

*IS THERE A DECISIVE TEST BETWEEN
MATCHING AND MAXIMIZING?*

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Reinforcers under typical concurrent variable-interval, variable-ratio schedules may be (a) earned and obtained during the variable-interval component, (b) earned and obtained during the variable-ratio component, or (c) earned during the variable-ratio component and obtained during the variable-interval component. Categories a and b, which have no bearing on matching versus maximizing accounts of choice, were set at zero. The rate of Category c reinforcers and the duration of a changeover delay were varied. Simple matching, which predicts exclusive choice of the variable-interval component, and strict maximizing of overall reinforcement rate, which predicts a bias towards the variable-ratio component, were both disconfirmed: Subjects spent approximately 25% of their time in the variable-ratio component, contrary to the matching prediction, but earned only about one third of the reinforcers predicted by strict maximizing. However, maximizing describes the findings functionally in terms of discounting of delayed reinforcers; matching may describe the data in terms of a restructuring of the alternatives. Matching and maximizing are not competing theories about the fundamental nature of choice, but compatible points of view that may reveal environmental function and behavioral structure.

Key words: matching, maximizing, choice, concurrent variable-interval variable-ratio schedules, economic psychology, pigeons

Recently, Heyman and Herrnstein (1986) reviewed and replicated experiments in which pigeons chose between concurrent variable-interval (VI) and variable-ratio (VR) reinforcement schedules. They claimed that these studies test decisively between matching and maximizing and prove that the matching law, not maximizing, is the correct description of choice behavior. The authors conclude: "The time has come to accept the data and move beyond them, to explore further the empirical and theoretical implications of the limited behavioral adaptation implicit in matching" (p. 347). We will argue that what we are in effect enjoined to do by Heyman and Herrnstein is to turn away from the traditional behavioral interest in function and to concentrate on behavioral structure. Before so drastically circumscribing our field of inquiry, it may be worthwhile to examine the grounds of the injunction.

With concurrent variable-interval or concurrent variable-ratio schedules (*conc VI VI* or *conc VR VR*) a subject that simply matches

relative rate of responding to relative rate of reinforcement also maximizes overall rate of reinforcement. With concurrent variable-interval variable-ratio schedules (*conc VI VR*), a subject whose responding is described by a generalized version of the matching law (Baum, 1974) may still maximize overall rate of reinforcement. But maximization on *conc VI VR* schedules occurs only with a strong bias towards the VR component (Rachlin, 1978). The evidence marshaled by Heyman and Herrnstein (1986) shows that animals exposed to *conc VI VR* schedules match relative rate of responding to relative rate of reinforcement but fail to exhibit any bias. That is, subjects in these studies match but apparently do not maximize. Therefore, VI VR behavior constitutes presumptive evidence for matching and against maximization as a behavioral description.

It is widely agreed that the essential difference between the interval and ratio components of *conc VI VR* schedules does not rest on the time-dependence of the former and the response-dependence of the latter; it rests, rather, on a distinction between "earning" and "obtaining" reinforcers. An "earned reinforcer" is made available by one contingency (the programmed VI or VR schedule) but not necessarily obtained when earned. Earned rein-

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forcers may be obtained only after an additional contingency has been satisfied.

With *conc* VI VR schedules, reinforcers programmed by the VI contingency are earned throughout the experimental session but obtained only by explicit choices of the VI component. Usually a VI timer operates throughout the session (in some experiments stopping and "setting up," in some, accumulating reinforcers). The earned reinforcer is then obtained by the subject when the VI component is chosen (in response-dependent procedures by a VI response, in time-dependent procedures by a changeover response to the VI component). On the other hand, reinforcers programmed by the VR contingency are earned and obtained only when the VR component is chosen. Both VI and VR reinforcers may be time dependent (DeCarlo, 1985) or both may be response dependent (Green, Rachlin, & Hanson, 1983). In either case, as long as the above relationship holds between earned and obtained reinforcers, a pair of concurrent schedules exemplifies the basic VI VR contingency.

