QUANTITATIVE STUDIES OF REINFORCEMENT RELATIVITY¹

JAMES E. MAZUR

HARVARD UNIVERSITY

Three experiments examined an application of the matching law to the area of reinforcement relativity. In Experiment I, rats ran in a wheel and drank a sucrose solution. Equations derived from the matching law made fairly accurate predictions of the amounts of time spent running and drinking when licks and wheel revolutions had to occur in fixed proportions. In Experiment II, rats were required to spend four times as much time drinking as running, but the absolute durations of the cycles of drinking and running were varied. Except for the shortest cycle size tested, durations were close to those predicted. Experiments III investigated a tendency for obtained durations of running and drinking to be slightly longer than predicted. Simply shortening the periods when these behaviors were available increased their values. It was concluded that the matching law equations provided reasonably accurate predictions in some experiments, but changes in motivation set the limits of such accuracy.

Key words: matching law, Premack's principle, drinking, running, rats

Premack's work (1959, 1965, 1971) undermined the traditional distinction (*e.g.*, Miller, 1951; Skinner, 1953; Spence, 1956) between reinforcers and reinforced responses. Premack (1962) demonstrated that the roles of reinforcer and reinforced response could be reversed by changing an animal's motivational state. For rats deprived of water, the act of drinking reinforced running when the rats were required to run in a wheel to gain the opportunity to drink. When the rats had free access to water but were deprived of running, running acted as a reinforcer for drinking.

Premack (1959) suggested that the dichotomy between reinforcers and reinforced responses should be replaced by a hierarchy of behaviors. A behavior's position in the hierarchy was determined by its probability in a condition where the behavior was freely available. He subsequently refined his position by stating that the best measure of a behavior's probability is its duration in a fixed period of observation (in effect, its relative duration), because the durations of topographically

different behaviors can be compared (Premack, 1965). Premack's experiments with running and drinking in rats seemed to confirm his prediction that a particular behavior could act as a reinforcer for less probable behaviors (those lower in the probability hierarchy) but would itself be reinforced by more probable behaviors. This hypothesis, sometimes called "Premack's differential-probability principle", deals with relativity in the reinforcement relation that does not depend on changes in motivational states, but rather on differences in behavior probabilities.

Later experiments called the generality of this principle into question, while directing attention to another type of reinforcement relativity. Eisenberger, Karpman, and Trattner (1967, Experiment 2) showed that a behavior with lower probability could actually reinforce a higher probability behavior, given an unequal "rate of exchange" (Smith, 1974) between the two. For example, human subjects required to engage in a large amount of wheel turning to earn the opportunity for a small amount of bar pressing (a behavior of lower probability) displayed increases in the amount of wheel turning. This phenomenon, which has also been found in other studies (*e.g.*, Allison and Timberlake, 1974, Experiments 1, 2), shows that the reinforcement relation takes into account the rate of exchange between the

¹This research was supported by Grant MH-15494 from the National Institute of Mental Health to Harvard University. I thank R. J. Herrnstein for many valuable suggestions. Reprints may be obtained from James E. Mazur, 760 William James Hall, Harvard University, Cambridge, Massachusetts 02138.

behaviors being controlled, not simply their relative probabilities.

Timberlake and Allison (1974) formulated the "response deprivation" theory of reinforcement to explain these results. In essence, the theory states that, given a contingency between two responses, reinforcement will occur if and only if the organism is deprived of the contingent response, which is to say, if the rate of exchange specifies a lower contingent-to-instrumental ratio than occurred in an unrestricted condition. This explanation seems intuitively reasonable: one would not expect, say, drinking to reinforce running (to increase running above its baseline rate) when, in the contingent procedure, the amount of running established during the baseline condition allows as much, or more, drinking than occurred in the baseline condition.

The blurring of the theoretical distinction between reinforcers and reinforced responses has led to a class of procedures in which the methodological asymmetry between instrumental and contingent behaviors disappears. In a simple contingency, the instrumental behavior (e.g., bar pressing) produces the opportunity to engage in the contingent behavior (e.g., eating), but the contingent behavior is not required. The subject has unrestricted access to the instrumental behavior. However, in an *interdependent* condition (Mazur, 1975), or what Allison (1971) called a *reciprocal contingency*, each behavior sets the occasion for the other, and the rate of exchange between the two behaviors is controlled. For example, in Mazur's (1975) experiment with rats, the amount of drinking time relative to running time was controlled in the interdependent conditions. The sessions began with only running available until the rat ran for a specified amount of time. The running wheel was then locked and the drinking tube was made available until the rat drank for a certain amount of time, and then the running-only condition was restored. These cycles of running and drinking continued throughout the session as long as the animal fulfilled the behavior requirements. Thus, in an interdependent procedure, each behavior is both contingent on, and instrumental in gaining access to, the other.

