A RESPONSE DURATION SCHEDULE: EFFECTS OF TRAINING, EXTINCTION, AND DEPRIVATION

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Rats were trained to hold down a lever for at least 40 consecutive seconds. When the lever had been held down for 40 sec, white noise came on. Releasing the bar in the presence of the noise turned off the noise and operated a feeder that delivered a pellet of food. At the end of training, frequency distributions of response durations peaked at 40 to 41 sec. If as in training, holding down the lever produced white noise at the end of 40 sec, and release of the lever terminated the noise and operated the feeder, but no food delivery occurred, duration distributions and several other measures were initially not very different from when food was delivered. However, if during extinction white noise was never produced by lever holding, and feeder operation did not occur upon lever release, most responses were shorter than 1 sec in duration, some were much longer than 41 sec, and duration distributions did not peak at 40 to 41 sec. When reinforcement was reinstated after extinction, performance quickly returned to pre-extinction measures. Further sessions at different levels of deprivation produced only temporary disruptions in performance.

Although most schedules of reinforcement do not restrict response duration other than the minimum required to close a switch, changes in duration nevertheless occur. With rats bar pressing, response durations are relatively long during operant level responding, decrease with extended continuous reinforcement (CRF) training, and again increase during extinction (Hurwitz, 1954; Margulies, 1961; Thompson, Heistad, and Palermo, 1963). Although duration is not affected by many external stimuli (Trotter, 1957; Schaefer and Steinhurst, 1959), it increases temporarily when new schedules are introduced. However, such changes are all of low magnitude, involving tenths of a second.

A precise timing response was obtained in humans, monkeys, and rats trained by a process of successive differentiations to press a bar for at least 1.00 sec but for no longer than 1.27 sec (McMillan and Patton, 1965). Longer response durations have also been obtained. When pigeons were required to stand within a 2-in. (5 cm) square area, well-trained birds

stood for 5 to 6 sec, but seldom longer (Blough, 1958). A response of waiting away from a feeder was difficult for rats to perform, and even with considerable training, rats often approached the feeder in the absence of the discriminative stimulus for approach (Zimmerman, 1957). Studying response differentiation as a characteristic of operant as opposed to respondent behavior, Skinner (1938) trained rats to press a bar for up to 30-sec durations. In the present experiment, responding under a 40-sec response duration schedule, with white noise coming on after 40 sec of continuous holding, was investigated over training, extinction with and without white noise, and different deprivation conditions.

METHOD

Subjects

Nine experimentally naive, male rats of the Sprague-Dawley strain were approximately three months old at the beginning of the experiment. Their mean free-feeding weight was 307 g, with a range of plus or minus 14 g. From two weeks before the experiment until the last part of the experiment, they were maintained at 75% free-feeding weight.

Apparatus

The experimental chamber was enclosed in a chest (Grayson-Stadler, Model E 3125A-300)

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in a room separate from the control and recording apparatus. A 2-in. (5 cm) wide response bar protruded 1.125 in. (3 cm) from one wall and rested 3.50 in. (9 cm) from the floor. A force of 12 g (0.117 N) was required to press the lever. When completely depressed, the bar could be raised about $\frac{3}{16}$ in. (0.5 cm) before its microswitch opened. A food cup was located to the lower left of the bar. The white noise, used as a stimulus for release of the bar, was held at an essentially constant intensity of 87 db, re: 0.0002 dynes/cm² (2×10^{-9} N/cm²). Each reinforcer was a 45-mg Noyes food pellet. In addition to a cumulative recorder, digital counters recorded the number of bar presses and reinforcements, and a print-out counter, which counted once per second whenever the lever was depressed, printed the duration of each press.

Procedure

Pretraining. Pretraining refers to increasing gradually the bar-press requirement for turning on white noise. Throughout pretraining, once noise was produced, release of the bar terminated the noise and operated the feeder. First, each rat produced 20 white noise presentations followed by reinforcements with only a minimal response duration requirement. It was then required to hold down the bar for 2 sec before producing white noise. The duration requirement was then increased to 3 sec for 20 presentations, and so on up through 7 sec. Each rat then produced 10 presentations at each of the following durations: 8, 9, 10, 12, 14, 16, 18, 20, 25, 30, 35, and 40 sec. Each session began with the last duration reached on the previous day. The requirement was decreased if a rat began to show a decrease in response duration. In an attempt to keep all nine rats performing at equivalent durations, the session length depended on an individual's performance and ranged from 10 min to 90 min. Pretraining lasted for 13 sessions.