Maximization of overall reinforcement rate with *conc* VI VR schedules requires a bias towards the VR schedule because of an asymmetry in the earning of reinforcers inherent in these concurrent schedules. When choosing the VI component, a subject earns and obtains only VI reinforcers. However, when choosing the VR component, the subject not only earns and obtains VR reinforcers but also earns VI reinforcers. VR choices, in this sense, are more efficient than VI choices. Therefore, to maximize overall rate of reinforcement, choices should be heavily biased towards the (more efficient) VR component. The subject should choose the VI component only occasionally so as to obtain any reinforcers that may have accumulated.

Heyman and Herrnstein (1986) refine this analysis still further. They note that the reinforcers obtained with *conc* VI VR schedules may be divided into three categories: (a) those earned and obtained by choosing the VI component; (b) those earned and obtained by choosing the VR component; and (c) those earned by choosing the VR component and obtained by choosing the VI component. If Categories a and b are made equal to each other, the basis for choice between the VI and VR components boils down to Category c, reinforcers the subject earns by choosing the

VR component and then obtains by changing over to the VI component.

The basic VI VR contingency with Categories a and b equal was studied in three conditions of the Heyman and Herrnstein (1986) experiment and in the present experiment. We will concentrate henceforth on these latter studies. In all of these studies, pigeons, by pecking a continuously available changeover key, alternated between VI and VR components signaled by differently colored cue lights. In the Heyman and Herrnstein experiment, Category a reinforcers were delivered at various times at a given rate during one signal, whereas Category b reinforcers were delivered at variable times at the same rate during the other signal. These two categories of reinforcers are completely irrelevant to either matching or maximizing accounts of choice. Henceforth, we will call these categories "background reinforcers." Considering only background reinforcers, any distribution of responding between the components results in matching, and all distributions of responding result in the same overall rate of reinforcement. This consideration greatly simplifies analysis of *conc* VI VR schedules; to explain any specific choice by either matching or maximizing principles, only Category c reinforcers (henceforth called "extra reinforcers") need be considered. Another experiment, by Vaughan, Kardish, and Wilson (1982), uses a similar procedure. In that experiment, however, background reinforcers programmed during each component were earned in both components (as with *conc* VI VI schedules). In the Heyman and Herrnstein experiment and the one reported here, background reinforcers of each component were earned only during that component (as with concurrent VR VR schedules).

Extra reinforcers are usually programmed by a timer that operates only during one component (the VR) but are obtainable only during the other component (the VI). To obtain any extra reinforcers at all, the subject must alternate between the two components, earning extra reinforcers in one and obtaining them in the other. To maximize the rate of extra reinforcers the subject must spend considerable time earning them in the VR component and somewhat less time obtaining them in the VI component. The matching law, however, makes a different prediction—that subjects will spend the whole session in the VI component, where extra reinforcers are initially obtained, thereby

losing them entirely. To understand why this is so, remember that, according to the matching law, animals always allocate their time proportionally to obtained reinforcers. Because no extra reinforcers are obtained in the VR component (and because background reinforcers must match any time allocation, even exclusive allocation) the matching law says that no time will be spent in the VR component. In two of three conditions studied by Heyman and Herrnstein (1986) in which background reinforcers were balanced (Conditions 2 and 6) matching was indeed found. In these conditions pigeons allocated almost all of their time to the VI component and consequently lost almost all extra reinforcers. This is the sort of loss to which Heyman and Herrnstein refer as "... the limited behavioral adaptation implicit in matching." This result is the core of the evidence behind their injunction to "accept the data. . . ." However, in a third condition, in which background reinforcers were also balanced (Condition 5), their pigeons spent an average of 25% of the session in the VR component, significantly deviating from matching and obtaining a considerable number of extra reinforcers. The difference between Conditions 2 and 6 and Condition 5 was that the former two conditions incorporated a changeover delay (COD) and the latter one did not. In Conditions 2 and 6, a 1.5-s delay was imposed between a changeover (from the VR to the VI component) and reinforcement. Thus, in these conditions, there was at least a 1.5-s interval between the earning and obtaining of an extra reinforcer. In the non-COD condition there was no minimum delay between earning and obtaining an extra reinforcer.

