

Reversibility of reinforcement between eating and running by schedule changes: A comparison of hypotheses and models

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Rats increased eating that produced access to a running-wheel or increased running that produced access to food, depending on which response was potentially deprived, relative to baseline, by the scheduled ratio of responding. Under both schedules, instrumental responding significantly exceeded appropriate baselines of the noncontingent effects of the schedule. The results contradicted the hypothesis that reinforcement is produced by an overall or momentary probability differential between two responses; instead, they supported the condition of response deprivation as a key determinant of reinforcement. Of several recent quantitative models that predict reversibility of reinforcement by schedule changes, only the predictions of the relative response-deprivation model did not differ significantly from the data of either schedule.

The phenomenon of reversibility of reinforcement by schedule changes is important because it distinguishes between two recent approaches to the prediction of learned performance, the probability-differential hypothesis (Premack, 1959, 1965) and the response-deprivation hypothesis (Eisenberger, Karpman, & Trattner, 1967; Timberlake & Allison, 1974). The probability-differential hypothesis predicts reinforcement of one response by another only when the response of higher baseline probability is contingent on the response of lower baseline probability (Premack, 1965). The reinforcement relation can be reversed only if the relative baseline probabilities of the two responses are reversed.

In contrast, the response-deprivation hypothesis predicts reversibility of reinforcement by appropriate changes in the terms of a ratio schedule relating the two responses. No manipulation of baseline probabilities is necessary. The basis for this prediction is the assumption that the paired baseline levels of instrumental and contingent responding represent a preferred equilibrium state. A scheduled ratio of responding that differs from the baseline ratio challenges the baseline equilibrium and tends to increase instrumental behavior that produces access to the relatively deprived (contingent) response. By appropriate changes in the ratio schedule relating two responses, it is possible to produce relative deprivation of either response.

The essential components of this approach are illustrated in Figure 1 for the responses of wheel-

running and eating.¹ In a two-dimensional space in which each dimension corresponds to a response, the paired (operant) baseline levels of running and eating are represented by a single point (O_e, O_r). A fixed-ratio schedule in this space is a collection of points that fall on a straight line through the origin. The slope of the ratio line is determined by the relative amounts of the two responses specified by the schedule. The top diagonal line in Figure 1 represents a ratio schedule in which the ratio of the

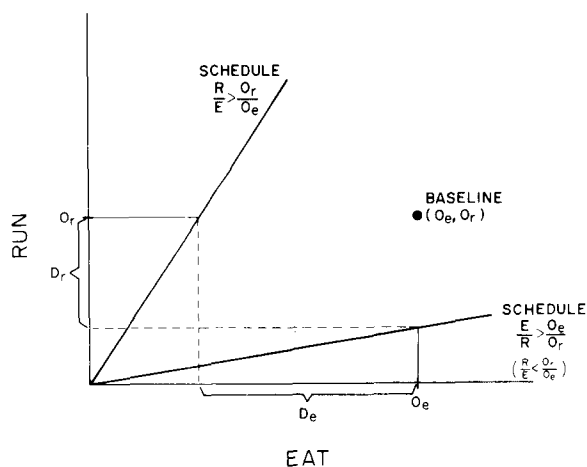


Figure 1. A two-dimensional representation of the paired baseline of eating and wheel-running, and two fixed-ratio schedules relating them. The thin horizontal and vertical lines intersecting the schedule lines show the paired operant level of the undeprived responses, while the dotted lines show the amount of eating or running earned by this operant level. D_r and D_e represent the amount of deprivation of the contingent response under the schedule if the instrumental response is performed only at its operant level.

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amount of running to eating is greater than their ratio in baseline. If the subject were to run at its baseline level (the thin horizontal line), it would be deprived of amount D_e of eating (the distance on the abscissa between the baseline level of eating and the amount of eating earned by the baseline level of running). To approach its baseline of eating, the subject must increase running above its baseline.

The lower diagonal line in Figure 1 represents a fixed-ratio schedule that produces response deprivation in the opposite direction; the ratio of the amount of eating to running is greater than the ratio in baseline (conversely, the ratio of running to eating is less than the baseline ratio). If the subject were to eat at baseline level (the thin vertical line), it would be deprived of amount D_r of running (shown on the ordinate). To approach baseline level of running, the animal must increase eating above its baseline.

