LIMITATIONS ON ENVIRONMENTAL CONTROL OF MULTIPLE FIXED-RATIO BEHAVIOR¹

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Eight white rats were trained to make fixed numbers of responses on each of two bars alternately in the presence of different exteroceptive stimuli. Three types of error were observed: *alternating*—bar switching before response requirements for reinforcement were met; *perseverating*—responding on the wrong bar after reinforcement; and *overshooting*—responding on a bar after reinforcement became available. Alternating and perseverating errors occurred mainly on the bar requiring the smaller ratio. When the ratios on the bars were changed, alternating errors were most common, but they diminished rapidly. Perseverating and overshooting errors did not diminish.

According to operant conditioning principles (Skinner, 1938), discriminative stimulus control of a response is obtained by differential reinforcement. If the response is reinforced in the presence of a stimulus (S^D) but not in its absence (S^Δ) the response extinguishes in S^Δ but occurs with high probability in S^D ; that is, the response is controlled by the exteroceptive discriminative stimulus, S^D . However, the precision of exteroceptive stimulus control may be upset or obscured by a number of factors including; cue properties acquired by reinforcers (Jenkins, 1965), reinforcement properties acquired by discriminative stimuli (Skinner, 1938; Keller and Schoenfeld, 1950), various consequences of the response itself, like proprioceptive feedback during fixed-ratio runs, and stimuli correlated with time (Keehn, 1965). When stimulus discrimination and response differentiation are attempted concurrently, other factors may interfere with environmental control.

For instance, if reinforcement is obtained more easily by one response than by another then that response may be emitted even though the exteroceptive stimulation sets the occasion for the other; or contrast effects may occur (Reynolds, 1961). Likewise, when re-

sponses alternate, some internal consequences of alternation may override the correlated exteroceptive stimulus changes in controlling the behavior. One method for investigating the extent to which an experimenter can control a subject's behavior is to use all known experimental tactics to shape "errorless responding" (Terrace, 1963). A second method is to modify the behavioral requirements for reinforcement while maintaining the same exteroceptive stimulation, and to observe ways in which the behavior fails to come completely under exteroceptive stimulus control. This method was used in the present research.

Alternating two-component multiple fixed-ratio schedules of reinforcement (*mult* FR x FR y) were used, with each ratio performed on a different response bar under different exteroceptive stimuli. Extent of exteroceptive stimulus control was probed by altering the ratio requirements in the presence of the different stimuli. Specifically, white rats received a sucrose reinforcer after making one or more presses on one bar in bright light and, alternately, one or more presses on a second bar in dim light. Ways in which behavior failed to come under control of the exteroceptive stimuli were examined by making relatively small changes in the number of responses required on each bar for reinforcement.

METHOD

Subjects

Eight 150-day-old male albino rats from the colony maintained by Washington State Uni-

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versity were used. They had been trained at 90 days of age to bar press on a fixed-ratio reinforcement schedule, but their prior experience ended a month before the present experiment.

Apparatus

The experimental chamber was a Grason-Stadler two-bar rat box (type E3125D). A liquid reinforcer was delivered by means of a dipper which presented 0.1 cc 12% sucrose solution by weight in tap water for 2 sec when scheduled. The internal dimensions of the chamber were 11½ in. by 9¼ in. base, by 7⅝ in. high. The response bars were 2-in. wide and mounted so that the inside edges were about 3¾ in. above the chamber floor, and protruded ⅝ in. from the wall. A weight of about 22 g on a bar activated the automatic programming and recording equipment. Three 10-w stimulus lights were located in the same wall as the bars and the access-opening to the dipper. Red and white lights were slightly above and about 1¼ in. from the outside edges of Bar 1 (left bar) and Bar 2 (right bar) respectively. A green light was centered above the dipper opening, midway between the response bars and about 1⅞ in. above them. The experimental chamber was enclosed in a commercially adapted picnic chest to reduce extraneous stimuli. A blower provided ventilation and masked extraneous noises. Programming and recording equipment were in an adjacent room. Response records were obtained on Gerbrands cumulative recorders, magnetic counters and a

Grason-Stadler multiple event pen recorder (type E11040A) moving at 1 in. per min.