Because all extra reinforcers were earned in the VR component and obtained only after a changeover to the VI component, all extra reinforcers were obtained exactly 1.5 s after a changeover from the VR to the VI component in COD conditions, whereas in the non-COD condition all extra reinforcers were obtained immediately after a changeover. Because (by both matching and maximization principles) extra reinforcers were the only ones that could have influenced choice in this experiment, it is perhaps not surprising that the presence or absence of a COD had a strong effect on choice.

So far, the current analysis has closely followed that of Heyman and Herrnstein (1986). We part company, at this point, in our differing explanations of the effect of the COD.

How does the matching law explain the apparent failure of matching in the non-COD condition, and how does maximization theory explain the apparent failure of maximization in the COD condition? (We deal here only with this limited issue. Later we will discuss the more general issue of how the matching law explains the many apparent failures of matching and how maximization theory explains the many apparent failures of maximization.)

According to Heyman and Herrnstein, "... absence of the COD allows the two alternatives to lose their separate identities as response categories" (p. 339). This is an explanation in terms of structure. It says that without a COD animals restructure the ostensible components to form a single component. Matching then takes place with respect to the larger component as a whole vis-à-vis all other behavior and all other sources of reinforcement. The matching law may thus reveal how the animal structures its environment.

But a functional explanation of these data is also possible (and, we think, plausible). Because extra reinforcers are earned in one component and obtained in another, there must frequently be delays between the time they are earned and the time they are obtained. Delayed reinforcers are worth less than immediate reinforcers (like the background reinforcers that were obtained as soon as they were earned). If failure to maximize the overall rate of delayed reinforcers were evidence against maximization theory then our own earlier experiment (Rachlin & Green, 1972), in which pigeons chose immediate 2-s reinforcers over delayed 4-s reinforcers, would be evidence enough against maximization. But matching, maximization, and common sense all agree that delayed reinforcers are discounted relative to immediate ones and, evidence indicates, very sharply discounted (Green, Fisher, Perlow, & Sherman, 1981; Mazur, 1987).

With concurrent VI VR schedules, extra reinforcers are delayed relative to background reinforcers and, where there is a COD, still further delayed. Although extra reinforcers are worth less than background reinforcers, even with no COD, they are worth still less with a COD. The COD degrades the value of extra reinforcers. The less valuable these reinforcers are, the less meaningful is their loss. Thus, although Heyman and Herrnstein (1986) explain the failure of matching in their non-

COD condition in terms of a structural reorganization in which the absence of the COD causes the components to "lose their identities," a more functional view of their results would see the presence of the COD in COD conditions as causing extra reinforcers to lose their value relative to background reinforcers.

Without a COD pigeons fail to match and fail to maximize on *conc* VI VR schedules. Heyman and Herrnstein (1986) attribute failure to match to a restructuring based on confusion between the components. We agree with Heyman and Herrnstein that in this situation the VI and VR components are not independent. The relationship between them is that of a tandem schedule (a chain schedule in which completion of the initial-link requirement is unsigned) with reinforcers earned in the initial link and obtained in the terminal link. We disagree with Herrnstein and Heyman's contention that the behavioral dependence observed is due to a confusion between the well-signaled components. The pigeons fail to maximize, we believe, because they tend to move too soon from earlier to later links of the tandem schedule. In other words, failure to maximize occurs because of the pigeon's impulsiveness. This is the crux of the issue between matching and maximizing and the point addressed by the present experiment.