Several researchers have shown apparent reversibility of reinforcement by schedule changes, either explicitly (Mazur, 1975; Timberlake & Allison, 1974) or by implication, through the demonstration that a low-probability response can reinforce a response of higher baseline probability (Allison & Timberlake, 1974; Eisenberger et al., 1967). However, it is difficult to interpret these results within a traditional learning framework because most experiments did not use baseline procedures suitable for distinguishing the contingent effects of the schedule from its potential noncontingent effects (Timberlake, 1979). Increased instrumental responding may have occurred because the schedule reduced contingent responding below its paired baseline level (Allison, 1976), thereby providing greater opportunity for expression of the instrumental response than existed in the paired baseline condition. Increased instrumental responding may also have been related to adjunctive behavior produced by intermittent presentation of access to the contingent response (Falk, 1971; Staddon, 1977).

The primary purpose of this experiment was to contrast the predictions of the response-deprivation and probability-differential hypotheses with respect to reversibility of reinforcement by schedule changes. Changes in responding were evaluated using appropriate noncontingent baseline procedures (Timberlake, 1979). The reversibility of eating and running should be a particularly good test of the response-deprivation hypothesis because eating seldom has been shown to function as an instrumental response (Premack, 1959). From the viewpoint of biological appropriateness (Seligman, 1970; Shettleworth, 1972), it would be predicted readily that the opportunity to eat will increase wheel-running, but not that the opportunity to run will increase eating.

A second purpose of this experiment was to determine how the concept of momentary probability-

differential (Premack, 1971) is related to reversibility of reinforcement by schedule changes. Premack (1971, Note 1) used the concept of momentary probability in at least two senses. In the first sense, the term calls attention to the potential difference between the average probabilities of two responses, computed over an entire baseline session, and their local probabilities, computed over a portion of the baseline session. For example, if two responses monotonically decreased in probability across a baseline session, but at different rates, first one and then the other might be the more probable (Premack, 1971). Given such a circumstance, one could presumably reverse the reinforcement relation by imposing a schedule during the earlier and later portions of the baseline session. However, differences in local relative probabilities will not explain how a response of lower average probability could reinforce a response of higher average probability over an entire session, or predict what schedule changes are necessary to reverse the reinforcement relation across the entire session.

The second interpretation of momentary probability (Premack, 1971, Note 1) refers to the changed local response probabilities produced by a schedule. For example, Mazur (1977) showed that reduction in access to a contingent response of either licking or wheel-running produced an increase in probability, relative to baseline, during the time it was available. This change in probability produced by the schedule appears potentially related to the molar concept of response deprivation. However, at present it is not clear how to integrate molecular changes in response probabilities with response deprivation, and how to use molecular changes to predict reversibility of reinforcement by schedule changes. Premack (Note 1) suggested that the deviation from baseline probability could be measured at any point in the contingency session by computing the amount of baseline responding not yet expressed. The prediction of reversibility by schedule changes follows because, for any schedule that satisfies the response-deprivation condition, the unexpressed baseline of the contingent response (no matter what its relative baseline probability) will at some point exceed the unexpressed baseline of the instrumental response. Prior to that point, the instrumental response should reinforce the contingent response. After that point, the direction of reinforcement should reverse. As long as the point of reversal in unexpressed baseline occurs less than half way through the session, the instrumental response, on the whole, should increase.

Allison and Timberlake (1974) and Timberlake and Allison (1974) criticized this last version of the momentary probability-differential hypothesis because it made incorrect predictions in the case of schedules in which the ratio of the schedule terms

equaled the ratio of the baselines. In this case, there is always a momentary probability differential in favor of the higher probability response, but no increase in instrumental responding occurs (Premack, 1965). In the present experiment, we test the hypothesis further. In the first test, we examined the location of the pause in responding on a reciprocal ratio schedule (Timberlake & Allison, 1974). Since the pause should occur following the reinforcer (Ferster & Skinner, 1957), it would be expected to occur following the higher probability instrumental response during the first part of the session, and following the lower probability contingent response after the shift in relative size of the unexpressed baselines. A second test was made by examining the correlation between the point at which the lower probability contingent response had the higher unexpressed baseline and the increase in the higher probability instrumental response. The earlier the shift in relative unexpressed baseline, the larger should be the increment in the instrumental response.