The differential-probability and response-deprivation analyses were at first at the qualitative or descriptive level, but there have been

some recent approaches toward a more quantitative analysis. Allison (1976) developed a "conservation model", which attempts to predict durations or amounts of interdependent behaviors in a wide variety of experimental conditions. The present research takes a different approach, based on an effort to close the gap between research on reinforcement relativity and research related to the matching law (Herrnstein, 1961, 1970). Mazur (1975) used matching law equations dealing with time allocation (Baum, 1973; Baum and Rachlin, 1969) to derive quantitative predictions for interdependent conditions. These predictions were approximately confirmed for the durations of running and drinking by rats.

The predictions were based on the values of drinking, running, and other behaviors, where a behavior's *value* was defined as the percentage of time spent in that behavior in a baseline condition with all behaviors available. For example,

$$V_d = \frac{T_d}{T_d + T_r + T_o}, \quad (1)$$

where V_d is the value of drinking, and T_d , T_r , and T_o are the durations of drinking, running, and other behaviors, respectively, in the baseline condition. Predictions were made for behavior durations in interdependent conditions, where the amount of drinking time relative to running time was controlled. The value of drinking plus running as a whole was assumed to be a weighted average of the values of drinking and running:

$$V_{d+r} = pV_d + (1 - p)V_r. \quad (2)$$

The parameter p is the required proportion of time spent drinking in the drinking-plus-running combination:

$$p = \frac{T'_d}{T'_{d+r}}, \quad (3)$$

where the superscript ' indicates that the durations are those of the interdependent condition. It should be clear that p reflects the rate of exchange between the two interdependent behaviors, drinking and running. (These combined behaviors will be called *drinking plus running* to distinguish them from references to drinking and running considered separately). The proportion of time spent drinking plus running in the interdependency was predicted with the following equation:

$$\frac{T'_{a+r}}{T'_{a+r} + T'_o} = \frac{pV_a + (1-p)V_r}{pV_a + (1-p)V_r + V_o} \quad (4)$$

Since Equation 4 predicts the proportion of time spent drinking plus running, the predicted proportion of time spent drinking can be obtained by multiplying Equation 4 by p :

$$\frac{T'_a}{T'_{a+r} + T'_o} = p \frac{pV_a + (1-p)V_r}{pV_a + (1-p)V_r + V_o} \quad (5)$$

The predicted proportion of time spent running can be obtained by multiplying Equation 4 by $(1-p)$:

$$\frac{T'_r}{T'_{a+r} + T'_o} = (1-p) \frac{pV_a + (1-p)V_r}{pV_a + (1-p)V_r + V_o} \quad (6)$$

(see Mazur, 1975, for a detailed discussion of the derivation of these equations).

Mazur's (1975) experiment demonstrated the reasonable accuracy of these equations in interdependent conditions that might be more specifically called *interdependent-time* conditions, since the ratio of drinking time to running time was controlled. Experiment I of this research extended this approach to *interdependent-amount* conditions, in which specific numbers of wheel revolutions had to alternate with specific numbers of licks. This experiment was designed to determine whether the equations could predict the allocation of time when no specific time requirements were set, since the value of p was not controlled. In addition, the number of wheel revolutions and number of licks were recorded, whereas the latter were not measured in Mazur's (1975) experiment. Experiment II featured a number of time interdependencies where p equalled 0.8, but where the absolute durations of the cycles of drinking and running were varied. This experiment attempted to determine the range of cycle sizes for which behavior durations would approximate the predictions. It was hypothesized that the predictions would be inaccurate for very small cycle sizes. In several experiments, there was a slight, yet consistent tendency for interdependent durations to be longer than predicted. Experiment III explored the possibility that these deviations from predictions might be due to increases in the values of drinking and running when their availability was restricted. No interdependent conditions were used in Experiment III. Instead, the availability of drinking and running

was restricted to certain periods within the sessions.

EXPERIMENT I

METHOD

Subjects

Four male Lashley rats from a previous experiment in the same chamber (Mazur, 1975) were housed separately and had free access to food and water in their home cages.

