

## CHOICE, RELATIVE REINFORCER DURATION, AND THE CHANGEOVER RATIO

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Relative reinforcer duration was varied in concurrent schedules with a fixed-ratio four changeover requirement. The schedule in effect after each reinforcer was randomly chosen. For all three pigeons, relative response rates overmatched relative reinforcer durations. Time allocation was less extreme and, on the average, matched relative reinforcer duration. In a subsequent manipulation, the level of preference was shown to depend on the size of the changeover requirement. These results are similar to those from related unequal reinforcement-frequency procedures.

*Key words:* reinforcer duration, choice, concurrent schedules, changeover ratio, key peck, pigeons

Concurrent schedule procedures have provided inconsistent data on the sensitivity of choice behavior to unequal reinforcer durations. Results from two preliminary efforts suggested that relative response rate (Catania, 1963) and time allocation (Brownstein, 1971) matched relative reinforcer duration—a pattern readily accepted as parallel to the wealth of evidence for matching to relative reinforcement frequency (de Villiers, 1977; Herrnstein, 1970). However, neither procedure provided firm footing for generalization. Catania investigated only two comparisons other than equality, and in his study, two birds matched, the third undermatched. Brownstein also included only two comparisons of unequal reinforcer durations; two birds undermatched and one overmatched. Subsequent procedures have usually involved variation in both relative duration and frequency of reinforcement (Fantino, Squires, Delbrück, & Peterson, 1972; Schneider, 1973; Todorov, 1973; cf. Keller & Gollub, 1977). The typical finding has been that, although relative response rates often undermatch relative reinforcement frequency in these procedures, choice is considerably more sensitive to the frequency, rather than the du-

ration, of the reinforcer. Moreover, when reinforcement rates were equal, relative response rates undermatched relative duration. For example, Schneider's (1973) procedure included three comparisons of reinforcer magnitude (number of pellets) with equal frequencies of reinforcer delivery. Relative rates of responding substantially undermatched reinforcer magnitude for all four subjects. In two studies (Walker & Hurwitz, 1971; Walker, Schnelle, & Hurwitz, 1970), rats undermatched the relative durations of access to a sucrose solution presented with equal frequency.

It may be that sensitivity to reinforcer duration is determined in part by procedural detail. For example, de Villiers (1977) has argued that forced-choice (Stubbs & Pliskoff, 1969) procedures may engender undermatching to reinforcer duration. In forced-choice or single-tape procedures when a reinforcer is available on one schedule alternative, the schedule timers on both alternatives are stopped until that reinforcer is delivered, i.e., until the specified response occurs. Thus, reinforcement on either schedule requires responses to both schedules during the course of a session. In the case of unequal frequencies of reinforcement, fewer reinforcers are programmed, and therefore fewer responses are required, on the less-preferred schedule—the relative response requirement is compatible with the overall distribution of responses. However, in the case of unequal duration procedures with equal frequencies of reinforcement, half of the reinforcers (the shorter durations) are programmed on

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the less-preferred schedule. Therefore, half of the required responses in forced-choice procedures (e.g., Schneider, 1973; Walker & Hurwitz, 1971) are on the less-preferred schedule. The absolute number of responses typically far exceeds the required number, but the constraints of a forced-choice procedure may contribute to the disproportionately high rates to the schedule providing the shorter reinforcer duration (undermatching).

There is more general evidence suggesting that performance on concurrent schedules is procedurally bound. When the concurrent schedules are not simultaneously present (as in Findley, 1958), the size of a fixed-ratio changeover requirement has been shown to determine the measured level of preference for the more frequent reinforcer. Pliskoff, Cicerone, and Nelson (1978) obtained consistent overmatching with changeover ratios (COR) of 10 and 5 responses. The sensitivity to reinforcer frequency was greater with a COR 10. Pliskoff and Fetterman (1981) obtained increased sensitivity with an increasing COR requirement (COR 1, COR 2, and COR 4). Baum (1981) reported substantial overmatching when the travel time required for changeover was increased.

