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RATIO REQUIREMENT AND REINFORCER EFFECTS IN CONCURRENT FIXED-INTERVAL FIXED-RATIO SCHEDULES[1]

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The fixed-ratio requirement was varied in concurrent fixed-interval fixed-ratio schedules. Fixed-interval responding was reinforced by food. In different phases, fixed-ratio responding was reinforced by food or water. There was a direct relation between the ratio requirement and interval response rates when both responses were reinforced with food, but essentially no relation when the reinforcers were different. The role of reinforcers in concurrent schedules merits detailed study.

LaBounty and Reynolds (1973) described the performance of pigeons on concurrent fixed-interval fixed-ratio (*conc* FI FR) schedules. Pecks on one key produced grain according to an FI 4-min schedule; timed from a reinforcement on that key, the first peck after 4 min produced grain. Every *n*th peck on a second (FR) key produced grain. Increasing the FR requirement decreased FR response rates and increased FI response rates.

Catania (1966) suggested that performance on concurrent schedules may depend on the reinforcers used. The present data support this idea. We compared performance on *conc* FI_{food} FR_{food} schedules with performance on *conc* FI_{food} FR_{water} schedules.

METHOD

Subjects

Two male, experimentally naive Long-Evans descent hooded rats were approximately 63 days old and weighed approximately 275 g on free food and water. Both rats were housed individually in a light–dark cycle controlled colony room and were deprived of both food and water. The temperature was maintained at 70 ± 2°F (21.1 ± 1.1°C). Both rats were studied daily early in the evening.

Apparatus

Two operant chambers each contained two retractable levers, 3 cm above the grid floor and 14 cm apart. The required response force was approximately 0.20 N. A water dipper was 8 cm to the right of the left lever. The water reinforcer was 0.01 cc tap water, available for 2.5 sec and accompanied by a 2.5-sec clicker. A food magazine was 4 cm to the left of the right lever. The food reinforcer was one 0.045-g Noyes standard formula pellet, accompanied by a 2.5-sec tone. Three white cue lights above the left lever at times served as discriminative stimuli for different FR requirements. Masking noise was continuously present, except for 30 msec following a response: the resulting "pop" served as response feedback. Dim general illumination was provided by a 7.5-W lamp. Each chamber was located in a sound- and light-attenuating box. Standard electromechanical scheduling and recording equipment was located in an adjacent room.

Procedure

The rats were adapted to the food- and water-deprivation regimen and magazine trained. Then, responding was reinforced on *conc* FI_{food} FR_{water} schedules, and the FR_{water} requirement was varied. Then, the FR rein-

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forcer was changed to food, and the FR_{food} requirement was varied.

Each subject received food and water at the time it was to be studied for at least 10 days before magazine training. Magazine training was conducted with the levers retracted. After a subject rapidly approached the water dipper following clicker onset, and rapidly approached the food magazine following tone onset, both levers were introduced. Early in pretraining, the levers alternated until the left lever controlled responding appropriate to the FR_{water} schedule and the right lever controlled responding appropriate to the FI_{food} schedule. Responding was then developed on a *conc* FI 4-min LH 11-sec_{food} FR 10_{water} schedule. Specifically, both levers were present. Left-lever FR responses were reinforced with water. Right-lever FI responses were reinforced with food. To aid the development of FI schedule control, a rat had a brief time (limited hold, or LH) in which to respond, receive food, and restart the FI timer. In some aspects, the LH could act like a changeover delay in reducing the probability of superstitious chaining. At least 200 pretraining sessions preceded collecting the present data.