Procedure

Food and water were available for 1 hr daily for three weeks before the experiment began. Subjects were 22 to 23 hr food and water deprived at the beginning of daily experimental sessions. After its daily session each subject was fed 10 to 12 g of Purina Rat Chow and allowed free access to water for 1 hr.

In Sessions 1 through 4 all subjects were trained to press Bar 1 with each response reinforced (FR 1) in the presence of the red, white, and green stimulus lights (high illumination, S^D_1), but not in the presence of the green light alone. During the fifth session, Bar 2 responses were reinforced in the presence of the green light (low illumination, S^D_2), but not in the presence of S^D_1 . That S^D_1 and S^D_2 can be discriminated by the rat was shown in earlier experiments (Keehn, 1965). In Session 5, reinforcements were scheduled on alternating *mult* FR 1 FR 1: one response on Bar 1 in S^D_1 was reinforced and followed by S^D_2 , in the presence of which one response on Bar 2 was reinforced, and so on. All lights were off during reinforcement cycles. In Sessions 1 through 4 each subject received 100 reinforcers per session for pressing Bar 1, and in the fifth session 50 reinforcers were delivered for responses on Bar 1 and also for responses on Bar 2. The remainder of the experimental time-table is summarized in Table 1.

Both bars were available at all times but

Table 1
Experimental Training Timetable*

Experimental Sessions	Experimental Condition				Number of Reinforcements per Session
	Group I		Group II		
	(Subjects 1, 2, 3, and 4)		(Subjects 5, 6, 7, and 8)		
	Bar 1 FR	Bar 2 FR	Bar 1 FR	Bar 2 FR	
1-4	1	—	1	—	100
5	1	1	1	1	100
6-7	1	1	1	1	60
8	2	1	2	1	60
9	3	1	3	1	50
10-21	3	3	3	3	50
22-26	10	3	3	10	50
27-31	3	10	10	3	50

*Responses were reinforced on alternating *multiple* FR FR schedules with alternate ratios performed on Bar 1 and Bar 2. Ratio requirements on each bar in each session are shown.

only responses on a bar in the presence of the SP for that bar were appropriate. Other responses were counted as errors. Total errors on each bar were recorded on magnetic counters, and detailed distributions of errors monitored on the event recorder.

RESULTS

Three kinds of errors were observed: *alternating*, *overshooting*, and *perseverating*. Alternating errors are those that occur through switching before a ratio is completed, and overshooting errors are responses made beyond the requirements of a ratio, *i.e.*, when reinforcement is available. Perseverating errors result when switching fails to occur after a reinforcement, *i.e.*, responding is resumed on the just-reinforced lever.

Table 2 shows the total errors, regardless of type, made on each bar by each subject in Sessions 7 through 10. The subjects averaged 15.9 errors on Bar 1 and 7.6 errors on Bar 2 in Session 7 when the reinforcement schedule was *mult FR 1 FR 1*.

Alternating errors were not possible on this schedule and most perseverating errors occurred on Bar 1, probably because before this session each subject had received 510 reinforcers for pressing Bar 1 and only 110 reinforcers for pressing Bar 2. Increasing the ratio requirement on Bar 1 from FR 1 to FR 2 in Session 8 made very little difference to the Bar 1 errors but more than doubled the errors made on Bar 2, from 7.6 to 20.9 on the average; six of the eight subjects now over-responded to Bar 2. These errors occurred partly through perseveration on Bar 2

after SP_1 onset, and partly through alternation as the subjects switched from Bar 1 to Bar 2 in the presence of SP_1 when the first Bar 1 press was not reinforced. Bar 1 errors were always of the perseverating type, and were virtually absent in Subjects 1, 3, and 7. Behavior in Session 9 with the reinforcement schedule at *mult FR 3 FR 1* resembled that in Session 8. The most dramatic increase in errors occurred in Session 10 when the schedule was changed to *mult FR 3 FR 3*. Errors on Bar 2 were hardly affected but those on Bar 1 increased almost fivefold, even though the schedule on this bar was unchanged from the previous session.