The present study is a further step in the investigation of these procedural variables. If the level of preference for the longer of two reinforcement durations does depend on procedural detail, it should be possible to produce higher preference levels with a relatively high changeover requirement. In the present procedure a COR 4 was employed. Relative reinforcer duration was varied across three proportions (.25, .33, .40), their reversals, and .50. In a subsequent manipulation, the COR was varied. In addition, the schedule in effect after each reinforcement in the present procedure was randomly chosen. This guaranteed some exposure to the less-preferred alternative and was intended to minimize the variation in the relative frequency of reinforcement without the problems associated with forced-choice procedures. There was no changeover delay.

## METHOD

### *Subjects*

Three male White King pigeons were maintained at 80% of their free-feeding weights

with supplemental feedings after experimental sessions. All had previous experience on single fixed- and variable-interval schedules.

### *Apparatus*

The experimental chamber was built into a wooden enclosure. The chamber was a cube, 38 cm on each side. There were three pigeon keys and two food hopper openings on the aluminum front panel. The keys were 2.5 cm in diameter and were equally separated from each other at 22 cm above the grid floor. When illuminated, the left key was red, the center key was a white horizontal bar on a dark background, and the right key was green. All keys were dark during food delivery. A force of approximately .16 N was required for key operation. The operation of a relay solenoid provided auditory feedback for key pecks. The hoppers were located directly beneath the two side keys. When operated, the hoppers were illuminated by a white light and provided access to mixed grain. The back panel was aluminum. The remaining sides and ceiling were plywood. A houselight was mounted on the rear ceiling and remained lighted except during operation of the hoppers. A ventilation fan in the external housing helped mask extraneous sounds. Standard electromechanical equipment, located in an adjacent room, scheduled and recorded experimental events.

### *Procedure*

Responses on either of the two side keys operated the corresponding hopper on independent variable-interval (VI) 120-sec schedules. Intervals were determined according to the method suggested by Segal (1964). Only one side key was illuminated and operative at a time. Four consecutive responses on the center key alternated the operative side key. During the changeover ratio, the VI tapes continued to run and the operative side key remained lighted until the ratio was completed. Any side-key responses during this changeover ratio reset the ratio requirement to four. Following a changeover ratio, a single response to the newly operative side key was required before another changeover was possible. Following hopper operation, the initially operative side key was randomly selected. The relative durations of hopper operation correlated with the two side keys were varied. Table 1 (first two columns) presents the durations in each condi-

Table 1

Hopper durations and results in each condition in the order of presentation. Asterisks denote COR 1 conditions.

Bird	Hopper Duration left/right	R/min left/right	Time (min) left/right	Reinforcer Rate (left) Stability	COR/min	Sessions to Stability	
B64	3/4.5	4.2/24.0	14.8/39.3	.51	7.0	24	
	2.5/5	3.5/21.7	12.1/42.9	.52	6.6	29	
	2/6	1.9/25.4	8.5/48.4	.48	3.4	35	
	5/2.5	30.9/5.9	39.4/16.1	.50	5.1	41	
	6/2	34.9/2.2	49.6/9.4	.53	4.1	21	
	4.5/3	20.2/4.4	36.6/18.0	.50	6.2	45	
	3/4.5	6.7/15.0	16.8/39.1	.49	7.6	49	
	3.5/3.5	10.5/10.1	25.3/29.7	.50	9.0	24	
	* 6/2	31.5/5.6	34.5/19.4	.52	7.9	32	
	6/2	38.9/2.5	44.6/11.2	.53	3.0	20	
	G92	4.5/3	15.0/6.1	36.6/18.8	.50	8.2	22
		3/4.5	6.5/11.4	21.8/34.2	.49	7.9	36
		2/6	4.5/17.1	16.2/41.5	.50	8.4	35
5/2.5		34.8/7.1	36.0/19.4	.52	12.0	21	
2.5/5		8.7/20.2	21.0/32.8	.50	10.0	36	
3.5/3.5		14.6/11.9	27.5/27.5	.50	10.8	27	
4.5/3		18.3/7.8	36.7/18.9	.49	9.7	20	
6/2		34.8/3.0	47.1/11.8	.53	7.2	21	
* 6/2		19.5/10.9	33.9/21.6	.49	19.2	24	
6/2		41.0/7.2	40.9/15.1	.48	9.4	24	
G94		5/2.5	18.6/6.9	38.5/19.0	.50	7.2	21
		4.5/3	17.9/7.7	32.6/20.0	.51	7.7	35
		2.5/5	7.5/13.2	25.7/27.8	.49	11.1	42
	3/4.5	8.3/11.4	29.7/25.3	.50	8.9	28	
	6/2	21.5/5.0	41.0/13.0	.51	7.2	24	
	2/6	4.7/15.7	20.5/33.5	.50	10.3	44	
	5/2.5	23.9/8.4	36.7/17.3	.50	8.6	34	
	3.5/3.5	11.7/11.7	28.0/27.0	.49	10.9	33	
	* 6/2	29.4/9.3	35.5/17.5	.50	11.3	37	
	6/2	42.6/4.7	42.9/12.1	.49	5.3	22	