Training. During training, no response duration of less than 40 sec was reinforced. That is, only a bar press lasting 40 consecutive seconds produced white noise. Release of the bar terminated noise and operated the feeder. Training continued for nine 40-min sessions.

Extinction. The nine rats were separated into three groups such that the mean number of reinforcements produced during the last four training sessions was as equal as possible

for all groups (Table 1). One group (S^+) worked under the same schedule as in training, the only difference being the absence of a pellet at the end of the response chain. That is, when a response duration reached 40 sec, white noise came on and stayed on until release. Release operated the feeder, but no food pellets were ever delivered. For the second group (*No S^+*) no noise, feeder sound, or food followed any response. Response durations were simply recorded. The third group, $S^+/\text{No } S^+$, received each of the above two conditions, alternating at 10-min intervals; each session began with the S^+ condition. For all three groups, extinction lasted for four, 40-min sessions.

Retraining. Responses were reinforced on the same schedule as in training, for three 40-min sessions.

Training under different deprivation levels. Rats still worked on the same schedule as in training, for three 40-min sessions. Each of three deprivation groups had one rat from each of the three extinction groups (Table 1). Furthermore, the rats were placed such that the group mean 75% weights were as equal as possible. Then, the rats assigned to the high deprivation group were not fed after the last retraining session. Because a day of no testing elapsed between retraining and deprivation training, this group began without having been fed for 72 hr. After the first deprivation training session only, each rat in this group was fed 6 g of ground chow, with water added. The *no-change* in deprivation group was maintained exactly as in previous sessions, on 8 to 11 g of ground chow mixed with water. The low deprivation group received 32 g of chow. These amounts were given about 30 min after each session. Furthermore, 2 hr before a session, each rat in the low deprivation group was fed the difference between its then current weight and its 90% weight.

RESULTS

Training

The 40-sec response duration schedule required 13 sessions of pretraining before responding was maintained. While holding down the bar with both forepaws, the rats made many other responses, such as moving hind feet, bar chewing, raising head toward the top of the box, and sniffing. However, no

Table 1
Numbers of Responses and Reinforcements over 40-min Sessions

	Group S*			Group No S*			Group Alternating S*/No S*		
	Rat 1	Rat 2	Rat 3	Rat 4	Rat 5	Rat 6	Rat 7	Rat 8	Rat 9
Training									
Session 9	57 25	57 40	62 46	74 25	70 40	56 46	65 36	49 40	48 42
Extinction									
Session 10	82 (20)	62 (35)	82 (40)	105	62	—	66 (20*)	56 (14*)	44 (16*)
Session 11	61 (11)	69 (19)	109 (13)	86	77	—	35 (3*)	47 (5*)	31 (6*)
Session 12	31 (8)	67 (8)	105 (9)	35	26	—	18 (3*)	28 (2*)	20 (2*)
Session 13	21 (5)	43 (4)	20 (5)	45	31	—	16 (3*)	22 (0*)	14 (3*)
Retraining									
Session 14	48 12	65 40	71 46	78 25	67 41	57 53	52 31	49 32	53 40
Session 16	50 12	58 39	49 47	50 22	52 44	50 46	51 37	44 40	42 41
Deprivation									
Session 17	68 18	49 43	25 15	40 19	56 43	44	52 38	28 19	46 42
Session 19	high 88 16	75 36	low 25 41	low 62 21	77 43	high 61 41	50 36	low 47 38	high 50 42
	high		low	low		high		low	high

( ) = presentations of white noise and feeder sound only, not food
 * = over a 20-min period only, not 40 min
 low, high = change in food deprivation

stereotyped pattern was noticed for any rat. On the ninth training day, the total number of responses made in the 40-min session ranged from 48 responses for one rat to 74 for another, with a mean for all nine rats of 60 responses. The number of reinforcements produced over this session ranged from 25 to 46, with a mean of 38 (Table 1). When response durations were summed over this last 40-min training session to get total time spent holding down the bar for each rat, these ranged from 21 min, 53 sec to 32 min, 4 sec, with a mean of 27 min, 57 sec (Table 2).

How durations were distributed within a session is shown in Fig. 1 and 2. Figure 1 shows the per cent of total responses at each response duration over the last three of the nine training days. As an indication of "typical performance" on this schedule, the inset provides results of all nine rats. That is, all their response durations were simply put together, and the percentages of total responses at each duration calculated. In the main part of the figure, distributions for three individuals were plotted over the last three training days. These individuals were chosen because subsequently each went into a different extinction group, and because on the last day of training each produced 40 reinforcements during a 40-min session. As with all nine individuals, two peaks in the duration distributions occurred: one at 40 to 41 sec and one at 0 to 1 sec. These 0 to 1-sec responses were not an initial "warm-up" (for example on the last training day, two rats' first responses and three rats' second responses lasted the required 40 sec); did not occur in "bursts" (on the last training day, seven out of nine rats did not give more than two 0 to 1 sec responses in suc-

cession); and persisted in spite of not being reinforced.