Apparatus

The experimental chamber was 192 mm high, 209 mm wide, and 230 mm long. The chamber contained a retractable drinking tube, which protruded through a 13-mm diameter hole in the middle of one 209-mm wall, 25 mm above the floor. A 102- by 102-mm opening in the opposite wall led to a running wheel 380 mm in diameter and 95 mm wide. White lights above the running wheel were lit when the wheel was free to rotate, and white lights above the drinking tube were lit when drinking was possible. A drinkometer recorded the number of times the animal made contact with the liquid in the drinking tube. The number of revolutions in the wheel was recorded through a gear and microswitch arrangement.

The apparatus was enclosed in a sound-attenuating box that contained an air blower for ventilation and a speaker producing continuous white noise to mask extraneous sounds. A PDP-8F computer housed in another room controlled the stimuli and recorded the responses.

Procedure

All sessions lasted 1000 sec. Before and after all sessions, the wheel was locked, the drinking tube was retracted beyond the animal's reach, and the chamber was dark.

A 25% sucrose solution was used. When drinking was available, a timer measuring cumulative drinking operated as long as licks occurred at a rate of at least one per second. Another timer measured cumulative running and operated whenever the wheel was rotated at a minimum rate of 1/72 revolution per second. A third timer, measuring the duration of other behavior, operated when neither the drinking nor running timer was operating.

Table 1
Order of Experimental Conditions in Experiment I

Condition	Lick Requirement in One Cycle	Revolution Requirement in One Cycle	Mean p-value
Free	none	none	—
Running-only	unavailable	none	0.000
Interdependent	25	4	0.235
Interdependent	50	3	0.474
Interdependent	75	2	0.679
Interdependent	100	1	0.823
Drinking-only	none	unavailable	1.000
Free	none	none	—
Drinking-only	none	unavailable	1.000
Interdependent	100	1	0.864
Interdependent	75	2	0.727
Interdependent	50	3	0.552
Interdependent	25	4	0.308
Running-only	unavailable	none	0.000
Free	none	none	—

Table 1 shows the order of the experimental conditions. In free conditions, drinking and running were continuously available throughout the session. In running-only conditions ($p = 0$), running was continuously available and drinking was never available. In drinking-only conditions ($p = 1$), drinking was continuously available and running was never available. Interdependent conditions began with the drinking tube available and the wheel locked. When the rat completed the required number of licks, the drinking tube was retracted and the running wheel was unlocked until the rat completed the required number of revolutions, at which point the drinking-only condition was restored. Such cycles of drinking and running continued throughout the session, dependent, of course, on the animal's behavior. For convenience, interdependent, running-only, and drinking-only conditions will be collectively referred to as "experimental conditions" to distinguish them from baseline, or free conditions.

Each free condition lasted at least six sessions. For each rat, a free condition was terminated when two criteria were met for five consecutive days: (1) no duration of drinking differed from the mean of these last five days by more than 10% of the total session time, and (2) no duration of running differed from the five-day mean by more than 5% of the total session time. Experimental conditions lasted at least four sessions and were terminated when these criteria were met for three consecutive days (*i.e.*, the durations of drink-

ing and running did not differ from the means of these three days by more than 10% and 5% of the total session time, respectively).

RESULTS AND DISCUSSION

The last column in Table 1 shows the mean value of p for each experimental condition. These values are the mean proportions of time spent drinking in the drinking-plus-running combination, based on the last three days of each condition for each subject.

The baseline proportions of drinking, running, and other time were calculated for each rat using the means of the last five days of each free condition. These values are shown in Table 2.

Predictions for the experimental conditions were made with these values and Equation 4. Figure 1 shows the predicted and obtained proportions of drinking plus running for each rat. For each experimental condition and each rat, the obtained values are the means of six days, the last three days of each occurrence of that condition. This figure also shows the obtained proportions of time spent drinking and running separately, and the lined areas show those values of p where either drinking or running was reinforced (occurred for longer durations than in the free condition). The bottom-right panel shows the mean predictions and results for the group. The predictions were made using the mean durations of drinking and running in baseline, and obtained points are based on the mean durations of drinking and running in each experimental condition.