tion in the order of presentation. The first condition was replicated later in each sequence.

The COR value was decreased to one in the next-to-last condition and subsequently was restored to four. For one pigeon, G92, the last three conditions are an ABA sequence (COR 4, COR 1, COR 4—all at 6- vs. 2-sec hopper operation). For the other two pigeons, the original assessment of the baseline condition did not occur immediately prior to the COR 1 condition.

Sessions were terminated after 55 reinforcers. Each condition continued for a minimum of 20 sessions and until stability criteria had been satisfied. After 20 sessions the relative rates of responding for the previous nine sessions were divided into blocks of three sessions. Performance was considered stable when the means of the three blocks neither differed by more than  $\pm .05$  nor exhibited a trend, i.e., neither  $\bar{X}_1 > \bar{X}_2 > \bar{X}_3$  nor  $\bar{X}_3 > \bar{X}_2 > \bar{X}_1$ . The

number of sessions in each condition is presented in the far right column of Table 1.

## RESULTS

The data were averaged over the last nine sessions of each condition. Absolute response rates and time-allocation data for each condition are presented in Table 1. Response and changeover rates are in terms of responses per minute of total session time. The record of time allocation included time spent in changeovers and aborted changeovers to the alternate schedule (since the side key remained lighted and operative until a changeover was completed).

The logs of the response and time-allocation ratios are plotted as a function of the log of the ratio of hopper durations for the first seven conditions for each bird in Figure 1. In the log/log regression  $y = ax + b$ , the slope ( $a$ )

