and *chain* FR5FR40 as P1 and P2 respectively. For both S2 and S4 the P2 curves show the accumulated pauses after reinforcements scheduled on *chain* FR20FR5 and *chain* FR40FR5 respectively. The P1 curves show the accumulated pauses following reinforcements scheduled on *chain* FR5FR5 for these animals. Pauses after both chains were equally short in the case of S2 and equally long in the case of S4.

The data of Fig. 2 were taken from the 12th session with the designated schedules. The same schedules were maintained for 14 more sessions but S2 still did not pause differentially after the separate chains, although S4 showed differential pausing similar to that of S1 and S3 by this time (Table 1). The Table shows the total amount of post-primary and post-

Fig. 2. Cumulative records of post-reinforcement pauses after the respective chains of the reinforcement schedules alternating *mix* (chain FR5FR5 chain FR5FR40) (S1 and S3), *mix* (chain FR5FR5 chain FR20FR5) (S2), and *mix* (chain FR5FR5 chain FR40FR5) (S4). Solid curves are pauses after the shorter chain, broken curves those after the longer chains.

secondary reinforcement pausing of each subject for sessions 20 through 25. Post-primary reinforcement pauses were measured on sessions 20, 21, and 22, and post-secondary reinforcement pauses were measured on sessions 23, 24, and 25. The Table shows the total amount of pausing after 30 reinforcements for each subject (because each obtained at least this number of reinforcements in each session), and also after 60 reinforcements for S3 and S4.

From session 13 to the final session, S4 came to resemble S1 and S3 by pausing relatively less after the longer chain. Animal S2 continued to make only short pauses after both chains.

Conventional cumulative response records produced by S3 and S4 on session 26 are shown in Fig. 3. Responses to each bar were recorded separately, and a recorder motor ran only when the responses that that recorder was reg-

Table 1

Total minutes of post-reinforcement pausing after 30 reinforcements

Subject	Session	Post-primary pauses		Session	Post-secondary pauses	
		Short Chain	Long Chain		Short Chain	Long Chain
S1	20	6.51	.74	23	.15	.22
	21	2.40	.78	24	.16	.23
	22	3.11	1.79	25	.20	.18
S2	20	1.57	1.09	23	.14	.14
	21	1.46	1.49	24	.11	.12
	22	1.02	.91	25	.14	.11
S3	20	2.09	.89	23	.30	.28
		(7.93)	(1.73)		(.70)	(.63)
	21	2.63	.97	24	.29	.26
		(10.73)	(1.78)		(.52)	(.57)
	22	2.27	.76	25	.20	.25
		(9.79)	(1.64)		(.53)	(.62)
S4	20	1.16	1.24	23	.20	.22
		(5.03)	(2.30)		(.45)	(.46)
	21	1.45	.80	24	.21	.21
		(8.73)	(2.55)		(.57)	(.44)
	22	.93	.46	25	.20	.27
		(3.15)	(1.28)		(.43)	(.50)

The short chain is *chain* FR5FR5 for every subject. The long chain is *chain* FR5FR40 for S1 and S3; *chain* FR20FR5 for S2; and *chain* FR40FR5 for S4. The chains alternate for each subject. Post-primary pauses are pauses after primary reinforcements delivered at the end of each chain; post-secondary pauses are pauses after secondary reinforcements within each chain. Bracketed numbers are total minutes pausing after 60 reinforcements.

istering were appropriate. Records A and B are of responses made by S3 to Bar I and Bar II respectively; records C and D are records of Bar I and Bar II responses of S4.

Reinforcements are indicated by lateral spurs on all records, although primary reinforcements were actually delivered only after responses registered on records A and C. Post-primary reinforcement pauses appear on records B and D because these records began at the end of each reinforcement cycle. Post-secondary reinforcement pauses are indicated in records A and C.