The results are similar to those of a previous experiment (Mazur, 1975) in several respects. The predictions were fairly accurate for all subjects, although the obtained durations tended to be slightly longer than predicted. Reinforcement of both drinking and running

Table 2
Free Condition Time Allocation in Experiment I

Rat	Per Cent of Total Time		
	Drinking	Running	Other
1	31.20	4.77	64.03
2	29.27	3.91	66.82
4	43.24	0.84	55.92
5	19.31	6.21	74.48
Mean	30.76	3.93	65.31

Fig. 1. For each rat in Experiment I, predicted and obtained proportions of drinking-plus-running time are shown as functions of p , the proportion of drinking time in the drinking-plus-running combination. Obtained times spent running and drinking are also shown separately, and the lined areas show where the durations of running or drinking were longer than in the free condition. The lower-right panel shows the group means.

occurred in different conditions for two rats. The reinforcement effects for drinking, the behavior with higher value, were small for two rats and nonexistent for the other two. The

times spent drinking plus running in the experimental conditions were lower than the free condition durations of drinking and running, except for Rat 4 in two conditions.

Fig. 2. Predicted and obtained number of wheel revolutions and number of licks in Experiment I are shown for each rat as functions of p , the proportion of drinking time in the drinking-plus-running combination. The lower-right panel shows the group means.

Predictions of the *amounts* of running and drinking in the interdependent conditions can be made using Equation 4 and the mean free condition *local rates* of running and drinking. The *local rate* of running in baseline, R_{loc} , is defined as follows: $R_{loc} = R/T_r$, where R is the number of revolutions in baseline and T_r is the duration of running in baseline. The predicted number of revolutions in any experimental condition, R' , is equal to $R_{loc} \times T'_r$. Similarly, $L_{loc} = L/T_d$ and $L' = L_{loc} \times T'_d$,

for the local rate of licking and the predicted number of licks in the experimental condition, respectively. Predicted and obtained numbers of wheel revolutions and numbers of licks are shown for each rat in Figure 2. The bottom-right panel shows the mean predictions and results for the group. The obtained numbers of licks were close to the predictions, but more revolutions than predicted occurred, especially for Rats 2 and 4. The large amounts of running in the interdependent conditions coin-

cided with faster local rates of running, as Figure 3 shows. This figure displays the means of the local rates of drinking and running for each condition. These results of this interdependent-amount experiment contrast with the results of Mazur's (1975) interdependent-time experiment, where slower running occurred in the interdependent conditions. This difference might be explained by the fact that amount interdependencies are in some ways similar to ratio schedules, since faster running leads to faster drinking availability. This is not true in time interdependencies, where all speeds of running above some minimum rate are equivalent in terms of satisfying the running requirement. It is well established that ratio schedules produce faster responding than interval schedules (*e.g.*, Herrnstein, 1964).

Figure 3 also shows that the mean local rates of licking in the experimental conditions were about the same as in the free conditions. This result is consistent with the hypothesis that rats' licking rates remain fairly constant over different experimental conditions (Schaeffer and Premack, 1961; Stellar and Hill, 1952).

In summary, the predictions of Equation 4 were fairly accurate for the time spent running

and drinking in this interdependent-amount experiment. On the average, slightly longer durations than predicted were obtained: the mean duration of drinking plus running was 9.3% longer than predicted. Predictions for the number of licks were also accurate, but predictions for the number of wheel revolutions were not. Faster running than in the free condition occurred in the interdependent conditions, and 39.4% more revolutions than predicted were obtained.

EXPERIMENT II

Equation 4 predicts constant amounts of time spent at each behavior for a given p -value, regardless of the absolute size of the drinking and running requirements in one cycle. An experiment by Allison and Timberlake (1974, Experiment 2) provides some support for this prediction. In an interdependent-amount situation where the two behaviors were licking 0.4% saccharin and licking 0.3% saccharin, the number of licks did not vary significantly when the sizes of the requirements were varied by a factor of four. However, Mazur (1975) suggested that this invariance should break down with very small cycle sizes, if only because the nature of the behavior possible in such brief units of time will be different from behaviors in a free condition. This experiment attempted to determine the limits of invariance of interdependent behaviors in an interdependent-time experiment where cycle size was varied over a greater range than in the Allison and Timberlake study.

METHOD

Subjects and Apparatus

The subjects and apparatus were the same as those of Experiment I.