Extinction

Figure 2 shows duration distributions for the three rats considered above on the first day of extinction. In the upper part of Fig. 2, filled circles represent the same rat as did the filled circles in Fig. 1. This rat was in extinction Group S^+ , which received the same stimuli as in training except that no pellets were delivered. That is, each response lasting 40 sec turned on white noise; release of the bar terminated the noise and operated the empty feeder. As for all three rats in Group S^+ , this individual's distribution resembled its training distribution (*cf.* Fig. 1): the highest per cents of total responses occurred at 40 to 41 sec and at 0 to 1 sec. For each rat in Group S^+ , the per cent at 40 to 41 sec was only slightly lower than in training. Similar extinction distributions were given by rats in the alternation Group $S^+/No S^+$ during the S^+ conditions, when responding also produced noise and feeder sound. This may be seen in the lower half of Fig. 2, which gives the distributions of the same rat represented by squares in Fig. 1. Filled squares refer to the first and third 10-min periods, when responding produced stimuli, and open squares the second and fourth 10-min periods, when no stimuli were presented.

When noise and feeder sound were eliminated during extinction, either in alternation with stimuli (open squares) or throughout the entire session (open circles), no peak occurred at 40 to 41 sec. Of the three rats in Group $No S^+$, and the three in the alternation Group $S^+/No S^+$ during the no-stimulus conditions,

Table 2
Response durations (in seconds) totalled over 40-min sessions of training, extinction, and retraining.

	Group S^+			Group $No S^+$			Group Alternating $S^+/No S^+$		
	Rat 1	Rat 2	Rat 3	Rat 4	Rat 5	Rat 6	Rat 7	Rat 8	Rat 9
Session 9	1313	1896	1924	1337	1771	1905	1549	1681	1721
Session 10	1412	1876	1836	1528	2011	1887	1639	1199	1211
Session 11	908	1278	816	603	1099	1105	507	514	491
Session 12	556	801	634	523	501	1053	280	221	178
Session 13	410	380	275	410	408	164	159	123	310
Session 14	827	1777	1921	1188	1758	2128	1350	1403	1744

For any particular session, italics represent lower values than those of any other individual in Group S^+ or Group $No S^+$.

Fig. 1. Per cent of total responses at each response duration over the last three training days for Rat 2 (filled circles), Rat 5 (open circles), Rat 8 (open squares), all nine rats (inset).

Fig. 2. Per cent of total responses at each response duration on the first extinction training day for Rat 2 from Group S⁺ (filled circles), Rat 5 from Group No S⁺ (open circles), Rat 8 during S⁺ conditions (filled squares), and Rat 8 during No S⁺ conditions (open squares).

only one rat released the bar at 40 to 41 sec, and this happened only once. Furthermore, none of these rats showed any clustering of response durations around 40 sec.

On the second day of extinction, the maximum per cent of responses was at less than 1 sec for all rats, and rats in both Group S^+ and the alternation Group $S^+/No\ S^+$ during the stimulus condition showed a lower per cent at 40 to 41 sec than on the first extinction day. Distributions on the third and fourth extinction days looked very much like those of the second, except that the per cent of responses occurring at 40 to 41 sec was lower for both Group S^+ and Group $S^+/No\ S^+$ during the stimulus condition.

The lack of evidence for any temporal discrimination made by rats not receiving white noise during extinction may be seen not only by the absence of a peak around 40 sec in the duration distributions, but also by the very long durations made by these rats. One rat in Group $No\ S^+$ did not release the bar until it had been held down for 495 consecutive seconds, more than 12 times longer than the bar was ever held down during training. For all rats, maximum response durations were higher when white noise was not presented during extinction than when it was. That is, over the first two extinction days, maximum durations were higher in Group $No\ S^+$ (upper half of Fig. 3, open circles) than in Group S^+ (closed circles); in the alternation Group $S^+/No\ S^+$ maximum durations were higher during the no-stimulus conditions (lower half of Fig. 3, open circles) than during the stimulus conditions (closed circles).

That white noise lost some control over release of the bar when it was produced during extinction is indicated by the higher numbers of responses of more than 40-sec duration that occurred in extinction than in training. This can be seen for the individual in Group S^+ by comparing Fig. 1 (closed circles) with Fig. 2 (closed circles). For each rat in Group S^+ (upper half of Fig. 3, filled circles) the maximum response duration was higher during extinction than during training.