Daily sessions ended with the first food delivery (or the end of an LH) approximately 2 hr after the levers were inserted. Purina chow was provided 30 min after each session to raise the daily intake of food to 12.2 g. Five minutes' access to tap water was provided at the same time. These amounts of food and water maintained stable body weights (less than 2 g difference per week) and maintained responding on both levers. When deprivation levels were different, either body weights gradually changed or responding would predominate on one lever (Willis, Van Hartesveldt, Loken, and Hall, 1974). We attempted to vary the FR_{water} requirement in a steady state design (Sidman, 1960). The FR_{water} requirement was increased to 80. Body weights slowly decreased over days. To reduce confounding body weight and FR schedule, we decided to use a multiple schedule procedure to vary the FR_{water} requirement. Different left-lever cue-light configurations were correlated with different FR_{water} requirements: none on for FR 10, the left on for FR 20, both the center and right on for FR 40, and all three on for FR 80. A randomized blocks design with one FR per session was used for 16 blocks (64 days). During this first phase of the experiment, Rat 10's weight changed from 297 to 305 g, and Rat 13's changed from 276 to 261 g. No trends in responding were evident after the first five blocks.

To assess our methods and to compare responding on *conc* FI_{food} FR_{water} with responding on *conc* FI_{food} FR_{food}, we used a *mult* FR 10 FR 20 FR 40 FR 80 schedule, with the same cue-light–FR_{food} requirements and the same randomized blocks design as had been used with water reinforcement. Since no water was available during sessions on *conc* FI_{food} FR_{food}, the daily ration of water was increased to 6 min of drinking. Water was presented before the session, and the amount of time spent drinking was recorded. If a rat drank for less than 6 min, the remainder of the 6-min water ration was provided 30 min after the session. Sessions were ended after 270 food reinforcers (12.2 g) or approximately 2 hr (± 4%).

During this second phase, there was little responding on the FI lever. After three blocks, the FR lever was retracted for three to five sessions (Phase 3). Fixed-interval responding was intact. We decided to increase the FR_{food} requirement by 20 responses per day. The cue lights above the left lever were never lit. The highest FR requirement attained by Rat 10 was 820 responses (37 sessions). Rat 10's weight changed from 302 to 282 g during this phase. The highest FR requirement attained by Rat 13 was 2180 responses (103 sessions). Rat 13's weight changed from 251 to 234 g during this phase (Phase 4).

After Rat 10 completed the ascending FR series, four geometrically spaced fixed ratios (100, 145, 210, and 305) were used with that subject in a multiple schedule, randomized blocks design that had been used previously. No left-lever cue lights were on during FR 100, the left was on during FR 145, the center and right were on during FR 210, and all three were on during FR 305. Rat 10's weight changed from 282 to 278 g during this final phase. Data collection ended after 16 blocks because the laboratory was moved. Rat 13 was completing the ascending series and was not trained on the multiple schedule.

RESULTS

Cumulative records of typical performance under FR 10_{water} are presented in the top

panels of Figures 1 (Rat 10) and 2 (Rat 13). At FR 10, both rats began the session with an extended episode of responding on the FR_{water} lever. The first available FI_{food} reinforcer was missed. After the initial FR response episode ended, Rat 10 tended to respond on the FI lever until food delivery, pause, changeover to the FR lever and respond there, then changeover to the FI lever and respond there until food delivery, pause, *etc.* Rat 13 responded more than Rat 10 on the FR lever toward the end of the fixed interval; Rat 13 had higher response rates and higher changeover rates than Rat 10. Rat 10 pressed both levers using its forepaws; Rat 13 bit both levers. Occasionally, no FR responses occurred between consecutive food deliveries. The FI responding of both rats was essentially the same whether or not FR responses occurred.

Cumulative records of typical performance under FR 80_{water} are presented in the bottom panels of Figures 1 and 2. Except for the absence of a large episode of FR responding and the presence of more FI responding early in the session, response rates and patterns were similar to those at FR 10. Fewer water reinforcers were earned at FR 80. No response pattern was uniquely associated with one FR requirement. Response rates and patterns at FR 20 and at FR 40 (not shown) were similar to those at FR 10 and 80. Responding on the FR lever occurred before the first food delivery and occasionally after food deliveries later on.