Most of the Bar 1 errors in Session 10 were of the alternating type, the subjects switching from Bar 2 to Bar 1 in the presence of SP_2 before the ratio on Bar 2 was completed. However, in general, each subject developed an idiosyncratic mode of responding. Subjects 3 and 6, for example, tended to respond with one bar press at a time, while Subject 4 typically responded in bursts of three or four bar presses. Likewise, each type of error had its own characteristic pattern. Overshooting errors typically occurred singly in all subjects on all the schedules, but perseverating errors varied across animals and schedules. Typically, each failure to switch bars after reinforcement yielded only one or two inappropriate bar presses, but as the ratios were increased the number of responses in each group of perseverating errors tended to increase, and the number of responses emitted before a failure to switch was corrected ranged from 1 to 55 responses. Similarly, alternating errors most frequently occurred as single bar presses, but the

Table 2
Total Errors Made by Each Subject on Each Bar on the Designated Sessions

Subject	Session 7		Session 8		Session 9		Session 10	
	FR 1 Bar 1	FR 1 Bar 2	FR 2 Bar 1	FR 1 Bar 2	FR 3 Bar 1	FR 1 Bar 2	FR 3 Bar 1	FR 3 Bar 2
1	12	13	6	16	1	25	18	30
2	29	9	22	23	16	38	54	31
3	7	1	0	19	2	25	31	18
4	16	0	10	15	13	13	62	2
5	16	16	21	12	1	25	38	15
6	7	10	20	40	21	28	87	31
7	16	2	1	23	15	15	61	11
8	24	10	29	19	23	16	79	29
Total	127	61	109	167	92	185	430	167
Mean	15.9	7.6	13.6	20.9	11.5	23.1	53.8	20.9

Table 3
Total Errors Made by Each Subject on Each Bar on the Designated Sessions

Group I	Session 21		Session 22		Session 26		Session 27	
	FR 3 Bar 1	FR 3 Bar 2	FR 10 Bar 1	FR 3 Bar 2	FR 10 Bar 1	FR 3 Bar 2	FR 3 Bar 1	FR 10 Bar 2
S1	19	11	3	112	0	41	143	0
S2	9	11	8	114	2	24	215	0
S3	2	29	13	148	14	15	127	6
S4	6	6	17	147	2	24	45	3
Total	36	57	41	521	18	104	530	9
Mean	9.0	14.2	10.2	130.2	4.5	26.0	132.5	2.2

Group II	Session 21		Session 22		Session 26		Session 27	
	FR 3 Bar 1	FR 3 Bar 2	FR 3 Bar 1	FR 10 Bar 2	FR 3 Bar 1	FR 10 Bar 2	FR 10 Bar 1	FR 3 Bar 2
S5	4	2	97	1	10	3	30	34
S6	22	10	120	1	29	0	3	211
S7	10	6	67	0	10	1	2	71
S8	19	3	49	2	54	1	10	113
Total	55	21	333	4	103	5	45	429
Mean	13.7	5.2	83.2	1.0	25.7	1.2	11.2	107.2

number of responses emitted after a single erroneous alternation ranged up to 43. There is some justification in counting only the first inappropriate bar press on any occasion as the error, successive inappropriate responses being considered only as part of that error. Data of this kind are reported below.

Gross error data for Sessions 21, 22, 26, and 27 are shown in Table 3. By Session 21, after 12 sessions of reinforcement on *mult* FR 3 FR 3, errors had reduced markedly from Session 10, but were still relatively common for six of the subjects. In Session 22, when the ratio on one of the bars was increased from FR 3 to FR 10, errors on the other bar increased from a total of 112 (57 + 55) in session 21 to 854 (521 + 333), over all animals. All subjects now made almost no errors on the bar with the largest ratio requirements (range 0-17) and many errors on the other bar (range 49-148). A significant decrease in errors on the smaller ratio bar occurred between Sessions 22 and 26 for all subjects but Subject 8, but still a total of 207 (104 + 103) errors were made on this bar as against only 23 (18 + 5) on the larger ratio bar. When the ratio requirements on the two bars were reversed in Session 27 the errors on the two bars reversed. When the Group 1 schedule was changed from *mult* FR 10 FR 3 to *mult* FR 3 FR 10, Bar 1 errors increased from 18 to 530 and Bar 2 errors decreased from 104 to 9.

Likewise, the Group 2 schedule change from *mult* FR 3 FR 10 to *mult* FR 10 FR 3 decreased Bar 1 errors from 103 to 45 and increased Bar 2 errors from 5 to 429.