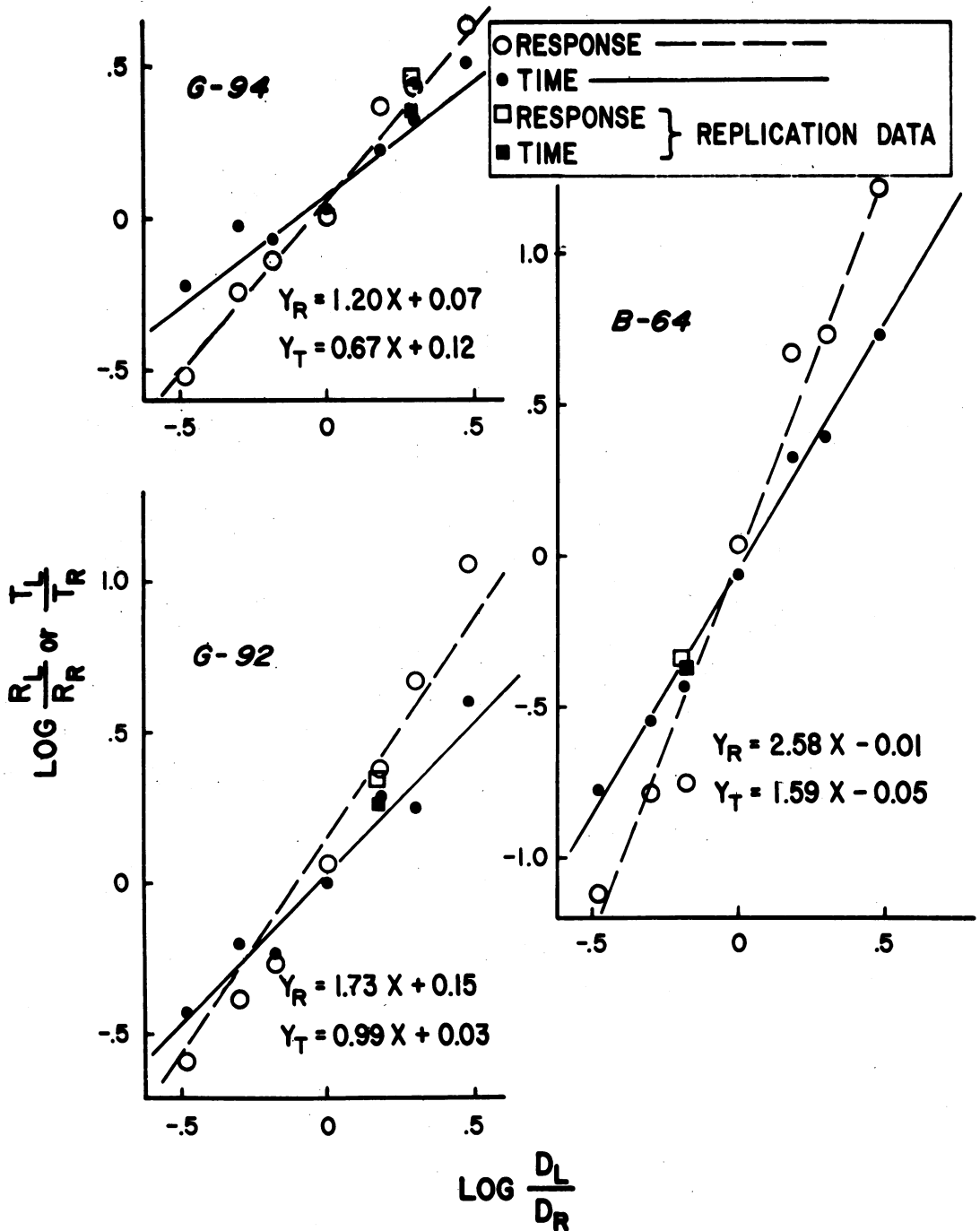


Fig. 1. The logs of the response ( $Y_R$ ) and time-allocation ( $Y_T$ ) ratios as a function of the log of the relative hopper durations for the first eight conditions, including a replication of the first condition in each sequence.

reflects the sensitivity of the behavioral measures to variations in the ratio of hopper durations. Behavior ratio is said to match duration ratio when  $a = 1.0$ . The intercept ( $b$ ) repre-

sents the level of proportional bias averaged across all hopper duration ratios. A zero intercept indicates no bias, i.e., no consistent preference for a particular color, position, or any

variable consistently correlated with either the left or right response. Baum (1974) provides a thorough discussion of this method of analysis. For all three birds, the ratios of response rates overmatched (slopes of 1.20, 1.73, and 2.58) hopper-duration ratios. For one bird, B64, time allocation ratios overmatched (1.59) the ratios of hopper durations. For the other two, time allocation matched (.99) or undermatched (.67) hopper duration. Some of the disparity between the time and response ratios is attributable to the inclusion of the roughly equal changeover times in the time recorded on each side key. In both measures of preference, G92 and G94 showed a bias ( $b > 0$ ) toward the left key. B64 exhibited a slight bias for the right key.

The data from the replication of the first condition in each sequence approximated the earlier determinations for G92 and G94. Although the time ratio obtained in the replication was similar to the first determination for B64, the response ratio was considerably nearer matching. These points are plotted as unfilled (response ratios) and filled (time) squares in Figure 1. The obtained relative rates of food delivery (Table 1) varied only slightly at the more extreme levels of preference.

In Figure 2, the relative response rates are plotted against the changing COR requirements (from 4 to 1, and back to 4) in the three 6- vs. 2-sec conditions. For all three birds, preference (both response and time allocation) dropped in the COR 1 condition and recovered in the subsequent COR 4 condition. As is evident in Table 1, changeovers occurred at a higher rate in the COR 1 condition. Fluctuations in the absolute rate of responding on the side keys were not consistently correlated with COR value.