Cumulative records of *conc* FI_{food} FR_{food} (not shown) closely resembled those published by LaBounty and Reynolds (1973). Absolute response rates are presented in Figures 3 and

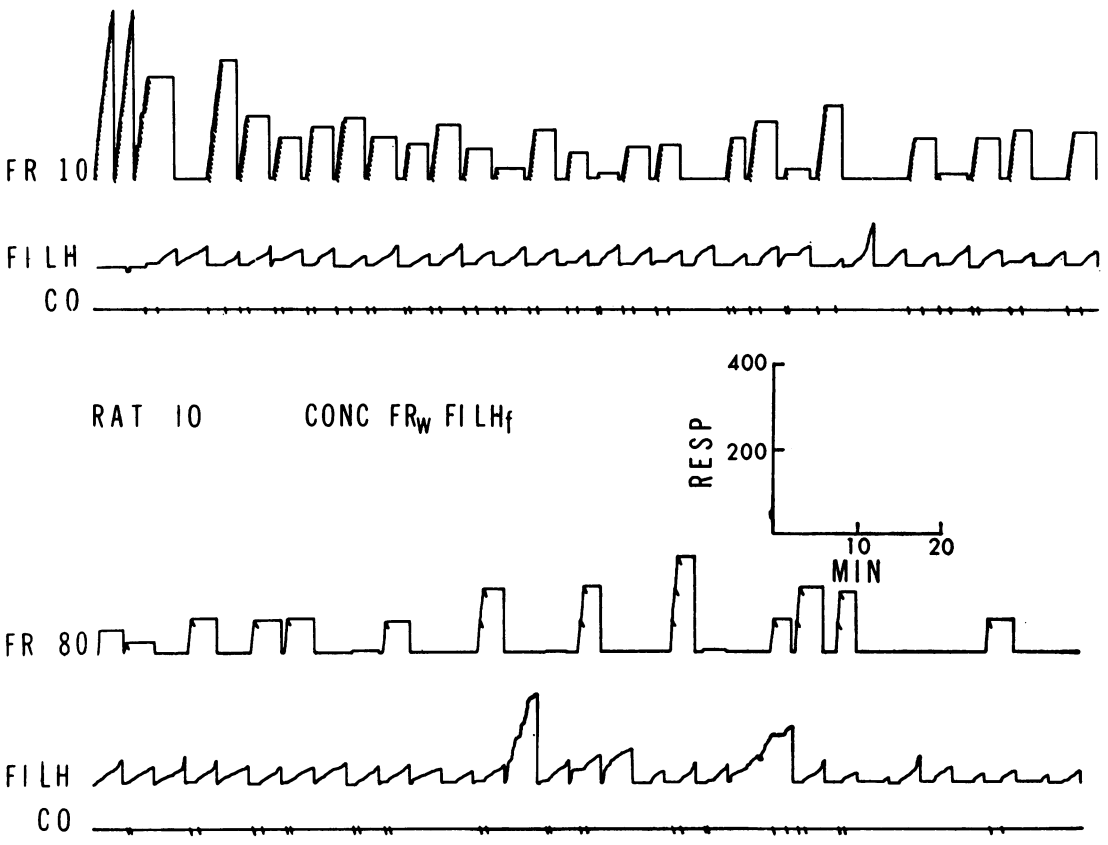

Fig. 1. Cumulative records of rates and patterns of responding by Rat 10 on *conc* FI_{food} FR_{water} at FR 10 (upper panel) and 80 (lower panel). Paper drive motors ran throughout sessions. In both panels, the top record is FR responding, the middle record is FI responding, and the bottom record is changeovers. Cumulating pens reset after 400 responses and whenever food was delivered. Pips on the FR record indicate water delivery. The cumulating pen on the FI record was displaced downward during the limited hold.

4. The number of responses was divided by the total session duration. Changing the FR_{water} requirement had essentially no effect on FI_{food} response rates (filled hexagons) for Rat 10 and minor effects on FI_{food} response rates for Rat 13. Highest FR_{water} response rates (filled triangles) occurred at FR 40 for both rats.