The last purpose of this experiment was to determine which of several recent quantitative models of

learned performance best fit the obtained results. The concept of response deprivation predicts the qualitative effect of reversibility of reinforcement by schedule changes, but does not predict the precise levels of responding under the schedule. Allison (1976), Luce (1959--see Timberlake, 1979), Mazur (1975), Staddon (1979), and Timberlake (Note 2) have proposed models that make the same qualitative prediction of reversibility by schedule changes, but differ in their quantitative predictions of responding and in their underlying assumptions.²

Table 1 displays, in a common notation system, the predictions of the different models for total instrumental responding in paired and single baselines, and expressions for the calculation of empirical constants. The last three models employ an empirical constant to fit the data, so they might be expected to enjoy an advantage in prediction. However, their dependence on the empirical constant also allows a more stringent test of these models by comparing the value of the constant for two different schedules. According to these models, the value should be invariant. Recent models proposed by

Table 1
The Expressions of Several Models for Calculating Total Instrumental Responding Under a Schedule and in Single Baseline, and the Empirical Constant Fitting the Prediction of the Model to Data

Model	Instrumental Responding	Single Baseline ^{a,d}	Empirical Constant ^b
Constant Relative Value (Luce, 1959; Timberlake, 1979)	$I \left(\frac{TO_i}{TI - IO_c + CO_i} \right)$	$\frac{TO_i}{T - O_c}$	
Value Averaging (Mazur, 1975)	$\frac{TI}{I + C} \left[\frac{IO_i + CO_c}{IO_i + CO_c + O_b(I + C)} \right]$	$\frac{TO_i}{T - O_c}$	
Conservation ^{c,d} (Allison, 1976)	$I \left(\frac{kO_i + O_c}{kI + C} \right)$	$\frac{kO_i + O_c}{k}$	$\frac{O_c - S_c}{S_i - O_i}$
Minimum Deviation ^c (Staddon, 1979)	$I \left(\frac{k^2 IO_i + CO_c}{k^2 I^2 + C^2} \right)$	O_i	$\frac{C(O_c - S_c)}{I(S_i - O_i)}$
Relative Response Deprivation (Timberlake, Note 2)	$\frac{k}{O_c} \left(O_c - \frac{O_i C}{I} \right) + O_i$	$k + O_i$	$IO_c \left(\frac{S_i - O_i}{IO_c - O_i C} \right)$

Where: I = instrumental requirement; C = contingent payoff; O_i = operant level of instrumental response in paired baseline; O_c = operant level of contingent response in paired baseline; O_b = operant level of background responses in paired baseline, (O_i + O_c + O_b = T); T = total time in session; k, k² = empirical constants; S_i = obtained instrumental responding under the schedule; and S_c = obtained contingent responding under the schedule.

^aActually, the predicted limit of instrumental responding as I approaches infinity.

^bThe empirical constants were calculated on the basis of the obtained rather than the predicted levels of responding.

^cFor the conservation and minimum deviation models, the empirical constant always modifies the same response measure. Thus, with the exception of the initial term in the first expression, I, which varies with the schedule, the remaining I and O_i terms refer to eating and C and O_c refer to running. This procedure is appropriate for conservation because the relative weighting of each response is determined by its fixed ability to express the dimension underlying responding. It is appropriate for minimum deviation, because the constant determines the unit size of one dimension of the space shown in Figure 1 relative to the other.

^dThe expression for calculating the single baseline of the conservation model changes as a function of which response is used as the instrumental response. The present expression predicts the single baseline of eating (see Note c); the single baseline of running should be predicted from the expression, kO_i + O_r.

Allison, Miller, and Wozny (1979), Rachlin and Burkhard (1978), and Staddon (1979) employ two or more empirical constants in fitting data. We did not include these models in our evaluation, because we felt that fitting two or three constants on the basis of only two schedules would not allow a reasonable test.

METHOD

Subjects

The subjects were nine female Wistar rats, approximately 90 days old at the beginning of the experiment. They were housed one per cage under a 12:12-h light-dark cycle, and were maintained at 90% of their ad-lib weights through reduced access to food. The rats were fed within 1½ h of being run in the light part of their day-night cycle.

