JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1978, 29, 191-198 NUMBER 2 (MARCH)

TIME-ALLOCATION MATCHING BETWEEN PUNISHING SITUATIONS[1]

MARVIN Z. DELUTY AND RUSSELL M. CHURCH

BROWN UNIVERSITY

In the presence and absence of white noise, response-independent aversive events were delivered to rats according to several variable-time electric-shock schedules. The animals could switch from the noise component to the no-noise component and *vice versa* by making a single lever-press response. If the schedule in one component was not in operation when the animal was in the other component, the proportion of time allocated to one component equalled or matched the proportion of obtained punishers in the other component. If both schedules were always in operation, minimizing tended to occur: the animals allocated almost all of their time to the component having the lower shock rate. An analysis of these results, in terms of the expected time until an aversive event, is presented.

Key words: choice, time allocation, punishment, matching law, lever press, rats

---

When animals are responding on concurrent variable-interval variable-interval (*conc* VI VI) schedules of reinforcement, their proportion of responses on one key or lever approximately equals or matches the proportion of obtained reinforcers associated with that key or lever (Herrnstein, 1961, 1970, 1971, 1974), *i.e.*:

$$\frac{R_1}{R_1 + R_2} = \frac{r_1}{r_1 + r_2} \quad (1).$$

R_1 denotes the number of responses to one key or lever, R_2 the number of responses to the second key or lever, r_1 the number of reinforcers for the first manipulandum, and r_2 the number of reinforcers for the second manipulandum.

The above matching relation specifies how responses will be allocated among various alternatives. A number of investigators have also studied the manner in which animals allocate their time to various activities and responses (see Baum, 1974, 1976). Catania (1966) and Shull and Pliskoff (1967) first reported that for *conc* VI VI schedules the relative amount of time devoted to responding to one key or lever approximately equals the relative number of reinforcers for that response, *i.e.*:

$$\frac{T_1}{T_1 + T_2} = \frac{r_1}{r_1 + r_2} \quad (2).$$

T_1 represents the amount of time allocated for one response and T_2 the amount of time allocated for a second response. This relation holds, as well, for more than two keys (Miller and Loveland, 1974; Pliskoff and Brown, 1976), for free reinforcers (Baum and Rachlin, 1969; Bauman, Shull, and Brownstein, 1975; Brownstein and Pliskoff, 1968), and for negative reinforcement (Baum, 1973*b*). For example, in the Brownstein and Pliskoff (1968) study, response-independent food was delivered according to a variable-time (VT) schedule when the key was one color; when the key was a different color, food was delivered according to another VT schedule. Food was not contingent on the pigeons' making any response. The birds, however, could switch from one component to the other component by making a single key-peck response. The proportion of time spent in the presence of a key color was approximately equal to the proportion of reinforcers the pigeons obtained by allocating their time to that alternative. A thorough review of the evidence on response-

[1]This research was supported by PHS Grant GM-23247 to R. M. Church. Data based on Experiment I were presented at the meeting of the Eastern Psychological Association, Boston, April 1977. We wish to thank D. S. Blough, J. Gibbon, S. Roberts, and J. S. Young for their comments on an earlier version of this paper. Reprints may be obtained from Marvin Deluty, Department of Physiology, School of Medicine, University of Pennsylvania, Philadelphia, Pennsylvania 19104.

allocation matching and time-allocation matching has been prepared by de Villiers (1977).

The present experiments investigated time allocation with respect to response-independent (free) aversive events. The procedure was similar to that used by Brownstein and Pliskoff (1968). In one component, punishers were delivered at one rate; in the second component, punishers were delivered at a different rate. The subjects could switch from one component to the other by making a single lever-press response. The study attempted to determine the manner in which the animals would allocate their time to the two components as the shock rates in both components were varied.