This experiment maintained the essential VI VR contingency of extra reinforcers but differed from that of Heyman and Herrnstein (1986) in two important respects. First, and most important, instead of merely balancing background reinforcers, we eliminated them entirely and thus isolated the extra reinforcers. Although a delay remained in our experiment between earning and obtaining extra reinforcers, there was no possibility of confusing the extra reinforcers with background reinforcers or of discounting their value relative to background reinforcers (because of differential delay or because of the decreased marginal utility of extra reinforcers). With the elimination of background reinforcers, reinforcers were obtained in only one component. The reinforcers themselves thus add, to the differently colored cue lights, a signal by which the components could be discriminated from one another. With the COD, this made it less likely for the components to "lose their separate identities as response categories." Retention of the essential feature of *conc* VI VR schedules (extra rein-

forcers) and elimination of extraneous features (background reinforcers) reduce the ability of either matching or maximizing theory to explain disconfirmatory data.

A second important difference between the present experiment and that of Heyman and Herrnstein (1986) was our use of a COD that varied within and (as a parameter) between conditions. The variable COD was introduced to avoid biasing the results against matching. Remember that the matching law predicts exclusive choice of the VI component. Eliminating background reinforcers ensures that reinforcement can only occur immediately after changeovers to the VI component. Thus the VI component cue light, after reinforcement, would be a clear discriminative stimulus for extinction (an S^A). Pigeons would soon learn to peck the changeover key to remove this stimulus, spending little or no time in the VI component; matching would thus be (less interestingly) disconfirmed. Inserting a fixed COD might not significantly alter this expectation; after changeovers from the VR to the VI component, pigeons would wait for the fixed COD time then change back to the VR component. The VI component signal, after the fixed COD time, would again be a discriminative stimulus for extinction.

To avoid this possibility we varied the COD time and also allowed earned reinforcers to accumulate during the VR component. If, for instance, two reinforcers had accumulated during the VR component and the pigeon then changed over to the VI component, the first reinforcer would be delivered at one interval by the variable COD timer, and the next only after another such interval had elapsed. To obtain the second reinforcer the pigeon did not have to switch back to the VR component. Thus, during the VI component, there was no discrete extinction signal (S^A), either extrinsic or temporal. Failure of the pigeons to spend almost all of the session in the VI component (failure to match) cannot be explained in terms of such a signal.

METHOD

Subjects

Three male White Carneau pigeons (20, 22, and 54) and one female (50), all of which had previous experience in operant experiments, served as subjects. All were maintained at be-

tween 80% and 85% of their caged free-feeding body weights. Grit and water were freely available in their home cages.

Apparatus

Subjects were studied in a one-key Coulbourn Instruments pigeon chamber contained within a light- and sound-attenuating box. The working space available to the subjects measured 25.5 by 28 by 30.5 cm. Illumination of the chamber was provided by either of two 7-W cue lights, one covered by a red plastic cap and the other by a green plastic cap. The red and green cue lights were located on the front panel 3.5 cm from the left and 3.5 cm from the right of center and 25 cm from the floor. A small fan provided ventilation and masked extraneous sounds.

The response key was centered on the front panel, 22 cm above the floor, and could be transilluminated with white light. The key was 2.54 cm in diameter and required a minimum force of 0.25 N to operate and produce a feedback click.

Access to the solenoid-driven food hopper was gained through an opening (5 by 5.5 cm) centered on the front panel and between the two colored cue lights; the center of the hopper opening was 5.25 cm above the floor. During food deliveries the hopper was illuminated by a 7-W white light; the light behind the response key was extinguished, but the cue light remained on.

All scheduling and data were controlled by solid-state programming equipment located in an adjacent room, and sessions were conducted daily.

Procedure

Each subject was studied daily for 1 hr (excluding reinforcement time) for an average of 33 days on each of 11 conditions. Each peck at the white key alternated between the cue lights that corresponded to the components in effect. On even-numbered days sessions began with the green component; on odd-numbered days they began with the red component.