Apparatus

The experimental apparatus consisted of four Acme running wheels, each mounted by the axle to an angle iron frame. A piece of Plexiglas mounted flush with the frame confined the animal to the wheel. As programmed, single 97-mg Noyes pellets were available in a small metal feeder (3.8 × 6.4 × 1.9 cm deep) mounted 5.1 cm above the center-bottom rim of the wheel. Access to the wheel was controlled by two solenoid-operated rim brakes. Food was delivered by a motor-operated feeder (Waltke Scientific Instruments). During the baseline determinations, a photocell recorded the presence of the pellet in a "V" carved in the brass bottom of the feeder. When the rat removed the pellet, another pellet automatically replaced it.

Each apparatus was contained in a large sound-attenuating chamber (Waltke Scientific Instruments) and illuminated by two 15-W bulbs. Masking noise was provided by a ventilating fan and white noise. The experiment was controlled by BRS solid-state programming equipment located a short distance away.

Procedure

Each subject received one 20-min session per day, 5 days a week. For each schedule (licking or running relatively deprived), each subject encountered at least 12 days of each of the following conditions: paired baseline, contingency, paired baseline, massed baseline, and matched baseline. In addition, a single baseline condition was run for 4 days just prior to each schedule. The subjects received each schedule and associated baselines in counterbalanced order. Only six subjects received all conditions in both types of schedule. The data for three additional subjects are also reported, two for the run-to-eat schedule and one for the eat-to-run schedule. Asymptotic performance under each schedule was defined as the mean of the last 4 days of responding, during which the average scores of the last 2 days did not differ significantly from those of the preceding 2 days.

During the *paired baseline*, the wheel was free and each pellet the animal ate was immediately and automatically replaced by another. Frequency and seconds of running and eating were measured. Seconds of running were cumulated when the animal turned the wheel at a rate \geq one-half turn each 1.5 sec. Seconds of eating were cumulated when the animal ate at a rate \geq one pellet every 12 sec.

The terms of the schedule in the *contingency* sessions were designed to reduce the frequency of the contingent response to one-third its baseline level if the subject performed the instrumental response at its baseline level. Further, each schedule was reciprocal (Allison, 1971), or, in Mazur's (1975) terms, interdependent. Only one response was available at a time, and it was necessary for the subject to complete the scheduled amount of each response before the next response was made available.

In the *massed baseline*, each subject received access to the same amount of the contingent response it had earned on the average over the last 4 days of the schedule, but in the absence of an instrumental requirement. To the subject, the massed baseline was identical to the paired baseline, except that once the subject exhausted its level of the contingent response earned under the schedule, access to the contingent response was removed. This baseline allowed an estimate of the effects of simple reduction in access to the contingent response on the amount of instrumental responding that occurred under the schedule.

In the *matched baseline*, each subject received access to the same number of presentations of the contingent response and in the same temporal locations in the session as on the last day of the contingency. Access to the contingent response was cumulated in that once presented, the contingent response remained available until the animal completed the allotted response time to that point in the session. The matched baseline allowed an estimate of the combined effects of intermittent access and reduction in access to the contingent response. The effects of intermittent access alone can be obtained by subtracting the massed baseline from the matched.

RESULTS

Reversibility of Reinforcement

Figure 2, based on the last 4 days of each condition, shows the mean amount of instrumental and contingent responding under each schedule, under preceding and following paired baselines, and under single, massed, and matched baselines. The top panel shows the results for run to eat (eating was the relatively deprived response), and the lower panel shows the results for eat to run (running was the relatively deprived response). Both schedules in-

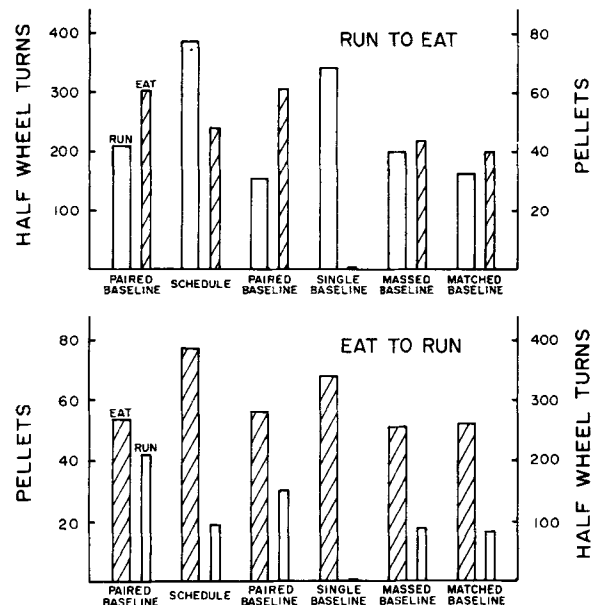


Figure 2. Frequency of eating and wheel-running under run-to-eat and eat-to-run schedules, preceding and following paired baselines, and single, massed, and matched baselines. The data are based on the last four (20-min) sessions of each condition.