EXPERIMENT I: CONSTANT EXPECTED TIME TO SHOCK: "TAPE" STOPS

In Experiment I, the punishing event in one component was not primed when the animal was in the other component: the "tape" in a component stopped when the rat was not in that component (the schedule in one component was not in operation when the rat was in the other component). Under these conditions, when shocks were scheduled to occur at random intervals, the expected time to shock in a component was unrelated to the length of time the animal had been in that component; when the rat changed to the other component, the expected time to shock in that component was unrelated to the length of time the animal had been in the previous component. Thus, if the schedule in one component was VT 2-min, the expected time to the next shock in that component remained 2 min, regardless of the time since the last shock and regardless of the time spent in the other component.

METHOD

Subjects

Three male, naive albino Norway rats of the Charles River CD strain were given free access to food and water in their home cages.

Apparatus

Three chambers each had inside dimensions of 23.2 cm by 20.3 cm by 21.9 cm. The floor consisted of 16 stainless-steel bars, with adjacent bars 1.5 cm apart. The front and back were made of aluminum; the two sides and the top were made of transparent acrylic. Attached to the outer surface of the top was a 6-W lamp. A single lever (5.1 cm wide, 1.3 cm thick, and 5.1 cm above the floor) was located 3.5 cm to the left of the food cup. Each chamber was enclosed within an insulated box.

Electric shocks were delivered to the lever, the bars on the floor, and the front and back aluminum sides through an autotransformer, a power transformer, and a 150 K-ohm resistor in series with the animal. Lever presses of at least 0.25N were recorded. A time-shared PDP-12 computer controlled each phase of the experiment and collected the data.

Procedure

No preliminary training was given and the animals were immediately exposed to the experimental treatments. In the presence and absence of white noise, response-independent aversive events were delivered according to various VT electric-shock schedules. The animals were able to switch from the noise component to the no-noise component and, likewise, from the no-noise component to the noise component by making a single lever-press response. The sequence of the VT schedules for the noise component (Component 1) and the no-noise component (Component 2) is shown in Table 1. The scheduled rate of noncontingent shock was either 0, 0.25, 0.50, or 2.0 shocks per minute in each component (no punishment, VT 4-min, VT 2-min, or VT 30-sec shock schedules, respectively). The time between two successive shocks under the VT schedules was an exponential waiting-time distribution, with 0.1 sec the minimum intershock time. Shocks were delivered with a specific probability every 0.1 sec; the probability was equal to 0.1 divided by the mean interval in seconds. When the animal was in one component, the VT schedule in the other component was not in operation.

Throughout the experiment, a changeover delay (COD) of 2 sec was used (Catania, 1966; Herrnstein, 1961): 2 sec had to elapse after the subject's switch from one component to the other before shocks were delivered. Shocks were of 0.8-mA intensity and 0.5-sec duration. The white noise was approximately 70 dB (re 0.0002 dynes/cm^2). Each session lasted 30 min, and data were collected from the last 25 min. Each session began with Component 1.

Table 1

Sequence of the scheduled rates of shock for the two components of each condition of Experiment I and the results. Each value is the mean of the last five sessions for each condition.

Condition	Scheduled Punishment Rate (pun/min) Comp. 1	Comp. 2	Rat	Sessions	$\frac{T_1}{T_1+T_2}$	S_m	Obtained Punishers per Session Comp. 1 (p_1)	Comp. 2 (p_2)	Changeovers per Minute
1	2.0	0.0	1	30	0.017	0.011	1.0	0.0	0.06
			2	12	0.019	0.015	1.2	0.0	0.26
			3	30	0.018	0.014	1.0	0.0	0.14
2	0.0	2.0	1	15	0.982	0.008	0.0	0.6	0.06
			2	7	0.980	0.020	0.0	1.0	0.06
			3	15	0.933	0.068	0.0	2.8	0.02
3	2.0	2.0	1	20	0.520	0.050	26.0	29.8	1.06
			2	25	0.465	0.088	24.0	26.0	0.20
			3	20	0.528	0.194	22.2	24.0	0.35
4	0.5	2.0	1	15	0.677	0.073	7.8	12.6	0.74
			2	7	0.677	0.197	9.0	15.0	0.10
			3	7	0.634	0.065	7.8	14.4	0.13
5	2.0	0.5	1	15	0.347	0.093	13.8	7.4	1.08
			2	10	0.402	0.093	17.8	8.2	0.81
			3	30	0.294	0.165	13.4	7.6	0.35
6	0.25	2.0	1	7	0.708	0.078	5.2	15.8	0.79
			2	15	0.764	0.160	3.0	12.6	0.38
			3	7	0.794	0.075	4.2	10.4	0.23
7	2.0	0.25	1	10	0.284	0.007	13.4	3.6	0.58
			2	7	0.283	0.046	11.6	5.0	0.35
			3	10	0.293	0.113	13.8	4.6	0.63