Analyses of errors by type between Sessions 21 and 31 are shown in Table 4. Only one error was counted each time perseveration or alternation occurred, regardless of the number of presses actually made on the incorrect bar. That is, if Bar 1 was correct every alternation to Bar 2 before the Bar 1 ratio was completed was counted as one error no matter how many Bar 2 responses were made before an animal reverted to Bar 1. Alternating errors are therefore the number of switches to the incorrect bar before the ratio on the correct bar was completed, not the total number of alternating errors made on the incorrect bar. Likewise, perseverating errors include only the first error in each group. Thus, only 25 perseverating errors to each bar were possible in each session. (Subjects received 50 reinforcers per session, 25 after responses on each bar. Hence, on only 50 occasions, divided equally between the bars, could a subject persevere on the just-reinforced bar). The same is true for overshooting errors.

Smaller ratio errors. When the ratio requirements on the two bars were unequal, most errors were made on the smaller ratio bar, and the majority of these were of the alternating type (Table 4). When the *mult*

Table 4
Mean Errors According to Type on the Designated Sessions*

Session and Reinforcement Schedule	Mean Smaller Ratio Errors Type of Error			Mean Larger Ratio Errors Type of Error		
	Alternate	Perseverate	Overshoot	Alternate	Perseverate	Overshoot
21 <i>Mult</i> FR 3 FR 3	.875	1.75	3.125	.125	2.875	2.375
22 <i>Mult</i> FR 10 FR 3	27.25	7.25	1.50	.25	1.25	2.375
24 "	6.125	7.50	3.50	.625	.25	3.50
26 "	1.50	6.625	5.125	0.00	.125	2.50
27 <i>Mult</i> FR 3 FR 10	20.25	1.50	2.125	0.00	1.0	3.25
29 "	1.25	4.25	4.25	.50	.625	2.625
31 "	.625	5.125	4.25	0.00	.125	7.50

*Only one error was counted for each type of error regardless of the number of responses emitted each time that type of error was committed.

FR 10 FR 3 (Group 1) or *mult* FR 3 FR 10 (Group 2) schedules were first introduced in Session 22, a marked increase in alternating smaller ratio errors occurred. The mean number of alternating smaller ratio errors in this session was 27.25, while the other two error types averaged only 8.7 errors between them, or less than one-fourth of the errors that occurred on the smaller ratio. However, although perseverating errors were absolutely few (average 7.25) they occurred on about one-third of the possible opportunities and almost six times more frequently than in Session 21 when the reinforcement schedule was *mult* FR 3 FR 3 for all subjects.

Between Sessions 22 and 26, alternating errors on the bar requiring the smaller ratio decreased to an average of 1.50, perseverating errors hardly changed, and overshooting errors increased. Hence, as the multiple schedule began to take effect, the subjects exhibited less switching from the larger ratio to the smaller ratio bar before completing the larger ratio, but showed relatively little change in their tendencies to return to the smaller ratio bar after responses on that bar were reinforced. There was an average increase in the number of overshooting responses on the smaller ratio bar from 1.50 in Session 22 to 5.125 in Session 26.

The schedule reversal in Session 27 was accompanied by a recurrence of alternating errors, this time on the new smaller ratio bar. Detailed data are shown in the lower half of Table 4. The change in error pattern from Sessions 27 through 31 resembles that shown between Sessions 21 and 26: absence of exteroceptive stimulus control is mainly exemplified,

first, by many alternating errors as the subjects switch from the larger ratio bar before completing the ratio, but later, as alternating errors diminish, by perseverating errors as the animals return to the smaller ratio bar after reinforcements.

Large ratio errors. Relatively few errors occurred on the bar requiring the larger ratio performance. Alternating and perseverating responses were virtually non-existent, and only in Session 24 did more than one subject alternate (Table 4). Except for Session 31, overshooting errors on the larger ratio bar varied little, each subject making approximately the same number in each session.

The increase in overshooting in Session 31 is entirely accounted for by the behavior of Subjects 5, 6, and 7. No explanation can be offered. Only one other error was made by all the animals in this session.