Procedure

Table 3 shows the order of the conditions in Experiment II. Free conditions were the same as those of Experiment I, and the first free condition in this experiment was also the last free condition in Experiment I. Interdependent conditions contained cycles of drinking availability and running availability as in Experiment I, except that drinking and running requirements were based on time spent running and licking, rather than amounts of running or drinking. For example,

Fig. 3. Mean rates of running and drinking for all subjects in Experiment I are shown as functions of p , the proportion of drinking time in the drinking-plus-running combination. The horizontal lines show the mean free-condition rates.

the first interdependent condition began with drinking available until the rat drank for a cumulative total of 20 sec, at which point the drinking tube was retracted and the running wheel was unlocked until it ran for a cumulative total of 5 sec. In each condition, the drinking requirement was scheduled to be four times as long as the running requirement, *i.e.*, *p* was scheduled to equal 0.8. What varied across conditions was the absolute duration of one running-drinking cycle, which ranged from 5 sec to 250 sec. The obtained values of *p* were not exactly those scheduled, both because the animals did not always complete the last cycle of a session and because of small corrections made to compensate for inaccuracies in the behavior timers. The average *p*-values for each condition are shown in the last column of Table 3.

The requirements for terminating each free or independent condition were the same as those of the free conditions in Experiment I. In all other details, the procedure was identical to that of Experiment I.

RESULTS AND DISCUSSION

Figure 4 shows the mean proportion of time spent drinking plus running in the last four days of each interdependent condition for each rat. The dotted horizontal lines show the mean free condition proportions, and the dashed horizontal lines show the proportions predicted by Equation 4. For each rat, the shortest durations of drinking plus running were occasioned by the smallest cycle requirements—1 sec running and 4 sec drinking. For the remaining conditions there may be a slight trend toward longer durations as cycle size

increased, as can be seen in the group mean in Figure 4.

Two factors may account for this pattern of results. Table 4 shows the mean durations of drinking and running bouts in each condition. A bout was counted at the occurrence of either behavior if that behavior had not occurred in the previous second. The mean drinking bout in baseline lasted 13.75 sec and the mean running bouts only 1.27 sec. In some interdependent conditions, especially in the condition with the shortest cycle size, drinking and running bouts were necessarily shorter. This restriction may help to explain why less drinking and running occurred in this condition. It is interesting to note that with the three largest cycle sizes, drinking and running bouts tended to be slightly longer than in the free condition. The second factor concerns the distance between the drinking tube and the wheel. Cycles of running and drinking actually included a third behavior—travelling between the wheel and the drinking tube. With smaller cycle sizes, more of these trips were necessary to obtain the same durations of drinking and running. In light of the restrictions on bout durations and the travelling required, it is not surprising that less drinking and running occurred with small cycle sizes.

Table 4
Mean Bout Durations in Experiment II

Drinking Requirement (in seconds)	Mean Drinking Bout (in seconds)				
	Rat 1	Rat 2	Rat 4	Rat 5	Mean
4	3.41	3.73	3.75	3.87	3.69
12	11.10	9.41	8.96	10.89	10.09
20	10.97	7.12	10.95	14.45	10.87
60	21.19	12.58	14.30	13.93	15.50
100	19.59	11.28	8.87	11.22	12.74
200	28.28	13.65	13.99	14.52	17.61
Free	15.86	10.60	13.30	15.25	13.75

Running Requirement (in seconds)	Mean Running Bout (in seconds)				
	Rat 1	Rat 2	Rat 4	Rat 5	Mean
1	0.71	0.66	0.80	0.73	0.73
3	1.18	0.87	1.79	0.82	1.17
5	1.67	1.77	2.43	1.26	1.78
15	1.72	1.65	4.68	1.83	2.47
25	2.22	2.75	4.49	1.83	2.82
50	1.79	2.01	4.62	2.08	2.63
Free	1.04	1.33	—	1.44	1.27 ^a

Table 3
Order of Experimental Conditions in Experiment II

Condition	Drinking Requirement in One Cycle (in seconds)	Running Requirement in One Cycle (in seconds)	Mean p-value
Free ^a	none	none	—
Interdependent	20	5	0.827
Interdependent	100	25	0.823
Interdependent	4	1	0.822
Interdependent	60	15	0.829
Interdependent	12	3	0.847
Interdependent	200	50	0.810
Free	none	none	—

^aThe first free condition is the same as the last condition of Experiment I.

^aRat 4 did not run in the free conditions, so this mean is based on the other three subjects.

Fig. 4. For each rat, obtained proportions of drinking-plus-running time are shown for each cycle size in Experiment II. The abscissa shows the duration of running in one cycle—the drinking requirement was four times as long in each case. The dashed horizontal lines are the predictions of Equation 4. The lower-right panel shows the group mean.