During the red component, subjects earned food reinforcers programmed at variable times (VT) but did not obtain any of the earned reinforcers. During the green component, subjects obtained, one at a time, any reinforcers that had accumulated during the red component (but did not earn any reinforcers). Each

reinforcer consisted of 4-s access to mixed grains, and was obtained at variable intervals programmed by a second timer (COD VT) during the green component. The intervals programmed by both timers were distributed exponentially (Fleshler & Hoffman, 1962). During the red component, reinforcers were earned but not obtained, whereas during the green component reinforcers were obtained but not earned. The red (earn) component of this experiment (extra reinforcers only) corresponds to the VR component of ordinary VI VR schedules; the green (obtain) component corresponds to the VI component. Independent timers (VT and COD VT) controlled the rates at which reinforcers were earned and obtained, respectively. If either timer was interrupted in the middle of an interval by a changeover, it did not reset but completed the same interval when the subject changed back from the other component. Furthermore, all reinforcers earned during the red component remained in the accumulator to be obtained during the green component. No earned reinforcer was ever canceled except by the end of the session. Thus, any given overall allocation of time resulted in about the same overall rate of obtained reinforcement regardless of the pattern or number of changeovers. For example, an equal allocation of time to the two components could result in the same overall rate of reinforcement regardless of whether subjects changed over once from the red (earn) to the green (obtain) component in the middle of the session or 60 times, once per minute. (An exception to this rule would have occurred if a large block of time had been spent in the red (earn) component just as the session ended, canceling any obtained reinforcers. This, however, never occurred.)

Nine experimental conditions were studied. Three VT schedules were studied in the red (earn) component: VT 15 s, VT 30 s, and VT 60 s, each of which was combined with each of the three COD VT schedules in the green (obtain) component: COD VT 5 s, COD VT 15 s, and COD VT 30 s. All subjects were exposed to the nine experimental conditions for a minimum of 21 days each and until the proportion of time spent in each of the two components was stable for 5 days (did not vary by more than $\pm 5\%$ over the last 5 days). Each subject completed the nine conditions in a different order, as shown in Table 1. After the

Table 1
Order of experimental conditions.^a

Earn:	VT 15 s			VT 30 s			VT 60 s		
	COD VT			COD VT			COD VT		
	5 s	15 s	30 s	5 s	15 s	30 s	5 s	15 s	30 s
Bird 20	6	4	5	2	1	3	8	9	7
Bird 22	8	9	7	2	1	3	6	4	5
Bird 50	5	4	6	3	1	2	7	9	8
Bird 54	7	9	8	3	1	2	5	4	6

^a Average number of days per condition was 33. Control conditions VT 60 s and VT 180 s were all subjects' 10th and 11th conditions, respectively.

final experimental condition, all subjects were studied in two control conditions, both of which were simple VT schedules of reinforcement during the green (formerly the obtain) component; one was a VT 60-s, the other a VT 180-s schedule. Extinction was programmed during the other (red) component. These two schedules bracket the rates of reinforcement obtained in the experimental conditions. The purpose of the control conditions was to discover whether any time spent by subjects in the red (VR) component could be attributed solely to reinforcement obtained during the green (VI) component as opposed to the contingency by which reinforcement was earned and obtained during the experimental conditions.

Data recorded included pecks to the white response key (number of changeovers), time spent in the red (earn) component, time spent in the green (obtain) component, and the number of reinforcers obtained.

RESULTS

Figure 1 and Table 2 show the mean proportion of time spent in the red (VR) component for the last 5 days of each of the nine experimental conditions and the two control conditions. All subjects in all experimental conditions spent significant proportions of time in the red (VR) component relative to control conditions. According to the matching law, subjects should have spent all of their time in the green (VI) component (where reinforcers were obtained) until the rate of these reinforcers was reduced to zero. At that point matching does not make a prediction. Perhaps extinction might be expected to increase variability, resulting in an oscillation between random allocation and exclusive preference. Figure 2 shows session-by-session allocations for two VT earn conditions at two COD VT obtain values. Note that at no time does any function oscillate between extinction and random re-

Table 2
Summary of results: Average of all 4 birds for each condition.