DISCUSSION

Two anticipated sources of interference with environmental control of behavior, when stimulus discrimination and response differentiation were attempted concurrently, were found. The subjects did show marked tendencies to perseverate on the lower ratio bar (perseveration errors) when the two ratios in the multiple schedule were unequal; they also switched before completing the ratio on a bar (alternating errors) whenever the ratio on that bar increased. A third type of error, overshooting, had not been anticipated, although a similar phenomenon has been reported (Hurwitz, 1958). With further exposure to a particular pair of ratios, alternating errors rapidly di-

minated, but perseverating errors did not diminish during the experiment: by the end, the animals still returned to the smaller ratio bar after about 20% of the reinforcements obtained at that bar. Likewise, overshooting errors showed no sign of decreasing and occurred equally frequently on either bar.

Because they diminish rapidly, alternating errors probably do not interfere seriously with exteroceptive stimulus control of behavior; they can even be eliminated by the procedures adopted by Terrace (1963). But their occurrence does demonstrate a powerful source of response-produced stimulus control of the behavior of organisms, a fact which is already well known (Ferster and Skinner, 1957). The reduction of these errors to near zero can probably be attributed to the normal process of differential reinforcement. Overshooting errors probably do not interfere with the normal reinforcement schedule in any significant way. They occurred only singly and did not occupy enough time to prevent the animals securing all of the reinforcer when it was presented. Overshooting on the smaller ratio might be expected through induction (Skinner, 1938) from responding on the larger ratio, and overshooting on the larger ratio might have been a result of "response momentum". This kind of error probably occurs frequently in simple fixed-ratio behavior, although normal methods of data collection do not allow it to be observed.

Perseverating errors do reduce the density of reinforcement, a characteristic they share with alternating errors, but they occur less frequently and do not drop out as alternating errors do. This may be because perseverating errors occur relatively less frequently and so have less opportunity to go unreinforced, or it may be a characteristic of the stimuli controlling these errors. Alternating errors occur after a ratio has begun, so proprioceptive consequences of responding enter directly into their control, while after-effects of reinforcement do not. Perseverating errors, on the other hand, are made at the beginning of a

ratio and occur after reinforcement. One way of accounting for these errors is to appeal to aversive characteristics of fixed-ratio schedules (Thompson, 1964). White rats pause longer before beginning larger than beginning smaller fixed ratios (Patrikiou and Keehn, 1964; Keehn, 1965, Exp. 1) and differential pausing may reflect differences in the aversiveness of different ratios. (This, of course, is not an explanation but a suggested orientation for research). In this sense, perseverating errors would be the joint outcome of stimuli responsible for avoidance of the larger ratio and those controlling emission of smaller ratio responses. Thus, a possible method of reducing perseverating responses would be to increase the aversiveness of smaller ratio responding. This would not be just a matter of increasing the size of the smaller ratio, because postreinforcement pauses are relative, not absolute (Keehn, 1965, Exp. 1), but other methods are conceivable.

REFERENCES

- Ferster, C. B. and Skinner, B. F. *Schedules of reinforcement*. New York: Appleton-Century-Crofts, 1957.
- Hurwitz, H. M. B. A source of error in estimating the number of reinforcements in a lever pressing apparatus. *J. exp. Anal. Behav.*, 1958, 1, 149-152.
- Jenkins, H. M. Measurement of stimulus control during discriminative operant conditioning. *Psychol. Bull.*, 1965, 64, 365-376.
- Keehn, J. D. Temporal alternation in the white rat? *J. exp. Anal. Behav.* 1965, 8, 161-168.
- Keller, F. S. and Schoenfeld, W. N. *Principles of psychology*. New York: Appleton-Century-Crofts, 1950.
- Patrikiou, V. D. and Keehn, J. D. The effect of partial satiation on pauses after reinforcements scheduled on alternating fixed ratios. *Psychonom. Sci.* 1964, 1, 79-80.
- Reynolds, G. S. Behavioral contrast. *J. exp. Anal. Behav.*, 1961, 4, 57-71.
- Skinner, B. F. *The behavior of organisms*. New York: Appleton-Century-Crofts, 1938.
- Terrace, H. S. Discrimination learning with and without "errors". *J. exp. Anal. Behav.* 1963, 6, 1-27.
- Thompson, D. M. Escape from S^D associated with fixed-ratio reinforcement. *J. exp. Anal. Behav.*, 1964, 7, 1-8.

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