creased instrumental responding and decreased contingent responding, relative to paired baseline. Comparison of the schedule results with average responding in the preceding and following paired baselines showed that both the increase and decrease were significant [for $E \rightarrow R$, $t_s(6) = 10.84$ and 10.87 , both $p_s < .001$; for $R \rightarrow E$, $t_s(7) = 7.91$ and 3.40 , $p < .001$ and $< .01$].

To determine if the increased instrumental responding could be attributed to the noncontingent effects of reduced competition and/or intermittent access to the contingent response, we compared instrumental responding under the schedule with that obtained under the massed and matched baselines. For both schedules, instrumental responding clearly exceeded both massed and matched baselines [for $E \rightarrow R$, $t_s(6) = 6.53$ and 4.94 ; for $R \rightarrow E$, $t_s(7) = 4.35$ and 4.54 , all $p_s < .001$]. Instrumental responding under both schedules also significantly exceeded the single baseline of the instrumental response [for $E \rightarrow R$, $t(6) = 7.82$, $p < .001$; for $R \rightarrow E$, $t(7) = 2.52$, $p < .05$]. It should be noted that the single baseline is not an appropriate basis for judging the contingent effect of a schedule on the amount of instrumental responding when high-probability responses are involved (Timberlake, 1979).

Two other effects are of interest. First, there was a tendency for running to decrease and eating to increase over successive paired baseline assessments. Since these trends were consistent whether running was the instrumental or the contingent response, they seemed to reflect a decrease in the general activity of albino rats as a function of age (Valle, 1971), rather than any systematic effect of schedule experience. Though the baseline trends do not alter the conclusions of this experiment, their presence places limits on the use of within-subject designs using wheel-running in rats.

Second, the average within-burst rates of running and eating (frequency/cumulated time) were approximately constant across baselines (all $t_s < 1$) and between baseline and most schedule rates (most $t_s < 1$). A systematic exception was the increase in average rate of contingent eating under the schedule [$t(7) = 3.01$, $p < .01$]. Two animals also showed a similar marked increase in rate of instrumental eating. Thus, in general, the duration data adequately mirrored the frequency data; but, in the case of eating, especially contingent eating, the duration measure underestimated the frequency of pellet ingestion relative to baseline.

The Momentary Probability-Differential Hypothesis

The momentary probability-differential hypothesis was tested in two ways. First, the point of reversal of the relative amounts of unexpressed baseline during the last schedule session was computed for each animal, and the location of the postreinforcement pause was examined. No consistent change in pattern of responding was observed to occur after points of

reversal ranging from one through seven repetitions of the instrumental-contingent sequence. However, an interesting phenomenon revealed by these data was that the pattern of behavior showed little variation within or between sessions, or across schedules. Regardless of which response was instrumental, a pause in responding reliably followed eating. Evidently, a constraint existed on the pattern of scheduled responding that did not interfere with the use of eating as an instrumental response, but did determine the location of pausing. Whether the same temporal pattern would occur under other types of schedule remains to be seen.

A second test of the momentary probability-differential hypothesis in the present data was made by reasoning that the longer the animal was exposed to a schedule in which the lower probability running response had the higher unexpressed baseline, the greater should be the increase in the higher probability eating response. This prediction was tested by computing a rank-order correlation between the asymptotic increase in instrumental responding and the average number of times the animal completed the schedule requirements before the unexpressed baseline of the contingent response exceeded the unexpressed baseline of the instrumental response. The correlation, which was expected to be negative, was not significant ($r = .12$).

Tests of Models

We tested two types of quantitative model, those with an empirical constant fit from the data (Allison, 1976; Staddon, 1979; Timberlake, Note 2) and those without such a constant (Luce, 1959—see Timberlake, 1979; Mazur, 1975). Predictions of instrumental responding under both schedule and single-baseline conditions were generated using the expressions found in Table 1. Though two of the models can be applied readily either to frequency or duration data, the remaining models can be tested only with durations. Therefore, to facilitate comparison among the models, the predictions were made in terms of durations of responding.