In the COR 4 conditions, the rate of changeover (Table 1) varied consistently with the level of preference for only Bird B64 and was inconsistent for G92 and G94. The center-key response rate during changeover was occasionally recorded. The average in the COR 4 conditions was 170/min with little variance. Changeovers were seldom interrupted by pauses or side-key responses. G92 frequently exceeded the COR requirement by one or two responses in the COR 1 condition. The other two birds rarely exceeded the COR after the first two sessions in the COR 1 condition. The number of left-to-right changeovers was gener-

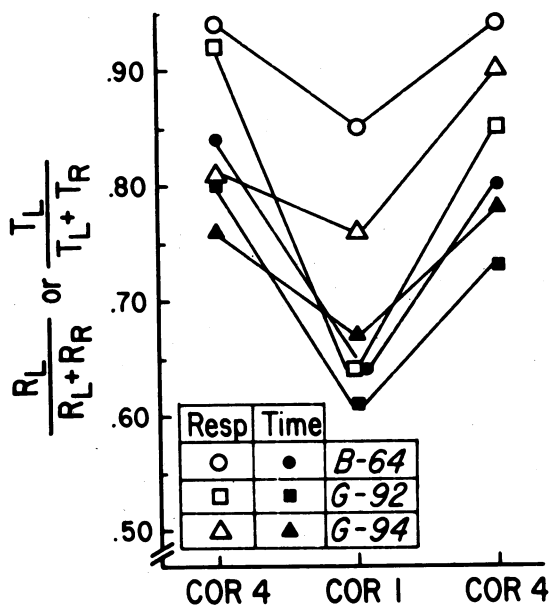


Fig. 2. Relative response rates and time allocation in the three 6- vs. 2-sec conditions: first with a COR 4 requirement, later in the sequence with a COR 1, and finally with a COR 4.

ally equal to the number of right-to-left changeovers (this was not a procedurally constrained result, due to the random return procedure).

## DISCUSSION

In this procedure, relative response rates overmatched relative reinforcer durations. The level of preference appeared to depend on the size of the changeover ratio. These results closely parallel those of Pliskoff and Fetterman (1981). They reported that response ratios undermatched reinforcement frequencies with a COR 1 and, in the one condition with a COR 4, overmatched reinforcement frequency.

It is not clear whether higher COR requirements merely engender schedule independence or whether they alter the interactions between behavior and each of the two schedules. It is possible, for example, to treat the changeover responses as part of the behavior maintained by the alternate schedule. Reinforcement on the schedule associated with an unlit key first requires responses on the center key and subsequent responding on that side key. It may be necessary to add the changeover responses to those on the two side keys to get an accurate

picture of relative response strengths.<sup>1</sup> The isolation of nearly equal numbers of changeover responses from both side-key response totals (as in the present report) would result in higher ratios of response rates associated with the longer reinforcer duration. Indeed, if the center-key responses during changeover are equally divided between the two side-key response totals in the present results, G92 and G94 undermatched, whereas B64 still overmatched the hopper-duration ratios (log/log slopes of .69, .46, and 1.29, respectively). Thus, the level of preference could be expected to vary directly with the number of responses required for changeover. This method of analysis would also be applicable to other procedures with a COR requirement. For example, Pliskoff et al. (1978) obtained overmatching with a COR 5 and more pronounced overmatching with a COR 10 in otherwise similar procedures. The proposed description would require that 5 and 10 responses, respectively, be included in the side-key totals for each changeover to that key. If the response ratios are adjusted accordingly (using their Table 2), they undermatch the reinforcer ratios in both procedures (although the COR 5 still resulted in less sensitivity to differences in reinforcer frequency).

There are problems with this notion. First, it would be difficult to estimate the contribution of a fixed-ratio response burst to the total responding on a VI schedule. Pliskoff et al. reported high changeover rates averaging 145/min in the COR 10 procedure (the COR 5 rates were not reported). In the present experiment, changeover responding was also rapid, 170/min, and seldom interrupted. It may be that a changeover ratio is best described as a unitary response. In any event, it is unlikely that such bursts would be equal to four slower, more discrete, VI responses.

The second problem concerns the description of time allocation. In other COR studies, time-allocation records could follow the format outlined above (i.e., the time in changeover could be considered part of the time in the forthcoming side-key schedule). One advantage of the way time spent on each schedule was recorded in the present procedure is that it includes time spent in changeover. Changeover time was recorded as time on the existing, not the forthcoming, schedule with the effect that changeover time is equally divided be-

tween the two side-key schedules. Thus, in the proposed description, time allocation would not be expected to vary with COR requirements (1 or 4) since none of the time appropriate to the side-key schedules is excluded. Figure 2 shows that choice proportions derived from this measure do vary with the size of the changeover requirement. Although time-allocation ratios did lag behind response ratios in this procedure, this is characteristic of the exclusive (of COR time) measures used in other studies as well.