During the second phase, when the FR reinforcer was changed to food, FI response rates (open hexagons) decreased and FR response rates (open triangles) increased for both rats. In the third phase, fixed-interval response rates (dashed lines) were higher for both rats with the FR lever retracted than when either food or water reinforced FR responding during the first two phases.

Fixed-interval response rates for Rat 10 in the ascending FR_{food} phase gradually increased as the FR was increased from 100 to 300. Further increases in the FR requirement had no systematic effects on FI response rates (open circles). Fixed-ratio response rates (open squares) gradually decreased as the FR requirement was increased (Figure 3).

During the ascending FR series, Rat 13 responded at near-zero rates on the FI lever at FR requirements lower than 1300 responses. Additional increases in the FR requirement eventually led to increased FI response rates. Fixed-ratio response rates increased as the FR requirement was increased from 100 to approximately 760 responses, then declined with additional increases in the FR requirement

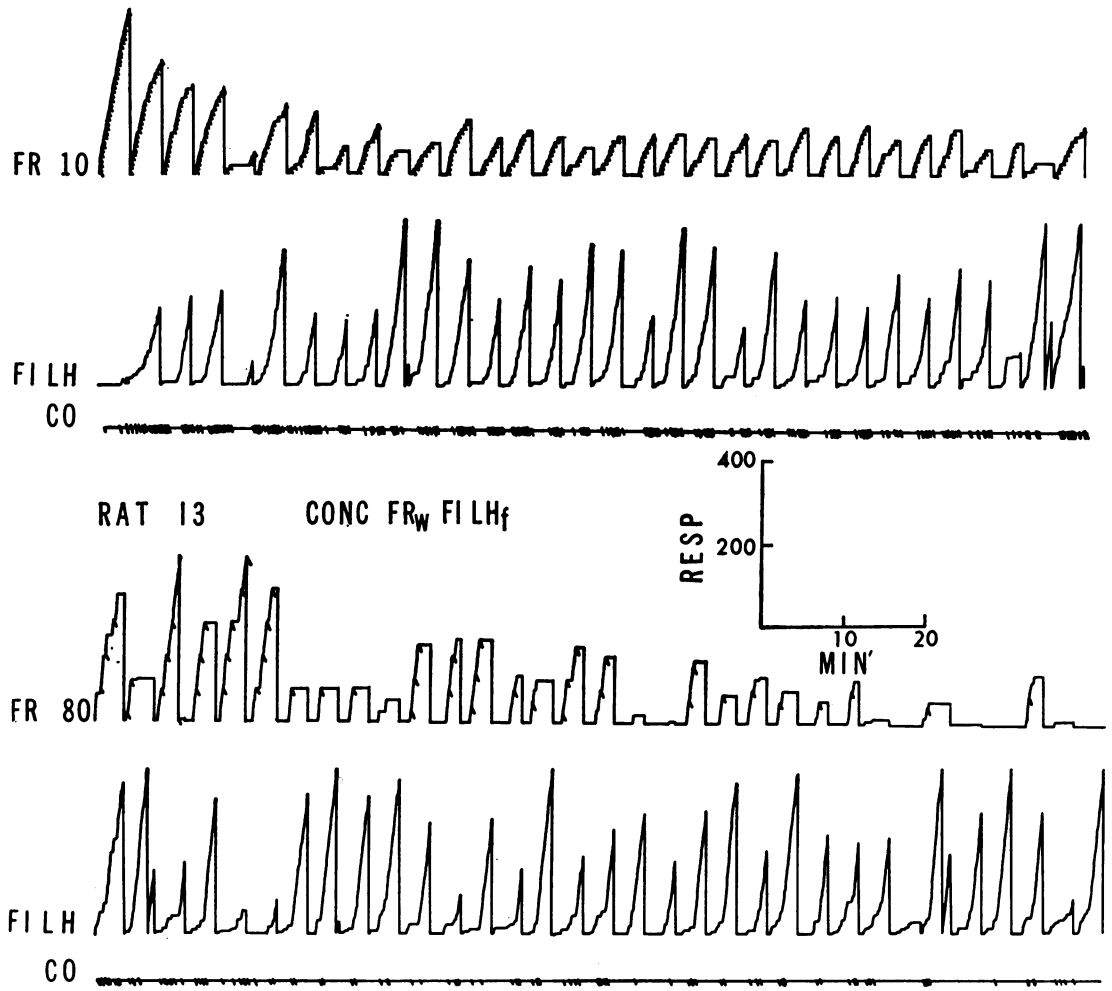

Fig. 2. Cumulative records of responding by Rat 13. See caption for Figure 1.

(Figure 4). This subject generated extremely high fixed-ratio response rates by biting the FR lever.

For Rat 10 in the final phase, FI response rates (open hexagons) were directly related to the FR requirement. At FR 210 and 305, the FR response rates for this subject were higher than under any other condition in this experiment. Fixed-ratio response rates (open triangles) were inversely related to FR requirements between 145 and 305 responses; FR response rates were approximately equal at FR 100 and 145 (Figure 3).

Additional quantitative data are provided in the appendix.

DISCUSSION

The present results indicate that the reinforcers used in *conc* FR FI schedules substantially influence the effects of the FR requirement on response rates. That FR_{water} response rates were consistently lower than the FR_{food} rates probably reflect the deprivation procedures used. Another variable that apparently can influence FR response rates is the procedure used in varying the FR requirement. Multiple FR_{food} responding maintained lower FR response rates than those obtained with the gradual FR requirement increase of the ascending series.

The greatest effect of different reinforcers for FR responding was seen on FI responding. The relatively stable FI response rates under *conc* FI_{food} FR_{water} conditions (Phase 1) differ from those under the *conc* FI_{food} FR_{food} conditions (LaBounty and Reynolds, 1973; the present experiment, Phases 2 and 4). Fixed-interval response rates in Phases 2 and 4 were considerably lower than those of Phase 1 for the same FR requirements. When responding on both schedules was reinforced with food,