Although white noise was nevertheless controlling release during extinction, as shown by the peaks at 40 to 41 sec in the distributions of response durations, white noise during extinction did not affect the total number of seconds during which the bar was held down

(Table 2). That is, no difference in total response durations between Group S^+ and Group $No\ S^+$ occurred on any extinction day, nor over all four extinction days (Table 2). However, when response durations for the group receiving alternating $S^+/No\ S^+$ conditions were totalled over a single extinction session or over all four extinction sessions, the durations were less than those of Group S^+ and of Group $No\ S^+$ (Table 2). Thus, the alternation of $S^+/No\ S^+$ conditions within a group rather than the presentation of either condition alone, decreased total time spent on the bar. That this was not due to the three rats in Group $S^+/No\ S^+$ producing the lowest total durations regardless of conditions can be seen by their total durations on the last day of training or the first day of retraining (Table 2).

Another measure, the number of responses emitted per session was even less sensitive to extinction conditions. Although seven of nine

Fig. 3. Maximum response durations for each rat over the last two training days, the four extinction days, and the first two retraining days. The upper half represents the three rats in Group S^+ (filled circles in extinction) and the three rats in Group $No\ S^+$ (open circles in extinction). The lower half represents the three rats in the alternation Group $S^+/No\ S^+$, during the S^+ conditions (filled circles) and the $No\ S^+$ conditions (open circles). Symbols falling on the same point are spread rather than superimposed.

rats made more responses on the first extinction day than on the last training day, this difference was not significant (Wilcoxon matched pairs, one-tailed). Furthermore, there were no differences between groups. That is, on the first extinction day, the total numbers of responses for each rat in Group *No S+* were 58, 62, and 105; in Group *S+*, 62, 82, and 82; and in Group *S+/No S+*, 44, 56, and 66. (Although on the second extinction day each rat in Group *S+/No S+* made fewer total responses than any other rat, this did not hold on other extinction days; it was also true for two rats in Group *S+/No S+* on the last training day.)

Finally, the number of times that white noise plus feeder sound was produced on the first extinction day was not much lower than in training for each rat in Group *S+*: 25, 40, and 46 for each rat on the last training day compared with 20, 35, and 40 for each rat on the first extinction day. The total number of presentations produced over all four extinction sessions was 44, 66, and 67 for each rat in Group *S+*, and only 29, 21, and 27 for each rat in Group *S+/No S+*. Since rats in both these groups produced only 0 to 5 stimulus presentations on the last extinction day, it can be assumed that responding had been nearly extinguished for both groups, although noise and feeder presentations not followed by food had not occurred as often in Group *S+/No S+* as in Group *S+*. This implies that responding itself contributed to extinction more than did the number of white noise and feeder presentations not followed by food.

Retraining

When all nine rats were put back onto the training schedule after four days of extinction, performance was very similar to that before extinction. Although total response durations (Table 2) were lower in Session 14 than in Session 9 for seven of the nine rats, this was not significant (Wilcoxon matched pairs, one-tailed). The number of responses, number of reinforcements (Table 1), and maximum response durations (Fig. 3) did not differ from those before extinction, and remained fairly constant over the three days of retraining.

Training under Three Levels of Deprivation

On the first training day with deprivation changed, all three rats at 90% body weight

(marked "low" on Table 1) made fewer responses and produced fewer reinforcements than on any of the retraining days at 75%. Furthermore, total response durations over a session decreased from 1179, 1655, and 1912 sec in the last retraining session to 942, 769, and 662 sec for each rat on its first day at 90% body weight. However, by the third session at 90%, total response durations were approaching what they had been at 75%: 1117, 1605, and 1679 sec (with each rat presented in the same order as above). Numbers of responses and reinforcements by the third session at 90% were also very close to those in retraining (Table 1).

For the very deprived rats (marked "high" on Table 1), no consistent differences from retraining performance were observed. Thus, any increase in activity due to the extreme deprivation did not interfere with the 40-sec response duration requirement, which required that the rats remain fairly still.