Condition	Proportion of time spent in red (VR) component (average of 4 subjects)			Reinforcers per hour			Number of changeovers
	Obtained	Predicted		Obtained	Predicted		
		Match	Max		Match	Max	
VT 15 COD VT 5	.28	0	.75	64.0	0	180	344
VT 15 COD VT 15	.23	0	.50	51.8	0	120	274
VT 15 COD VT 30	.17	0	.33	38.0	0	80	228
VT 30 COD VT 5	.36	0	.86	40.7	0	103	439
VT 30 COD VT 15	.22	0	.67	25.1	0	80	301
VT 30 COD VT 30	.20	0	.50	21.9	0	60	241
VT 60 COD VT 5	.31	0	.92	18.0	0	55	374
VT 60 COD VT 15	.26	0	.80	15.3	0	48	400
VT 60 COD VT 30	.22	0	.67	13.3	0	40	296
Control VT 60	.01	0	0	56.1	60	60	19
Control VT 180	.02	0	0	20.0	20	20	17

sponding. Of course, these data do not preclude the possibility of within-session oscillation.

The explanation offered previously by Heyman and Herrnstein (1986) for disconfirmatory results—restructuring of components—should explain why the degree of deviation from matching varied continuously in this experiment with the size of the COD. This continuity could be explained in terms of a partial restructuring or restructuring by degree. We leave it to others to develop in detail the dynamics of such a process and turn instead to a functional explanation of our results.

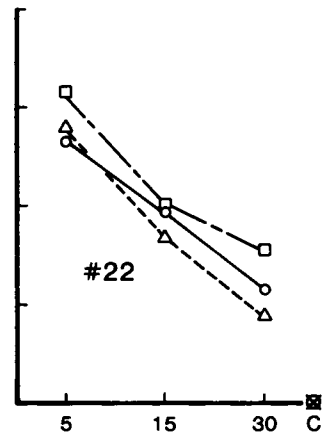
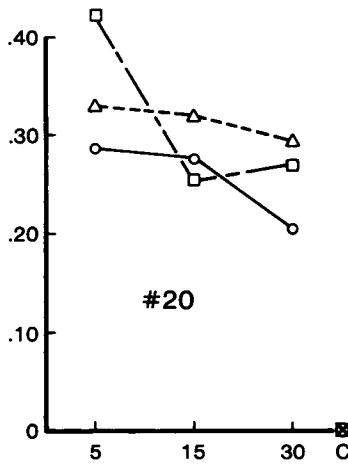
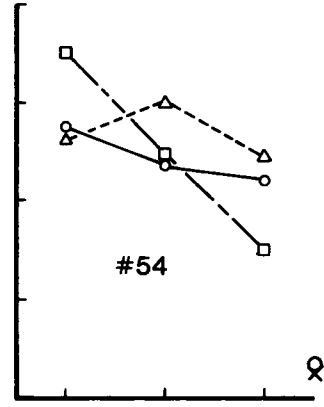
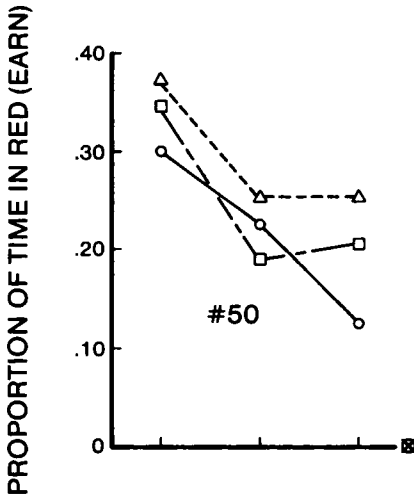
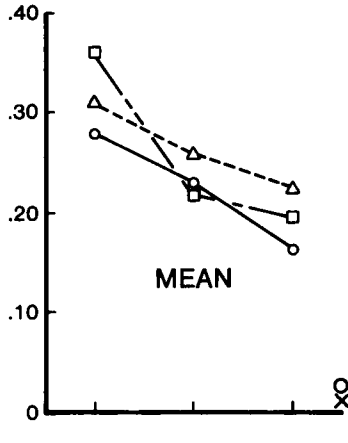
The maximum possible rate of reinforcement for each condition is the inverse of the sum of the VT and COD VT. For the condition in the top row of Table 2 (VT 15, COD VT 5), the maximum rate of reinforcement is 3,600 (seconds per hour)/(15 seconds plus 5 seconds), or 180 reinforcers per hour. Corresponding values are shown for each condition in the penultimate column of Table 2. Because neither timer was reset after a changeover, the maximum reinforcement rate could be approached by an allocation of time to the two components proportional to the interval programmed in each (inversely proportional to programmed rate). For the first condition the proportion of time in the VR component that would maximize overall reinforcement rate is $15/(15 + 5)$ or .75. Corresponding proportions are shown for each condition in Table 2. For a given VT schedule, the greater the COD VT, the lower this optimum proportion is. As shown in Table 2 and Figure 1, the obtained proportions of time spent in the red (VR) component decrease in corresponding fashion as maximization predicts. However, those proportions are much lower than the predicted proportions, resulting in a large loss of obtained reinforcers.