Predicted responding was obtained by computing separately the expected performance of each subject and averaging these values. To insure accuracy, the terms of the schedules were computed from the data. For models employing an empirical constant, the value of the constant was computed separately for each subject and each schedule. The two values of each subject were averaged, and the resultant value used to predict performance under each schedule. The data of only six subjects could be used in these tests, because computation of the constant required a value for each schedule and only six subjects completed both schedules.

Table 2 shows the obtained seconds of instrumental responding under both schedules, and the predictions of the different models. The models are ordered from

Table 2
Obtained and Predicted Seconds of Instrumental Responding for Different Models under Eat-to-Run and Run-to-Eat Schedules

Subject Number	Obtained	Relative Response Deprivation	Conservation	Minimum Deviation	Constant Relative Value	Value Averaging
Eat to Run						
4	762.5	855.6	565.2	527.2	585.7	546.0
8	881.5	840.8	649.7	624.1	673.5	607.6
10	780.2	811.3	606.7	474.2	639.0	511.6
11	617.0	597.6	560.0	469.0	460.3	430.6
16	668.2	593.7	574.4	368.9	401.0	349.9
17	649.0	697.5	640.9	627.3	666.0	591.6
Mean	726.4	732.8	599.2	515.1	570.9	511.3
t		-.25	3.56*	4.75**	3.99*	5.62**
Mean†		51.2	126.9	211.3	161.2	218.8
Run to Eat						
4	697.0	629.7	654.0	646.7	487.8	422.4
8	387.8	471.3	363.4	361.7	191.5	248.0
10	715.2	684.2	616.7	576.1	453.6	401.3
11	456.2	479.0	472.3	379.5	357.8	336.0
16	536.5	597.7	500.8	469.8	469.8	397.4
17	332.5	245.3	322.3	296.2	149.3	222.6
Mean	520.9	517.9	488.2	455.0	351.6	338.0
t		.10	2.08	3.99*	5.68**	5.10**
Mean†		58.8	37.8	65.9	169.2	182.9

* $p < .05$. ** $p < .01$. †Mean |observed - predicted|.

right to left in terms of mean difference between predictions and the data. Below each model is a t value comparing the data with the predictions. An index of variability of fit is provided by the mean absolute difference between the data and predictions for each subject. Only the predictions of the relative response-deprivation model did not differ significantly from the data for both schedules. The other models

underestimated the data, usually by large amounts. The conservation model did fit the run-to-eat data well, but not the eat-to-run data.

Table 3 shows the obtained seconds of instrumental responding under the single baseline, and the predictions of the different models. As shown in Table 1, the constant relative-value model (Luce, 1959) and the value averaging model (Mazur, 1975) are

Table 3
Obtained and Predicted Seconds of Instrumental Responding for Different Models in Single Baseline

Subject Number	Obtained	Value Models (Luce-Mazur)	Conservation	Minimum Deviation	Relative Response Deprivation
Eat					
4	631.0	614.2	583.2	524.8	988.0
8	847.0	761.9	700.6	609.8	1098.6
10	663.7	600.8	671.4	465.4	929.3
11	582.3	572.5	849.3	398.1	698.8
16	529.5	434.9	777.5	327.2	685.8
17	664.0	763.8	691.7	607.2	817.1
Mean	652.9	624.7	712.3	488.8	869.6
t		.96	-.88	5.89**	5.86**
Mean†		61.4	124.1	164.2	216.7
Run					
4	623.3	636.2	1775.6	390.6	853.8
8	338.3	256.7	1891.2	112.6	601.4
10	555.3	513.3	859.4	339.6	803.5
11	381.0	411.6	639.8	244.0	544.7
16	469.5	554.9	630.3	378.5	737.1
17	280.7	195.0	2088.3	83.0	292.9
Mean	441.4	428.0	1314.1	258.0	638.9
t		.48	2.95*	7.90**	4.92**
Mean†		56.0	872.8	183.3	197.6

* $p < .05$. ** $p < .01$. †Mean |observed - predicted|.

identical in their predictions for single baseline. In contrast to the results for scheduled responding, the value models provided the best fit to the obtained single baseline values, while the minimum deviation and relative response deprivation models did not fit the data well at all. The predictions of the conservation model did not differ significantly from the single baseline of eating, but the large mean absolute difference indicated that the fit between model and data was worse than that of the value models. The variability of the fit to single baseline responding by the value models appeared comparable to the fit of the relative response deprivation model to responding under the schedules.