Despite these considerations, the obtained durations at all cycle sizes except the smallest were not far from those predicted, except for Rat 2. The obtained durations tended to be slightly longer than predicted for the larger cycle sizes. The magnitude of the upward deviation does not seem to depend on cycle size. Both the Allison and Timberlake results (1974, Experiment 2), and the present results suggest that, within limits, and except for the physical constraints mentioned above, cycle size is not an important factor in interdependent conditions. The results of Experiments I and II and those of Mazur (1975) seem to indicate that the major determinants of behaviors in the interdependent conditions are the values of the behaviors involved and the rate of exchange between behaviors. At the same time,

however, there is clear evidence for a small but consistent deviation resulting in slightly longer durations than predicted by Equation 4.

EXPERIMENT III

In three experiments (Experiments I and II and Mazur, 1975), the obtained durations of drinking and running in interdependent conditions were slightly longer than predicted. It must be stressed that the predictions of Equation 4 are based on the assumption that the values of all behaviors remain the same as in the free condition, which is to say that the animal's drive state must be the same as in the free condition. Any experimental situation can only approximate such stability, yet the predictions will be inaccurate if this re-

quirement is not met. Since interdependent conditions impose restrictions on the availability of the behaviors involved, it is conceivable that the values of these behaviors might increase as a result.

Experiment III explored this possibility. In the experimental conditions, drinking and running were available for only certain fractions of the session time. If the values of drinking and running remain stable in spite of such restrictions, their total durations should be directly proportional to the percentage of the session time they are available. But if the values are changing, the durations may deviate from proportionality.

METHOD

Subjects

Five male Lashley rats, approximately eight months old, were housed separately and had free access to food and water in their home cages. Before the experiment, each rat received between 30 and 40 free-condition sessions.

Apparatus and Procedure

The apparatus was the same as that of Experiments I and II except that the drinking tube contained a 2.5% saccharin solution. The experiment began with seven 1000-sec free-condition sessions. Next, sessions were divided into ten 100-sec cycles. Running and drinking were both freely available for the first 75 sec of each cycle and unavailable for the last 25 sec. In the third and fourth procedures, the 100-sec cycles permitted running and drinking only during the first 50 sec and 25 sec, respectively. Finally, the original free condition was restored. Each procedure lasted seven sessions.

RESULTS AND DISCUSSION

The proportions of available time spent drinking and running in the last four days of each procedure are shown in Figure 5. The abscissa represents the proportion of session time during which drinking and running were possible. The points at 1.0 are based on the mean of the last four days of each of the two baseline conditions, where these behaviors were available for the entire session. The dashed horizontal line in each panel shows the predicted amount of time that would be spent running or drinking if the mean values of these behaviors were stable across the condi-

Fig. 5. The proportions of available time spent drinking and running in Experiment III are shown as functions of the proportion of session time the behaviors were available. The dashed horizontal lines show the mean expected proportions if the values of drinking and running were the same as in the free condition.

tions. (Because this line is based on the free-condition durations, the predicted and obtained proportions are, by definition, equal when the proportion of time available is 1.0.)

Since "value" is defined as the proportion of time the organism engages in a behavior when it is available, reducing the time a behavior can occur by, say, 50% should cause a 50% reduction in duration of that behavior. In most cases, both behaviors decreased in duration as the time they were available decreased, but not as much as predicted by an assumption of constant value, because the proportions

of available time spent drinking and running increased. Overall, the value of running changed less, but both behaviors increased in probability, or value, as their availability was decreased.

The restriction in the availability of drinking and running in this experiment differs from that in an interdependent procedure. With an interdependency, the animal can regain the opportunity to drink by running, and *vice versa*, but in the present experiment the animal had no control over when the behaviors were available. Nevertheless, a simple restriction in the overall availability of the behaviors was sufficient to cause increases in their values, as here defined. It seems likely that similar changes in behavior values occur in interdependent conditions, and this may explain why obtained durations tend to be longer than predicted. Another possibility is that the value of other behavior might decrease in interdependent conditions due to interactions between drinking or running and some behaviors in the "other" category. For example, a behavior such as grooming may occur less frequently when drinking is unavailable. Perhaps some combination of increases in the values of drinking and running and decreases in the value of other behavior combined to produce the longer durations in the interdependencies.