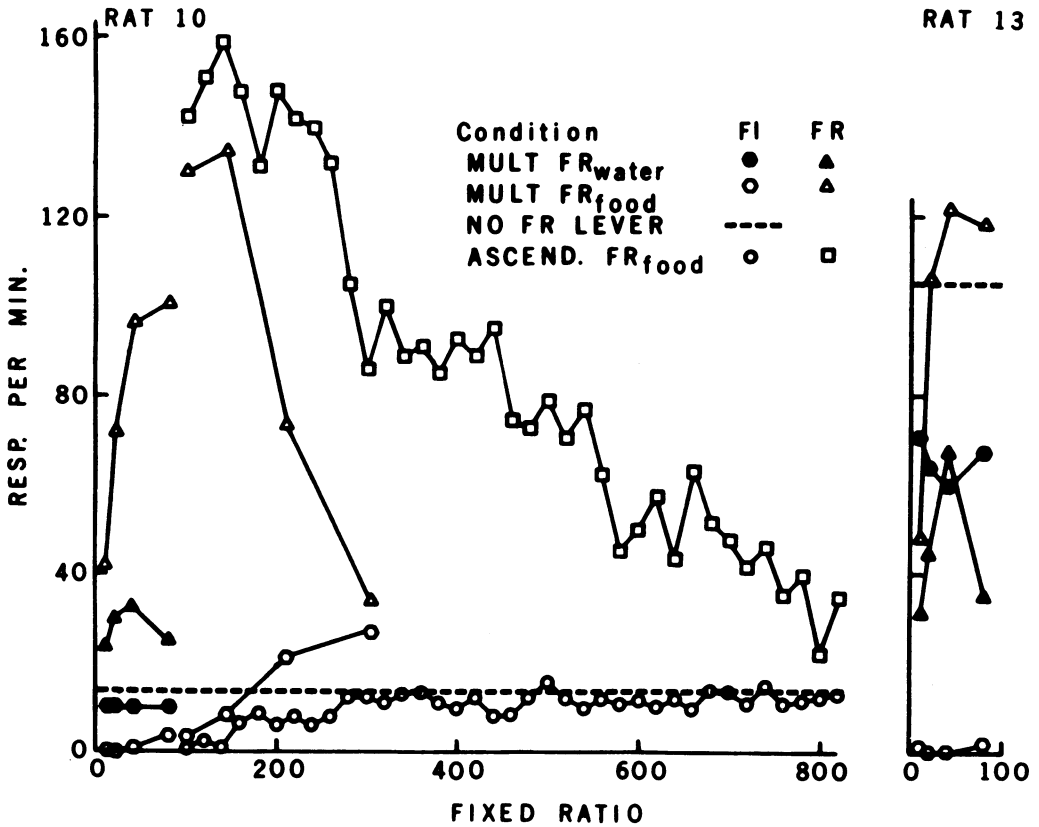

Fig. 3. Rates of responding for Rat 10 (left side) and Rat 13 (right side) as a function of the FR requirement. Filled symbols represent *conc* FI_{food} FR_{water} conditions, open symbols represent *conc* FI_{food} FR_{food} conditions. Hexagons and circles represent FI response rates; triangles and squares represent FR response rates. Details in text.

FR reinforcement rate seemed to predict the maintenance of asymptopic FI responding. When water reinforced FR responding, no such reinforcement rate effect was seen for the FR requirements used. Multiple FR requirements maintained the highest FI response rates of this study. Further studies should consider schedule, stimulus, and schedule value