Other features of the results deserve mention. The random-return procedure may have been successful in that the distribution of obtained reinforcements did not vary substantially from the programmed distribution. In addition, the use of VI 120-sec schedules probably encouraged sampling of the less-preferred alternative. That is, at this relatively low rate of reinforcement, responses on the schedule of short hopper durations had minimal impact on the obtained rate of longer hopper durations. On the average, relative response rates matched, rather than undermatched, relative hopper duration in the COR 1 condition. This result may be partially attributed to the use of two hoppers. The common practice with studies of reinforcer duration is to operate one hopper for different durations. Aside from problems of discrimination (cf. Mariner & Thomas, 1969), a principal drawback to this procedure is that the hopper opening and light, as conditioned stimuli, are associated with both hopper durations and follow responses on both schedules. The use of two hoppers avoids this problem.

In sum, these results appear to be consistent with those from unequal reinforcement frequency procedures. Increases in changeover requirements produce overmatching.

<sup>1</sup>I owe the recognition of this possibility to B. A. Williams.

## REFERENCES

- Baum, W. M. On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior*, 1974, 22, 231-242.
- Baum, W. M. Changing over and choice. In C. M. Bradshaw, E. Szabadi, & C. F. Lowe (Eds.), *Quantification of steady-state operant behaviour*. Amsterdam: Elsevier/North-Holland, 1981.

- Brownstein, A. J. Concurrent schedules of response-independent reinforcement: Duration of a reinforcing stimulus. *Journal of the Experimental Analysis of Behavior*, 1971, 15, 211-214.
- Catania, A. C. Concurrent performances: A baseline for the study of reinforcement magnitude. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 299-300.
- de Villiers, P. Choice in concurrent schedules and a quantitative formulation of the law of effect. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior*. Englewood Cliffs, N.J.: Prentice-Hall, 1977.
- Fantino, E., Squires, N., Delbrück, N., & Peterson, C. Choice behavior and the accessibility of the reinforcer. *Journal of the Experimental Analysis of Behavior*, 1972, 18, 35-43.
- Findley, J. D. Preference and switching under concurrent scheduling. *Journal of the Experimental Analysis of Behavior*, 1958, 1, 123-144.
- Herrnstein, R. J. On the law of effect. *Journal of the Experimental Analysis of Behavior*, 1970, 13, 243-266.
- Keller, J. V., & Gollub, L. R. Duration and rate of reinforcement as determinants of concurrent responding. *Journal of the Experimental Analysis of Behavior*, 1977, 28, 145-153.
- Mariner, R. W., & Thomas, D. R. Reinforcement duration and the peak shift in post-discrimination gradients. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 759-766.
- Pliskoff, S. S., Cicerone, R., & Nelson, T. D. Local response-rate constancy on concurrent variable-inter-val schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1978, 29, 431-446.
- Pliskoff, S. S., & Fetterman, J. G. Undermatching and overmatching: The fixed-ratio changeover requirement. *Journal of the Experimental Analysis of Behavior*, 1981, 36, 21-27.
- Schneider, J. W. Reinforcer effectiveness as a function of reinforcer rate and magnitude: A comparison of concurrent performances. *Journal of the Experimental Analysis of Behavior*, 1973, 20, 461-471.
- Segal, E. F. A rapid procedure for generating random reinforcement intervals on VI and VR tapes. *Journal of the Experimental Analysis of Behavior*, 1964, 7, 20.
- Stubbs, D. A., & Pliskoff, S. S. Concurrent responding with fixed relative rate of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 887-895.
- Todorov, J. C. Interaction of frequency and magnitude of reinforcement on concurrent performances. *Journal of the Experimental Analysis of Behavior*, 1973, 19, 451-458.
- Walker, S. F., & Hurwitz, H. M. B. Effects of relative reinforcer duration on concurrent response rates. *Psychonomic Science*, 1971, 22, 45-47.
- Walker, S. F., Schnelle, J., & Hurwitz, H. M. B. Rates of concurrent responses and reinforcer duration. *Psychonomic Science*, 1970, 21, 173-175.

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