At least with availabilities of 50% and 75%, the relative value of drinking increased more than the relative value of running in this experiment. This means that the total duration of drinking decreased less than that of running. This difference can be considered in terms of Nevin's (1974) definition of "response strength" as a behavior's "relative resistance to change". Drinking was more resistant to change than running under increasing temporal restrictions. A similar concept is embodied in the economic term "elasticity". As the price of an "elastic" commodity changes, changes in the consumption of this commodity are relatively large. An "inelastic" commodity is one whose consumption is relatively insensitive to changes in cost (Spencer, 1971). Drinking could be described as more inelastic, as the availability of these behaviors was restricted. Future research might investigate the relationship between changes in behavior value when its availability is restricted and the behavior's resistance to change in other circumstances (*e.g.*,

in interdependencies, or when response-independent reinforcers are added or removed).

GENERAL DISCUSSION

The results of three experiments show that the matching law can be extended to situations where Premack's principle has supplied qualitative predictions. Quantitative predictions were generated for procedures in which the distinction between reinforcer and reinforced response was nonexistent. Predictions for the durations of drinking and running were fairly accurate in Mazur's (1975) interdependent-time experiment, in Experiment II, another interdependent-time experiment, and in Experiment I, which used an interdependent-amount procedure. In an interdependent-amount experiment, values for p , the rate of exchange parameter, are not fixed by the experimental procedure, since the requirements are based on amounts of behavior (*e.g.*, number of licks, number of wheel revolutions) rather than behavior durations.

In all three experiments, obtained durations of drinking and running averaged slightly longer than predicted. This is not always the case, as an application of Equation 4 to an interdependent-time experiment by Allison and Timberlake (1974, Experiment 4) shows. The interdependent behaviors were licking a 0.4% saccharin solution and licking a 0.3% saccharin solution. Eight rats spent a mean of 37.8% of the session time licking either solution, as opposed to the predicted 44.0%, based on baseline durations of licking and an obtained p -value of 0.931. On the other hand, longer durations than predicted by Equation 4 occurred in another experiment by Allison and Timberlake (1974, Experiment 1). The experimental conditions did not require an interdependency between two behaviors, but rather a simple dependency of one behavior on another. For 11 rats, the opportunity to lick a 0.1% saccharin solution depended on licking 0.4% saccharin, but the rats were not required to lick 0.1% saccharin in order to continue licking the 0.4% solution. The durations of both behaviors were measured, so a value of p can be obtained. Baseline values were estimated from the group mean of three free-condition days, and dependent condition durations were estimated using the mean of the last five days, although the behavior may not

have been stable. An average of 50.8% of the session time in the dependent condition was spent licking, as compared to the 48.4% predicted by Equation 4, with p equal to 0.970.

In each of these five experiments, at least one behavior was drinking a saccharin or a sucrose solution. Evidently, the values of these behaviors did not change much between baseline and experimental conditions, since the results approximated the predictions of Equation 4. In each experiment, the rats had continuous access to water in their home cages. In contrast, rats in an experiment by Allison (1976) obtained all their water in daily 1-hr sessions. In the interdependent-time conditions, the two interlocked behaviors were drinking and bar holding. Durations of drinking and bar holding in interdependent conditions were much higher than predicted by Equation 4. These large deviations were probably due to large increases in the value of drinking, since the amount of water consumed averaged 31% less in interdependent conditions than in baseline. In other words, the value of water increased enough to result in larger durations of drinking and bar holding than predicted by Equation 4, yet not enough to restore drinking to its baseline level. These results illustrate an important point: the present approach relies on behavior values estimated in baseline conditions, and predictions will be inaccurate when behavior values change in interdependent conditions.

Restrictions on the times when drinking saccharin and running were available in Experiment III increased the values of these behaviors. This suggests that the behavior values may increase in interdependent conditions in a similar fashion, even when subjects are not deprived of water. This may explain the upward deviations in durations that often occur. Other factors may also affect value and subsequently cause inaccuracies in the predictions (see Mazur, 1975). For example, drinking and running may interact, so that the value of drinking depends on the availability of running or on the sheer amount of running. (It would be reasonable to suggest that the exercise of running in a wheel increases the animal's thirst.) Extremely small behavior requirements may cause the values of these behaviors to decrease—"running" that must occur in 0.1-sec bursts will not resemble running at all, and its value to the animal may be very

low. Less drinking and running in the smallest cycle sizes of Experiment II may have been the result of a decrease in the values of drinking and/or running when they could only occur in small bursts. The fact that the predictions of Equation 4 were fairly accurate in several experiments indicates that complicating factors like these did not play a major role.