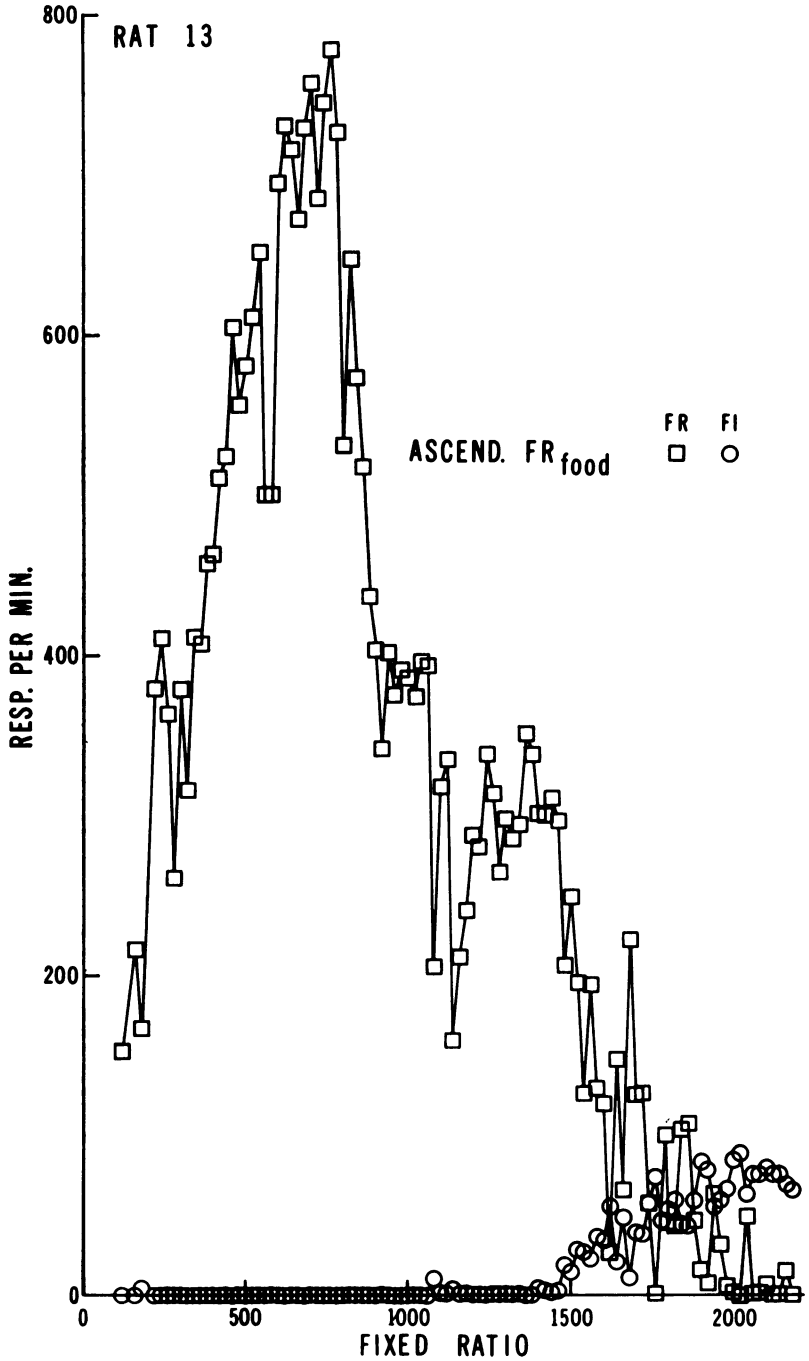

Fig. 4. Rates of responding for Rat 13 throughout the ascending series as a function of the FR requirement. Details in Figure 3. Additional details in text.

effects (perhaps the FR difference from one day to the next in the *mult* schedule was too great) in their investigations.

The present data merit systematic replications with other schedules and reinforcers. Catania (1973) pointed out that very little research has been done with concurrent schedules in which the reinforcers were different, and that such studies should consider motivational interactions between the reinforcers used. We used rats as subjects and food and water reinforcers because so much is known about relations between eating and drinking in rats (*e.g.*, Bolles, 1967; Code, 1967). It is unlikely that water-reinforced responding in the present experiment was an instance of schedule-induced polydipsia (*e.g.*, Falk, 1969), because at FR 10 most water reinforcers were earned before the first food delivery. It is possible that the present findings on *conc* FI_{food} FR_{water} depend on the levels of concurrent deprivations of food and water. Effects of varying deprivation levels might differ from effects of changing schedule parameters. Alternatively, the effects could be complementary. Substantial amounts of data will be needed to resolve these important issues.

REFERENCES

Bolles, R. C. *Theory of motivation.* New York: Harper and Row, 1967.