The pauses before each FR 5 to Bar II in the schedule *mix* (*chain* FR5FR5 *chain* FR5FR40) experienced by S3 are the alternate pauses shown in record B. Those before FR 5 and FR 40 to Bar II in the schedule *mix* (*chain* FR5FR5 *chain* FR40FR5) experienced by S4 are similarly shown in record D, but the differential pausing before each chain is less clearly shown by these data than by those of Fig. 2.

Non-functional (erroneous) responses made to either bar appear in Fig. 3 as vertical portions in the records (except at the beginning

of records A and C, where recorder failures occurred). A long run of non-functional responses to Bar I is shown at T in record A.

When the ratios were reversed in the unequal chains, *e.g.*, from *chain* FR5FR40 to *chain* FR40FR5 in the case of S1 and S3, the discrimination in terms of differential pausing after the reinforcements at the end of each chain in the *mix* (chain chain) schedule was maintained by these subjects; pauses remained short after *chain* FR40FR5, were long following *chain* FR5FR5, and were of the same order of magnitude as before. The relevant data are shown in Fig. 4. They were collected on the final training day and do not differ materially from those of the two preceding sessions. Similar data are also shown in Fig. 4 for animals S2 and S4.

Reversal of the ratio components in the unequal chains markedly affected the overall behavior output of S2 and S4 but not that of S1 or S3. The data of S1 and S3 in Fig. 4 resemble those of the same subjects in Fig. 2, even though the schedules are different. The performance of S4 represented in Fig. 3 shows much less pausing than was exhibited by S1

Fig. 3. Cumulative response records of S3 and S4 on their 26th session on schedule *mix* (chain FR5FR5 chain FR5FR40) and *mix* (chain FR5FR5 chain FR40FR5). Records A and B are of responses made by S3 to Bar I and Bar II respectively; C and D are records of Bar I and Bar II responses of S4. The second element of each chain was performed on Bar I, the first on Bar II. Each recorder ran only when the responses it registered were functional. Non-functional responses produce vertical lines, e.g., at T.

and S3 on the same schedule. Also, S2 obtained over twice as many reinforcements after about the same total amount of pausing when its longer chain was FR5FR20 (Fig. 4) than when it was FR20FR5 (Fig. 2). This subject had typically stopped responding after about 30 reinforcements when reinforced on schedule alternating *mix* (chain FR5FR5 chain FR20FR5), but would continue responding for 60 or more reinforcements when the second chain was FR5FR20.

Individual pauses following secondary reinforcements were uniformly short for all four subjects on all schedules, mostly falling in the range .01 to .02 min. Whenever a response on Bar II produced S^D , every subject immediately began pressing Bar I irrespective of the ratio that had just been performed on Bar II, or of the ratio requirement for primary reinforcement on Bar I. The pauses that typically develop after primary reinforcements scheduled on FR did not appear after secondary reinforcements. Illustrative data are shown in Fig. 3 and in Table 1.

DISCUSSION

In Exp 1, all four ratio components of the schedule repeating *mix* FR15FR45FR15FR 135 (or 5) were run in the same exteroceptive stimulus condition, and the FR 45 and FR 135 (or 5) components both followed reinforcements scheduled on FR 15. The exteroceptive stimuli were certainly the same, and the kinaesthetic cues possibly the same, before runs of 45 and 135 (or 5) responses were required for reinforcement. Yet when the alternatives were FR 45 and FR 135 both K3 and K4 paused markedly longer before FR 135, and when the alternatives were FR 45 and FR 5, subject K2 paused for considerably longer times before FR 45. These findings refute Hunter's (1920) conclusion that "the rat has practically no capacity to set up habits where the sensory complexes succeed each other merely in time"; unless the sensory complexes differed because the animals were able to discriminate the proprioceptive after-effects of responding on ratios FR135FR15 from those of responding on

Fig. 4. Cumulative records of post-reinforcement pauses after the respective chains of reinforcement schedules alternating *mix* (chains FR5FR5 chain FR40 FR5) (S1 and S3), *mix* (chain FR5FR5 chain FR5FR20) (S2), and *mix* (chain FR5FR5 chain FR5FR40) (S4). Solid curves are pauses after the shorter chain, broken curves those after the longer chains.