Predictions for amounts of behavior are possible if it is assumed that the local rates of these behaviors will not change between baseline and interdependent conditions. Changes in rate can occur, however, and predictions of amounts are therefore less reliable. For example, in Experiment I the local rates of running were higher in the interdependent conditions, and more revolutions than predicted were obtained.

The predictions of Equation 4 are based on (1) the values of the behaviors involved in the interdependency, where value is defined as the proportion of time spent in a behavior when all behaviors are continuously available, (2) the value of all other behaviors, and (3) the rate of exchange between the interdependent behaviors, measured in units of time. This quantitative approach therefore encompasses two important causes of reinforcement relativity: the *relative values* of the interdependent behaviors and of all other behaviors, and the *relative durations* of the two interdependent behaviors specified by the rate of exchange. Equation 4 makes no predictions concerning the *changes in relative values* that can occur over time. When such changes take place, observed behavior will deviate from predictions based on previous behavior values. Although Equation 4 cannot account for these deviations, their direction and magnitude may provide information about the changing motivational states that underlie them.

REFERENCES

- Allison, J. Microbehavioral features of nutritive and nonnutritive drinking in rats. *Journal of Comparative and Physiological Psychology*, 1971, **76**, 408-417.
- Allison, J. Contrast, induction, facilitation, suppression, and conservation. *Journal of the Experimental Analysis of Behavior*, 1976, **25**, 185-198.
- Allison, J. and Timberlake, W. Instrumental and contingent saccharin licking in rats: Response deprivation and reinforcement. *Learning and Motivation*, 1974, **5**, 231-247.
- Baum, W. M. Time allocation and negative reinforcement. *Journal of the Experimental Analysis of Behavior*, 1973, **20**, 313-322.

- Baum, W. M. and Rachlin, H. C. Choice as time allocation. *Journal of the Experimental Analysis of Behavior*, 1969, **12**, 861-874.
- Eisenberger, R., Karpman, M., and Trattner, J. What is the necessary and sufficient condition for reinforcement in the contingency situation? *Journal of Experimental Psychology*, 1967, **74**, 342-350.
- Herrnstein, R. J. Relative and absolute strength of response as a function of frequency of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1961, **4**, 267-272.
- Herrnstein, R. J. Secondary reinforcement and rate of primary reinforcement. *Journal of the Experimental Analysis of Behavior*, 1964, **7**, 27-36.
- Herrnstein, R. J. On the law of effect. *Journal of the Experimental Analysis of Behavior*, 1970, **13**, 243-266.
- Mazur, J. The matching law and quantifications related to Premack's principle. *Journal of Experimental Psychology: Animal Behavior Processes*, 1975, **1**, 374-386.
- Miller, N. E. Learnable drives and rewards. In S. S. Stevens (Ed.), *Handbook of experimental psychology*. New York: Wiley, 1951. Pp. 435-472.
- Nevin, J. A. Response strength in multiple schedules. *Journal of the Experimental Analysis of Behavior*, 1974, **21**, 389-408.
- Premack, D. Toward empirical behavioral laws: I. Positive reinforcement. *Psychological Review*, 1959, **66**, 219-233.
- Premack, D. Reversibility of the reinforcement relation. *Science*, 1962, **136**, 255-257.
- Premack, D. Reinforcement theory. In D. Levine (Ed.), *Nebraska symposium on motivation*. Lincoln: University of Nebraska Press, 1965. Pp. 123-180.
- Premack, D. Catching up with common sense or two sides of a generalization: Reinforcement and punishment. In R. Glaser (Ed.), *The nature of reinforcement*. New York: Academic Press, 1971. Pp. 121-150.
- Schaeffer, R. W. and Premack, D. Licking rates in infant albino rats. *Science*, 1961, **134**, 1980-1981.
- Skinner, B. F. *Science and human behavior*. New York: Macmillan, 1953.
- Smith, K. The continuum of reinforcement and attenuation. *Behaviorism*, 1974, **2**, 124-145.
- Spence, K. W. *Behavior theory and conditioning*. New Haven: Yale University Press, 1956.
- Spencer, M. H. *Contemporary economics*. New York: Worth Publishers, Inc., 1971.
- Stellar, E. and Hill, J. H. The rat's rate of drinking as a function of water deprivation. *Journal of Comparative and Physiological Psychology*, 1952, **45**, 96-102.
- Timberlake, W. and Allison, J. Response deprivation: An empirical approach to instrumental performance. *Psychological Review*, 1974, **81**, 146-164.

Received 19 August 1976.

(Final Acceptance 3 September 1976.)