RESULTS

Table 1 shows the mean proportion of time spent in Component 1, $T_1/(T_1 + T_2)$, the standard error of the mean, and the obtained number of punishers per session in each component (p_1, p_2) for all subjects in every condition. (To determine the amount of time spent in a component, multiply the proportion of time spent in the component by 25 min.) The number of changeovers per minute from one component to the other component is also given for each condition. Each value represents the mean of the last five sessions of each condition.

Figure 1 shows for each subject the relative amount of time spent in Component 1 as a function of the relative number of obtained punishers in Component 2. The solid line represents the locus of equality between the proportion of time allocated to Component 1 and the proportion of punishers in Component 2. The points do, indeed, fall along the diagonal, with the broken line being the best-fitting straight line as determined by the method of least squares. The linear regression lines for Rats R1, R2, and R3, respectively, are: $Y = 0.94X + 0.04$, $Y = 0.94X + 0.03$, and

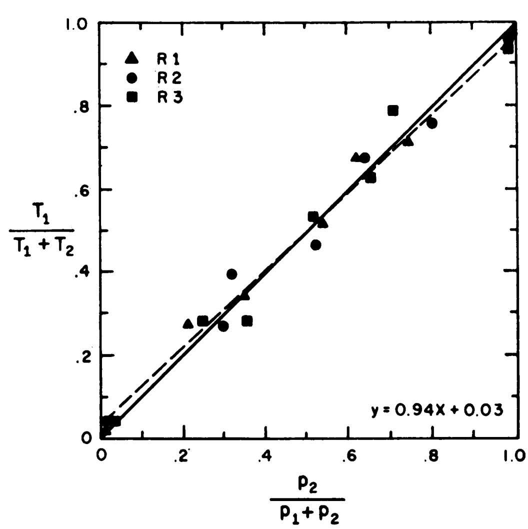

Fig. 1. The relative amount of time spent in Component 1 as a function of the relative number of obtained punishers in Component 2 (Experiment I). Perfect matching is indicated by the diagonal. The broken line is the least-squares regression line.

$Y = 0.95X + 0.02$; they account for 98% of the variance over all animals and 99%, 98%, and 97% of the variance for the individual subjects. The relative amount of time spent in one component equals or matches the relative number of obtained punishers in the other component.

Discussion

In an earlier study (Deluty, 1976), it was suggested that the effect of reinforcement and punishment on the relative rate of responding in concurrent schedules may be expressed as follows:

$$\frac{R_1}{R_1 + R_2} = \frac{r_1 + p_2}{r_1 + r_2 + p_1 + p_2} \quad (3).$$

Since the response-allocation matching relation for reinforcement (Equation 1) is the same as the time-allocation matching relation for reinforcement (Equation 2), then it may be that the response-allocation matching relation for reinforcement and punishment (Equation 3) is the same as the time-allocation matching relation for reinforcement and punishment, *i.e.*:

$$\frac{T_1}{T_1 + T_2} = \frac{r_1 + p_2}{r_1 + r_2 + p_1 + p_2} \quad (4).$$

The present study examined a corollary of Equation 4: namely that situation where there is no reinforcement ($r_1 = 0$ and $r_2 = 0$) and only punishment is present. In this special case, Equation 4 becomes the following:

$$\frac{T_1}{T_1 + T_2} = \frac{p_2}{p_1 + p_2} \quad (5).$$

The adequacy of Equation 5 was tested with the data shown in Figure 1; this formula (solid line) accounted for 98% of the variance over all animals, and 98%, 98%, and 97% of the variance for the individual subjects. Just as the relation expressed by Equation 2 between proportion of time and proportion of reinforcers suggests a simple molar law characteristic of the positive law of effect (Baum, 1973*a*), so, too, does the relation expressed by Equation 5 between proportion of time and proportion of punishers imply a rather simple molar law characteristic of the negative law of effect. But it still remains to be seen whether the time-allocation matching relation for reinforcement and punishment, suggested by Equation 4, is, indeed, correct.