The data in Table 2 indicate that the maximum obtainable number of reinforcers was always far above the actual obtained. The pigeons lost between one half and two thirds of the extra reinforcers by spending too much time in the VI component. Here, with background reinforcers removed, the reason for failure to maximize overall rate of reinforcement becomes clear. Like animals that respond too soon on differential-reinforcement-of-low-rate (DRL) schedules (and like people who cash in their savings bonds before they mature) our pigeons moved from an earlier link to a

later link in a tandem contingency before the point in time at which overall reinforcement would have been maximized. By changing over too soon from the red (VR; earn) to the green (VI; obtain) component, our subjects decreased overall rate of reinforcement but they also increased the probability of immediate reinforcement from zero to a finite fraction. Given a steep discount function relating value to delay, the pigeons in this experiment maximized present value.

In other words, the pigeons changed over too soon because of a "temptation," a relatively immediate reinforcer available at the cost of a decrease in overall rate of reinforcement. The greater the temptation, the more deviation from optimal behavior should be expected. In the present case, the shorter the COD (the more immediate the reinforcer after a changeover) the greater the temptation should be and the more deviation from optimal behavior should be expected. Table 2 reveals this expected deviation. For the first condition (VT 15 and COD VT 5), the average difference between optimal and obtained proportion of time in the VR component was $(.75 - .28) = .47$. When the COD was raised to 15 s (second condition) the average difference fell to $(.50 - .23) = .27$. When the COD was raised again to 30 s (third condition) the average difference fell again to $(.33 - .17) = .16$. Corresponding approaches to optimal proportions were obtained for the VT 30 conditions (.50 to .45 to .30) and VT 60 conditions (.61 to .54 to .45). These approaches to maximization were reflected in decreases in the number of reinforcers lost, as shown in Table 2. Thus, although the pigeons in this experiment behaved "impulsively" under all conditions (and thereby reduced overall reinforcement rate) they were somewhat less impulsive when the COD was longer.

Finally, Figure 1 shows that systematic changes in proportion of time spent in the components were due to changes of the COD and not to changes of the VT schedule. Reinforcement rate with the present procedure is almost entirely a function of the *relative* durations allocated to the two components. It is not clear why all the variation in relative duration was due to the COD and none of it to the VT. A more molecular model might explain why the point at which subjects switched *into* the obtain component and the point at which they