Catania, A. C. Concurrent operants. In W. K. Honig (Ed.), *Operant behavior: areas of research and application.* New York: Appleton-Century-Crofts, 1966. Pp. 213-270.

Catania, A. C. Self-inhibiting effects of reinforcement. *Journal of the Experimental Analysis of Behavior,* 1973, **19,** 517-526.

Code, C. F. (Ed.) *Handbook of physiology: Section 6: Alimentary canal, Volume I: Control of food and water intake.* Baltimore: Waverly Press (American Physiological Society), 1967.

Falk, J. L. Conditions producing psychogenic polydipsia in animals. *Annals of the New York Academy of Sciences,* 1969, **157,** 569-593.

LaBounty, C. E. and Reynolds, G. S. An analysis of response and time matching to reinforcement in concurrent ratio-interval schedules. *Journal of the Experimental Analysis of Behavior,* 1973, **19,** 155-166.

Sidman, M. *Tactics of scientific research.* New York: Basic Books, 1960.

Willis, R. D., Van Hartesveldt, C., Loken, K. K., and Hall, D. C. Motivation in concurrent variable-interval schedules with food and water reinforcers. *Journal of the Experimental Analysis of Behavior,* 1974, **22,** 323-332.

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APPENDIX

Quantitative data for Rat 10 on *conc* FI_{food} *mult* FR_{water} and on *conc* FI_{food} *mult* FR_{food} for the last three sessions for Phase 2, and the last five sessions for the first and final phases at each FR schedule. Sessions with procedural errors are excluded. Changeovers (CO), responses, and reinforcers per minute are based on total session duration (in minutes).