The matching relation expressed in Equation 5 is a correlation between two dependent variables—the amount of time allocated to the components and the number of shocks received in each component. But is it possible to predict the amount of time spent in a component on the basis of a scheduled variable? The manner in which time is allocated with respect to free punishers may be expressed in terms of the expected times until the aversive events. Let D_1 represent the expected time until shock in Component 1, and D_2 the expected time until shock in Component 2. Because in the present experiment the schedule in one component was not in operation when the animal was in the other component, the expected number of punishers in Components 1 and 2, respectively, are:

$$E(p_1) = T_1/D_1 \quad (6a)$$

$$E(p_2) = T_2/D_2 \quad (6b).$$

Substituting the value of $E(p_1)$ for p_1 and $E(p_2)$ for p_2 into Equation 5, and with further simplification:[2]

$$\frac{T_1}{T_1 + T_2} = \frac{\sqrt{D_1}}{\sqrt{D_1} + \sqrt{D_2}} \quad (7).$$

Figure 2 shows for each subject the relative amount of time spent in Component 1 as a function of the square roots of the relative delays until shock. If there is no shock in one of the components (as was the case in Conditions 1 and 2), then the expected delay until shock is defined to be infinite. In Condition 1, therefore, $\sqrt{D_1}/(\sqrt{D_1} + \sqrt{D_2})$ will approach 0 and in Condition 2, it will approach 1.0. The broken line is the least-squares regression line. The linear regression lines for Rats R1, R2, and R3, respectively, are $Y = 0.95X + 0.03$, $Y = 0.96X + 0.03$, and $Y = 0.94X + 0.03$; they

---

[2]

$$\frac{T_1}{T_1+T_2} = \frac{p_2}{p_1+p_2}$$

$$\frac{T_1}{T_1+T_2} = \frac{T_2/D_2}{(T_1/D_1)+(T_2/D_2)}$$

$$\frac{T_1^2}{D_1} + \frac{T_1T_2}{D_2} = \frac{T_1T_2}{D_2} + \frac{T_2^2}{D_2}$$

$$T_1^2/T_2^2 = D_1/D_2$$

$$T_1/T_2 = \sqrt{D_1}/\sqrt{D_2}$$

Expressed in terms of proportions:

$$\frac{T_1}{T_1+T_2} = \frac{\sqrt{D_1}}{\sqrt{D_1}+\sqrt{D_2}}$$

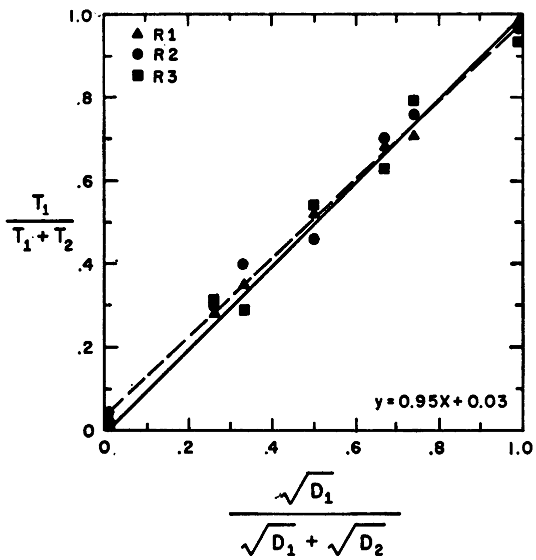

Fig. 2. The relative amount of time spent in Component 1 as a function of the square roots of the relative delays until shock (Experiment I).

account for 99% of the variance over all animals, and 99.8%, 99%, and 98% of the variance for the individual subjects.