However, the decrease in number of reinforcements produced when rats were changed from 75% to 90% body weight was not correlated with a decrease in the effect of the white noise as a discriminative stimulus for release. The most sensitive measure of this, the maximum response duration in any session, actually decreased for two of the three rats. What did affect maximum response duration was the lapse of one day between retraining (Session 16) and training at different levels of deprivation (Session 17). While no consistent trend over these days was found for rats that had been in Group *No S+* and in the alternation Group *S+/No S+* (maximum response durations for only three of the six rats increased, with the largest increase being only 12 sec), the maximum response durations increased markedly for all three rats that had been in Group *S+*: for Rat 1, 44 sec in Session 16 compared with 77 sec in Session 17; for Rat 2, 41 sec in Session 16 to 88 sec in Session 17; and for Rat 3, 41 to 81 sec. By Session 19, the maximum durations were back to 41, 40, and 42 sec for each of these rats. Why the lapse of one day between Sessions 16 and 17 affected the discriminative stimulus value of the noise for these rats and not the others could be related to the fact that during extinction these three rats had received more noise presentations not followed by food than did the rats in the other two groups (Table 1).

DISCUSSION

Building up performance on this response duration schedule required 13 days of pre-training. No doubt the white noise that signalled the end of the 40-sec duration not only made training less difficult than without it, but also made response durations more uniform. All rats had similar distributions of response durations, with a peak at 40 to 41 sec and a lower peak at 0 to 1 sec. These short-duration responses persisted in spite of not being reinforced (*cf.* Blough, 1966) and occurred as isolated responses rather than in bursts. Thus, the present experiment showed that bursts of responding are not an inevitable occurrence under a response duration schedule. Similarly, Kelleher, Fry, and Cook (1959) have shown that bursts of responding are not inevitable under schedules that require the spacing of responding in time.

Although results from DRL schedules with limited hold (Zimmerman, 1961) and short response duration schedules (McMillan and Patton, 1965) show that rats are capable of making temporal discriminations, there was no evidence of such a discrimination in the present experiment. The stimulus (white noise) that signalled the end of the required response duration during training also controlled response durations during extinction. If no stimulus occurred during extinction, most responses were of 0 to 1-sec duration, a few response durations were at or around 40 sec, and some were much longer than 40 sec.

When stimuli were produced during extinction, per cent distributions were bimodal and resembled training distributions. Although noise continued to be a discriminative stimulus for release, and release produced the feeder sound, these presentations did not increase resistance to extinction as measured by total number of responses or total time spent on the bar. Even when a group produced the above stimuli during extinction in alternation with conditions in which no stimuli were produced, the spacing out of stimuli did not increase number of responses or time spent on the bar. In fact, total time spent on the bar was actually less for this alternation group than for the group that could produce stimuli or for the group receiving no stimuli.

Skinner (1938, pp. 328-338) discussed a response duration schedule in which presumably

no external stimulus signalled the end of the required duration in terms of a conflict between holding down the lever and making a new response: "Continuing to hold the lever down is incompatible with making a second response, but both holding and pressing are reinforced and exist side by side with considerable strength." (Skinner, 1938, p. 332). He argued that if making a new response was weakened by decreasing food deprivation, then longer holds might occur. However, with the present schedule, rats going from 75% to 90% body weight did not hold longer. Although the number of presses lasting 40 sec temporarily decreased, the time of release did not increase. This finding that the response producing a stimulus (here, holding) is more readily disrupted with satiation than a response that follows (here, release) has been found with chained schedules involving the same response in both components (Fischer and Fantino, 1968).

However, neither extremely high deprivation (after being kept at 75%, not fed for 72 hr) nor extremely low deprivation (kept at 90%, fed 2 hr before testing) affected final performance. This is in line with the finding that a DRL schedule (Conrad, Sidman, and Herrnstein, 1958) and a waiting schedule (Blough, personal communication) were fairly insensitive to changes in deprivation level. The generalization that changes in deprivation are not very effective once responding is under schedule control (Morse, 1966) applies also to these schedules that require periods of not responding.

One way to examine any interaction between holding down the lever and releasing it is to alternate a response-duration schedule with a schedule that does not require long durations (Stevenson, 1962). When rats were first trained on a fixed-interval 43-sec schedule in the presence of one stimulus and then on the above response-duration 40-sec schedule in the presence of another stimulus, interaction did occur when the rats were finally put on a multiple response-duration 40-sec, fixed-interval 43-sec schedule. Response durations increased during the fixed-interval component and decreased during the response-duration component. Although durations during the response-duration component returned to their value when on a simple response-duration schedule, the durations during the fixed-

interval component remained at approximately 10 sec. This occurred in spite of the fact that any bar press originating before the end of the 43-sec interval was never reinforced. Even though a change to multiple response-duration 40-sec, fixed-ratio 10 training had a considerable effect in decreasing response durations, when rats were returned to the multiple response-duration 40-sec, fixed-interval 43-sec schedule some holding still persisted during the fixed-interval component.

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