Session Number	*Session Duration*	*CO*	*Responses*		*Reinforcers*	
			FI	*FR*	*FI*	*FR*
		FR 10_{water}				
257	121.5	0.363	9.144	27.498	0.247	2.675
259	121.7	0.411	10.329	15.999	0.263	1.545
265	120.0	0.433	10.267	27.775	0.250	2.725
267	118.0	0.441	11.314	24.136	0.254	2.347
275	117.6	0.476	9.872	22.423	0.221	2.228
		FR 20_{water}				
255	121.7	0.378	8.110	47.257	0.107	2.449
258	122.0	0.361	10.492	20.672	0.262	1.082
262	125.2	0.519	9.936	45.359	0.216	2.340
266	119.3	0.419	12.422	21.467	0.260	1.132
276	119.8	0.384	9.007	15.501	0.217	0.818

Session Number	Session Duration	CO	Responses FI	Responses FR	Reinforcers FI	Reinforcers FR
		FR 40_{water}				
260	118.1	0.305	10.491	15.741	0.262	0.423
264	121.1	0.363	9.571	50.388	0.231	1.346
269	118.0	0.559	9.831	31.898	0.186	0.856
270	117.3	0.494	9.054	58.627	0.230	1.620
277	123.2	0.276	11.445	7.541	0.179	0.203
		FR 80_{water}				
254	120.7	0.547	8.036	59.279	0.199	0.795
261	122.2	0.295	10.049	15.671	0.254	0.213
263	121.6	0.411	9.186	24.918	0.263	0.337
268	117.9	0.288	13.418	11.315	0.254	0.153
274	117.9	0.322	10.416	13.851	0.254	0.187
		FR 10_{food}				
286	64.0	0.0469	0.031	42.594	0.000	4.219
292	77.0	0.0909	0.065	34.857	0.000	3.506
297	56.0	0.0179	0.018	49.500	0.000	4.982
		FR 20_{food}				
289	66.8	0.0449	0.015	78.368	0.000	4.042
291	79.4	0.0318	0.025	66.713	0.000	3.413
296	74.2	0.1482	0.337	71.065	0.000	3.639
		FR 40_{food}				
288	105.1	0.371	1.770	95.252	0.000	2.569
293	104.0	0.471	1.019	97.183	0.010	2.587
294	104.0	0.259	0.587	97.058	0.010	2.587
		FR 80_{food}				
277	125.9	0.572	6.926	88.515	0.064	1.176
290	120.9	0.438	2.887	119.454	0.033	1.588
295	120.8	0.389	1.440	95.935	0.017	1.266
		FR 100_{food}				
393	121.4	0.527	1.557	121.911	0.033	1.219
397	120.3	0.366	1.421	121.361	0.008	1.214
401	120.0	0.500	0.917	139.167	0.008	1.392
402	121.0	1.818	8.545	122.314	0.107	1.223
407	121.5	1.300	4.477	144.033	0.049	1.440
		FR 145_{food}				
389	120.5	0.963	5.469	121.535	0.050	0.838
396	121.8	0.772	8.235	129.778	0.057	0.895
398	120.5	1.278	9.145	143.195	0.075	0.988
403	121.0	1.322	8.736	125.826	0.058	0.868
409	121.9	1.756	9.975	155.828	0.107	1.075
		FR 210_{food}				
392	122.9	0.976	19.048	82.050	0.179	0.391
395	122.0	0.984	18.557	91.230	0.139	0.434
399	120.0	1.083	23.092	68.242	0.158	0.325
404	122.3	1.979	24.996	53.230	0.188	0.253
408	120.3	1.180	21.131	75.121	0.125	0.357
		FR 305_{food}				
390	121.4	2.060	30.865	4.596	0.255	0.008
394	120.2	0.616	28.195	32.987	0.200	0.108
400	120.0	0.950	18.992	50.833	0.142	0.167
405	120.0	0.833	27.800	53.608	0.225	0.175
406	120.9	1.373	29.744	30.397	0.215	0.099