EXPERIMENT II: VARIABLE EXPECTED TIME TO SHOCK: "TAPE" MOVES

There was one major difference between the time-allocation punishment study of Experiment I and previous time-allocation reinforcement experiments (*e.g.,* Brownstein and Pliskoff, 1968). In the reinforcement studies, when the animal was in one component, the schedule in the other component was also in operation; in Experiment I, when the animal was in one component, the schedule in the other component was not in operation. The purpose of Experiment II was to see, therefore, whether this procedural factor affects time allocation with respect to free punishers. If the shock schedules for both components were always in operation, how would the animals allocate their time to the two components as the shock rates in both components varied?

Under these conditions, when shocks were scheduled to occur at random intervals, the expected time to shock in a component was unrelated to the length of time that the animal had been in that component; but, when the rat changed to the other component, the expected time to shock in that component was related to the length of time the animal had been in the previous component. Thus, if the rat had been out of a component for a long time, it was likely that a shock had been primed in that component, and the rat would receive it (after the 2-sec COD) when it entered the component.

METHOD

Subjects and Apparatus

Four male, albino Norway rats of the Charles River CD strain were given free access to food and water in their home cages. The three animals that began the experiment were those used in Experiment I. During Condition 4, one of the rats (R1) died and was replaced by an experimentally naive rat (R1b). The apparatus was the same as that used in Experiment I.

Procedure

The procedure was identical to that used in Experiment I, except for the following: when the animal was in one component, the VT schedule in the other component was also in operation. If a shock was primed in the component the rat was in, it received the shock immediately; if a shock was primed in the other component, it received the shock 2 sec after it switched to that component (2-sec COD). The sequence of the VT schedules for the noise component (Component 1) and the no-noise component (Component 2) is shown in Table 2 for the first eight conditions. The scheduled rate of free shock was either 0, 0.5, 1.0, or 2.0 shocks per minute in each component (no punishment, VT 2-min, VT 1-min, or VT 30-sec shock schedules, respectively).

During the final part of the experiment, the role of the noise signal in determining time allocation was assessed. Condition 9 (nine sessions) repeated Condition 8 (*i.e.,* 2.0 and 1.0 punishers per minute in Components 1 and 2, respectively), except that noise was not present in either component. Conditions 10 (nine sessions) then replicated Condition 8 exactly.

RESULTS

Table 2 shows the mean proportion of time spent in Component 1, the standard error of the mean, the mean obtained number of punishers per session in each component for all subjects in every condition, and the number of

Table 2

Sequence of the scheduled rates of shock for the two components of each condition of Experiment II and the results. Each value is the mean of the last five sessions for each condition.

Condition	Scheduled Punishment Rate (pun/min) Comp. 1	Comp. 2	Rat	Sessions	$\frac{T_1}{T_1+T_2}$	S_m	Obtained Punishers per Session Comp. 1 (p_1)	Comp. 2 (p_2)	Changeovers per Minute
1	2.0	0.0	1	9	0.065	0.029	2.8	0.0	0.29
			2	9	0.093	0.048	5.8	0.0	0.11
			3	9	0.002	0.001	0.8	0.0	0.03
2	0.0	2.0	1	9	0.972	0.028	0.0	1.4	0.02
			2	9	0.969	0.030	0.0	2.8	0.12
			3	9	0.931	0.068	0.0	4.6	0.08
3	2.0	2.0	1	15	0.354	0.111	18.2	35.6	2.66
			2	15	0.485	0.154	23.8	24.8	1.25
			3	15	0.587	0.125	29.0	17.2	0.93
4	0.5	2.0	2	15	0.917	0.036	10.8	4.6	0.30
			3	15	0.918	0.059	10.8	5.0	0.14
5	1.0	2.0	1b	15	0.768	0.089	24.4	12.4	0.21
			2	15	0.690	0.076	23.0	15.2	0.79
			3	15	0.779	0.081	17.2	14.6	0.41
6	2.0	0.5	1b	30	0.087	0.041	5.4	12.8	0.14
			2	30	0.068	0.028	3.4	10.4	0.37
			3	30	0.093	0.046	4.0	6.8	0.98
7	1.0	2.0	1b	30	0.686	0.085	19.8	18.4	0.52
			2	30	0.794	0.077	21.0	10.6	0.50
			3	30	0.974	0.021	21.2	2.6	0.22
8	2.0	1.0	1b	30	0.171	0.023	9.2	21.2	1.77
			2	30	0.160	0.013	8.0	21.6	1.43
			3	30	0.110	0.046	9.7	21.8	3.33