FR45FR15 (Schlosberg and Katz, 1943). In any event, behavior that has been taken to be difficult to establish in the maze was reliably demonstrated in a free operant analogue.

On whatever basis discriminations were made, prolonged pausing began to appear before the longest ratio in the schedule, while pauses before the other ratios remained short. Findley (1962, Fig. 12) has reported similar behavior on the part of a bird reinforced on an alternating increasing (FR33FR132FR528) and fixed (FR132FR132FR132) sequence of ratios. Findley (1962, p 132) has suggested that after considerable training, progressive ratios become established as chains, and this suggestion can apply to the present experiment. For example, subjects K3 and K4 did not pause in the repeating mixed chain as though each ratio were independently performed. Instead, their behavior resembled performances typically found in multi-unit fixed ratio chains (Ferster and Skinner, 1957; Findley, 1962), with brief pauses occurring within the chain and long pauses at the end. That is, the behavioral effects of scheduling reinforcements on repeating *mix* FR15FR45FR15FR135 resemble those expected when reinforcements are scheduled on *chain* FR135FR15FR45FR15. The nature of the stimuli correlated with the successive components cannot be determined from the present data.

The reinforcement schedule in Exp 2 most comparable to the conditions of Exp 1 was alternating *mix* (chain FR5FR5 chain FR40 FR5). In this schedule the same exteroceptive conditions prevailed for each of the alternate ratio requirements on Bar II, FR5 and FR40, and the kinesthetic cues immediately before each of these ratios were generated by a reinforced ratio of FR5 on Bar I. All three subjects run on this schedule (S1, S3, S4) exhibited temporal alternation by making long pauses before the longest ratio but not before any other.

However, differential pausing before the alternate chains occurred with less training when the ratios in the second chain were FR5 FR40 than when they were FR40FR5. While S4 was still making long pauses before both the chains FR5FR5 and FR40FR5, animals S1 and S3 were making much shorter pauses before *chain* FR5FR5 than before *chain* FR5 FR40 (Fig. 2). The long pauses of these latter subjects did not precede the longest ratio

(FR40), but the chain of which this ratio was a component (*chain* FR5FR40). The animals did not pause differentially to the increase in illumination that set the occasion for FR5 or FR40 in the respective chains; in both cases Bar I responses promptly followed S^D , which is typical of multi-ratio chain behavior (Ferster and Skinner, 1957; Findley, 1962).

If alternating *mix* (chain chain) ratio schedules also become established as unitary chains, then the more strained performance observed when the unequal component chain was FR40 FR5 than when it was FR5FR40 (S_4 vs S_1 , S_3 in Fig. 2) can be considered in terms of the amount of training required to establish the chain as a function of the position of the ratios in it. Taking the pauses to occur at the beginning of a chain (Findley, 1962; Thomas, 1964), the overall chain finally established by S_4 by the 26th session with reinforcements scheduled after alternating chains FR5FR5 and FR40 FR5 would be *chain* FR40FR5FR5FR5, while that of S_1 and S_3 would be *chain* FR5FR40 FR5FR5. Insofar as S_4 was required to make more of the initial responses in the chain in the presence of a stimulus not correlated with primary reinforcement, the extra training it required before the chain was established would be expected. Likewise, the much less pausing exhibited by S_4 (Fig. 4) than by S_1 and S_3 (Fig. 2) on the same reinforcement schedule could be the result of a shift from a less to a more favorable schedule—a shift experienced by S_4 , but not by S_1 or S_3 .

If the schedules used in Exp 1 and Exp 2 can be considered to have become established as chains, then the problem remains of identifying the stimuli associated with the components

of the chains. These stimuli presumably were generated by the animals' own behavior, although the nature of the stimuli cannot be specified from the present data. The appearance of temporal alternation was reliably obtained by two different kinds of schedules of reinforcement, but it may be that the sensory complexes that succeed each other differ in ways other than just their temporal distribution.

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