The adequacy of the three models with constants fit from the data was further tested by comparing the constants computed under each schedule. If the models are accurate, the constants should not vary. In the case of the minimum deviation model, all six animals that received both schedules showed a larger constant for the run-to-eat schedule [$t(5) = 2.88, p < .05$]. In the case of the conservation model, five of the six animals showed the same result [$t(5) = 2.18, .10 > p > .05$]. The results are similar if the data of animals that completed only one of the schedules are also included, and the constants for the two schedules are compared in a between-subjects test [minimum deviation, $t(14) = 3.74$; conservation, $t(14) = 2.43$, both at least $p < .05$]. In other words, for both models the relative value of a unit of running to a unit of eating was higher when eating was the contingent response than when eating was the instrumental response. A similar comparison of constants for the relative response deprivation model showed no difference [$t(5) < 1, p > .10$].

DISCUSSION

The results of the present experiment argue that the condition of response deprivation, produced by a disparity between the schedule and baseline ratios of the instrumental and contingent responses, is a key determinant of changes in instrumental responding. The results contradict the probability-differential hypothesis of Premack (1965). Either of two responses reinforced the other depending only on changes in the terms of the fixed-ratio schedule relating them. The results also contradict the assumption that reinforcing and nonreinforcing events form discrete empirical classes (Meehl, 1950; Premack, 1965). By means of a simple change in a ratio schedule, a member of the class of reinforcing agents became a member of the class of nonreinforcers, and vice versa.

Furthermore, the major part of the obtained changes in instrumental responding must be attributed to the contingent effect of the schedule, rather than to noncontingent effects associated with

its imposition. By measuring massed and matched baselines of instrumental responding, we eliminated the possibility that the effects of the schedule were due primarily either to reduction in, or intermittent access to, the contingent response. These baselines may be of general use in separating the contingent and noncontingent effects of schedules that employ highly probable or substitutable responses (Timberlake, 1979).

It is tempting to interpret these data as minimizing the importance of biological constraints on reinforcement. That rats increased eating to obtain access to a running wheel is not readily predicted from an a priori analysis of preparedness (Seligman, 1970). However, the invariance in pattern of responding under the schedule supports the existence of a particular biological mechanism relating running and eating. Such a relation may be based on foraging patterns toward which rats are predisposed (Barnett et al., 1978), or on a physiological mechanism by which running and eating may both serve to regulate body temperature or level of circulating metabolites (Collier & Hirsch, 1971; Stevenson & Rixon, 1957). Last, that eating was maintained at a level closer to baseline than running suggests the existence of different underlying regulatory processes.

Momentary Probability-Differential

As attested by Dunham's (1977) recent article, the relation between changes in the molecular structure of responding and overall (molar) changes in response frequency or duration is of considerable current interest. The hypothesis of momentary probability-differential has been treated as a means of bridging the gap between molecular structure and molar responding (Premack, 1971; Terhune, 1978). However, Dunham (1977) noted that the concept of momentary probability is not well defined. The present paper pointed out two different definitions of momentary probability, as local baseline probability and as the change in local baseline probability produced by the constraints of a schedule. Only the probability change interpretation, based on unexpressed baseline, appeared to have any possibility of explaining reversibility of reinforcement by schedule changes. However, Allison and Timberlake (1974) and Timberlake and Allison (1974) noted problems with this version of the momentary probability-differential hypothesis, and the present data contradicted it further. It seems necessary to consider more carefully exactly what molecular elements of responding may account for the molar effects of schedules.

Quantitative Models

Among the models employing a fitted constant, only the predictions of the response-deprivation model did not differ significantly from the data

for both schedules. The constants calculated for the conservation and minimum deviation models differed significantly between the two schedules, thereby contradicting the assumption of invariance and producing a poorer average fit to the data. None of these models accurately predicted single baseline responding. This failure shows, at minimum, that the constant necessary to fit data varies between single baseline and schedule conditions.

The success of the relative response-deprivation model suggests that subjects monitor the potential reduction in contingent responding under a schedule, and relate this potential reduction to the size of the baseline of the contingent response. The larger that baseline, the less effect a potential reduction in the contingent response should have on instrumental responding. If this relative scale of measurement is useful in further quantitative tests, it may be possible to incorporate a similar factor into other models.