changeovers per minute. (To determine the amount of time spent in a component, multiply the proportion of time spent in the component by 25 min.) Each value represents the mean of the last five sessions of each condition.

Figure 3 shows for each subject the relative amount of time spent in Component 1 as a function of the relative number of obtained punishers in Component 2. The diagonal represents the matching relation of Equation 5. The points do not fall along the line, except at the extremes (Conditions 1 and 2). In fact, with the omission of these two conditions, there is a strong negative correlation between the proportion of time spent in Component 1 and the proportion of shocks received in Component 2. The animals received more shocks where they spent more time.

Figure 4 shows the relative amount of time spent in Component 1 as a function of the square roots of the relative delays until shock. The step function indicates minimizing. To the left of the step at 0.5, the expected time until shock in Component 2 is greater than that in Component 1: minimizing will, therefore, occur if the animal allocates all of its time to Component 2 (0% in Component 1). To the right of the step at 0.5, the expected time until shock in Component 2 is less than that in Component 1: minimizing will, therefore, occur if the animal allocates 100% of its time to Component 1. Minimizing did tend to occur, with the data points falling very close to the step function.

Performance in Conditions 8, 9, and 10 provides evidence for the role of the white-noise signal. The three conditions were identical, except that there was no noise signal in Condition 9. The proportion of time spent in Component 1 of Condition 9 was 0.46 (range: 0.44 to 0.48). This is not distinguishable from indifference (0.5). The proportion of time spent in Component 1 of Condition 8 was 0.15 (range: 0.11 to 0.17), and the proportion of time spent in Component 1 of Condition 10 was 0.20 (range: 0.06 to 0.32). This indicates

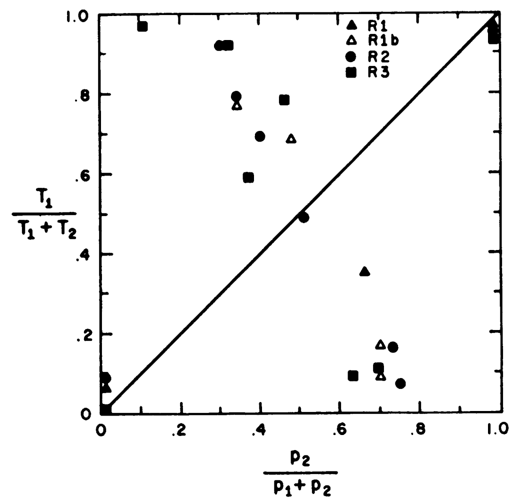

Fig. 3. The relative amount of time spent in Component 1 as a function of the relative number of obtained punishers in Component 2 (Experiment II).

that the noise signal was necessary for the results reported in the figures.

DISCUSSION

The results of Experiments I and II indicate that the manner in which animals allocate their time between punishing situations depends on whether the schedules for both components are always in operation, or whether the schedule in one component is not in operation when the animal is in the other component. The matching relation of Equation 5 occurs in a time-allocation punishment situation (Experiment I) when only one schedule is in operation at any time; minimizing occurs however, if both schedules are in operation (Experiment II).

The findings of both experiments may be understood in terms of the expected times until aversive events. In Experiment I, the expected time until shock was constant in each component during a particular condition, since only one schedule was in effect at any time. In this situation, the animals allocated their time in terms of the square roots of the expected times until shock (Equation 7). In Experiment II, the time the animal spent in one component affected the expected time until shock in the other component, since both schedules were always in effect. In this situation, the expected time until shock in one component decreased the longer the animal spent in the other component. A changeover from one component to the other component often resulted in shock delivery (after the COD had elapsed). This punishment contingency forced the animal to spend almost all of its time in the component having the smaller shock rate, *i.e.*, in the component where the expected time until shock was longer.

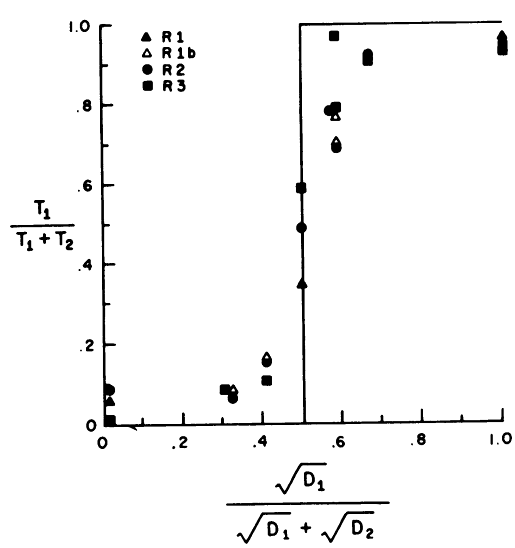

Fig. 4. The relative amount of time spent in Component 1 as a function of the square roots of the relative delays until shock (Experiment II). Minimizing is indicated by the step function.

REFERENCES

Baum, W. M. The correlation-based law of effect. *Journal of the Experimental Analysis of Behavior*, 1973, **20**, 137-153. (*a*)

Baum, W. M. Time allocation and negative reinforcement. *Journal of the Experimental Analysis of Behavior*, 1973, **20**, 313-322. (*b*)

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. Time-based and count-based measurement of preference. *Journal of the Experimental Analysis of Behavior*, 1976, **26**, 27-35.

Baum, W. M. and Rachlin, H. C. Choice as time allocation. *Journal of the Experimental Analysis of Behavior*, 1969, **12**, 861-874.

Bauman, R. A., Shull, R. L., and Brownstein, A. J. Time allocation on concurrent schedules with asymmetrical response requirements. *Journal of the Experimental Analysis of Behavior*, 1975, **24**, 53-57.

Brownstein, A. J. and Pliskoff, S. S. Some effects of relative reinforcement rate and changeover delay in response-independent concurrent schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1968, **11**, 683-688.

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.

Deluty, M. Z. Choice and the rate of punishment in concurrent schedules. *Journal of the Experimental Analysis of Behavior*, 1976, **25**, 75-80.

de Villiers, P. Choice in concurrent schedules and a quantitative formulation of the law of effect. In W. K. Honig and J. E. R. Staddon (Eds), *Handbook of operant behavior*. Englewood Cliffs, N.J.: Prentice-Hall, 1977. Pp. 233-287.

Herrnstein, R. J. Relative and absolute strength of response as a function of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1961, **4**, 267-272.

Herrnstein, R. J. On the law of effect. *Journal of the Experimental Analysis of Behavior*, 1970, **13**, 243-266.

Herrnstein, R. J. Quantitative hedonism. *Journal of Psychiatric Research*, 1971, **8**, 399-412.

Herrnstein, R. J. Formal properties of the matching law. *Journal of the Experimental Analysis of Behavior*, 1974, **21**, 159-164.

Miller, H. L. and Loveland, D. H. Matching when the number of response alternatives is large. *Animal Learning and Behavior*, 1974, **2**, 106-110.

Pliskoff, S. and Brown, T. G. Matching with a trio of concurrent variable-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1976, **25**, 69-73.

Shull, R. L. and Pliskoff, S. S. Changeover delay and concurrent schedules: some effects on relative performance measures. *Journal of the Experimental Analysis of Behavior*, 1967, **10**, 517-527.

Received 18 October 1976.
(Final acceptance 7 September 1977.)