As expected, the value models (without fitted constants) fared less well in predicting responding under the schedules. Less expected was the good fit between the predictions of these models and responding in single baselines. Apparently, the value-averaging and constant relative-value models are more appropriate for estimating the single baseline of the instrumental response than its increase under a schedule. Such a conclusion is reasonable in the case of the constant relative-value model, because it was originally proposed to predict unconstrained choice among independent alternatives (Luce, 1959). In single baseline, removal of access to the contingent response does not constrain choice between the instrumental and background responses, or change their relative values. However, under a schedule, the imposed correlation between instrumental and contingent responding does constrain choice and most likely increases the value of the instrumental response relative to the value of the background responses. Failure to consider this increase in value may account for the marked underprediction of instrumental responding by the constant relative-value model.

The conclusion that value models are not appropriate for predicting schedule results is more controversial in the case of the value-averaging model, because it has been used primarily in this capacity (Mazur, 1975, 1977). However, in the present experiment, the value-averaging model underpredicted schedule responding by nearly 200 sec per animal, an average deviation that was considerably larger even than that for the constant relative-value model. A possible reason for this poor fit lies in the assumption of the value-averaging model that probability of the contingent response remains constant from baseline to schedule conditions (Mazur, 1977). Such an outcome seems unlikely in the case of many typical reinforcers, including eating.

In the absence of constant probability, a corrected baseline can be computed by measuring the probability of the contingent response during that portion of the baseline session occupied by the reduced amount of responding obtained under the schedule (Mazur, Note 3). To account for the present data with a corrected baseline, the baseline probabilities of eating and running had to decrease rapidly near the end of the baseline interval. Reduction in total contingent responding under the schedule would then produce a higher corrected baseline probability. However, inspection of the present data revealed no sharp drops in probability; in fact, the probability of running actually increased near the end of the baseline session. In only 2 of 12 instances did consideration of corrected baseline probabilities actually improve the accuracy of the value averaging model in fitting the present schedule data. Concern with the ability of the value-averaging model to predict schedule data has also been expressed by Allison, Miller, and Wozny (1979).

That the value models best fit the single baseline data and the other models best fit the schedule data suggests that different factors determine responding in baseline and schedule conditions. This argument is strikingly illustrated by the difference in instrumental responding between the schedule condition and the massed and matched baselines. The amount of contingent responding was similar in both cases, but the existence of a schedule relating the instrumental and contingent responses produced much greater instrumental responding under the schedule than in either baseline. A more general model of learned performance should be able to deal accurately with both the contingent and noncontingent effects of schedules. None of the present versions of these models appear to be adequate to the task.

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NOTES

1. This representation is based in part on the approaches of Rachlin and Burkhard (1978) and Staddon (1979). These authors differ from the present approach in that they explicitly consider a third class (dimension) of responding that fills out the time in the session. The present two-dimensional approach has the advantage that it can be readily applied to frequency data.

2. The *conservation model* (Allison, 1976) assumes that the subject maintains a constant weighted average of a common dimension underlying the instrumental and contingent response. The relative weights of the two responses are determined from the data. The *minimum deviation model* (Staddon, 1979) assumes that the subject minimizes the (weighted) deviation from the baseline point in the type of space shown in Figure 1. The scale of each axis is weighted to reflect the relative value of the two responses. This model was proposed in three dimensions, but we are testing it in only two. The *relative response-deprivation model* (Timberlake, Note 2) assumes that responding is related by a constant to the relative amount of response deprivation. Relative response deprivation is the amount of decrease in the contingent response if the subject were to perform its baseline level of the instrumental response, divided by the baseline level of the contingent response. The result is a form of Weber's fraction in which the greater the baseline of the contingent response, the greater the amount of potential deprivation of the contingent response necessary to produce a constant increment in the instrumental response. The *value-averaging model* (Mazur, 1975) assumes that the subject maintains a constant ratio of the weighted sum of the paired baseline levels of the instrumental and contingent response to the total background responding in baseline. The weights are determined by the relative size of the instrumental requirement and contingent pay off. The *constant relative-value model* (Luce, 1959; Timberlake, 1979) assumes that subjects maintain the proportion of instrumental to background responses from baseline to contingency.

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