COD VT

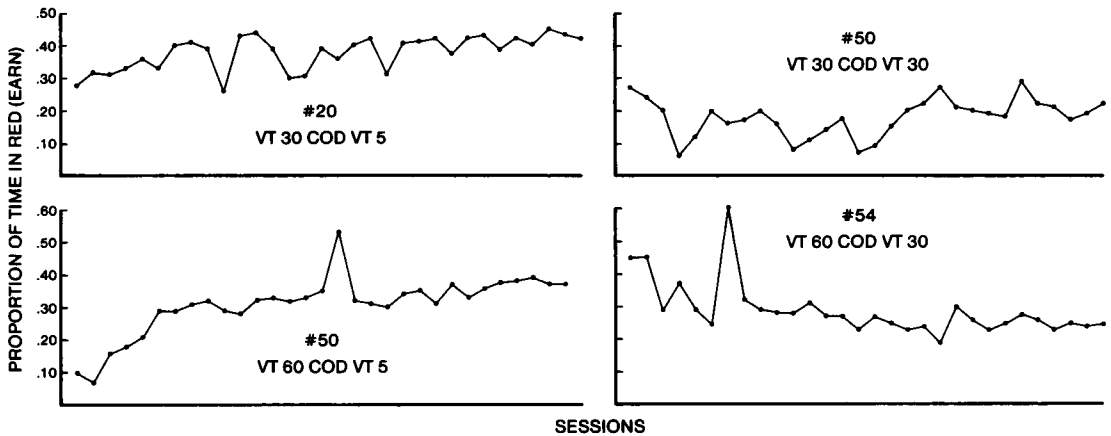


Fig. 2. Daily proportions of time spent in the red (earn) component for four experimental conditions.

switched out of the obtain component both depended on parameters of the obtain component and not on parameters of the earn component.

Melioration (Herrnstein, 1982), a molecular theory underlying matching, states that animals switch between components when the local reinforcement rate in the component switched into rises above that in the component switched out of. But the local reinforcement rate in the earn component was always zero in this experiment. Thus, additional assumptions are required for melioration to explain why subjects should ever voluntarily switch into it.

A molecular explanation, consistent with maximization of present value, would rely on the fact that (despite constant moment-to-moment reinforcement probability), as more and more time was spent in the obtain component without reinforcement, the overall probability increased that no reinforcer had been earned and therefore that no reinforcer would be obtained. If, as suggested by Rachlin, Logue, Gibbon, and Frankel (1986), probabilities act subjectively as delays, the expected delay to reinforcement would become larger and larger (approaching infinity) the longer the subject remained in the obtain component without re-

inforcement. At some point, the expected delay to reinforcement contingent on switching out of the obtain component (and then switching back in) would be less than the expected delay contingent on remaining in the obtain component. That point, at which the subject would switch back into the earn component, would depend strongly on the COD and only weakly on the VT (because switching back to the earn component would entail a relatively long delay anyway). This explanation implies that although the VT had no effect in the present experiment, it would have had an effect if it were varied over a wider range, especially if it were made small. Note that in this experiment the COD varied over a range of 6:1 with a minimum of 5 s, whereas the VT varied over a range of only 4:1 with a minimum of 15 s. Had these ranges and minima been reversed, the VT might have affected behavior.

DISCUSSION

It may be claimed that, for some reason, eliminating background reinforcers is not a true test of matching. Why, it may be asked, when background reinforcers are present, do

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 Fig. 1. Mean proportion of time spent in the red (earn; VR) component for each subject. The average of the 4 subjects is also presented. The parameter is the VT schedule governing the rate at which reinforcers were earned in the red (VR) component (VT 15 s, VT 30 s, and VT 60 s). Along the abscissa are the COD VT values governing the rate at which earned reinforcers could be obtained during the green (VI) component (5 s, 15 s, and 30 s). To the right (C) are the results from the VT60-s (X) and VT 180-s (open circles) control conditions in which reinforcers were earned and obtained in the green component.

the data from *conc VI VR* schedules better fit the matching law? In answer to this we point out that both relative rate of response and relative rate of obtained reinforcement are dependent variables and, with *conc VI VR* schedules, quite interdependent. As Heyman and Herrnstein (1986) themselves admit, there is a wide range of behavioral allocations that result in matching. The more background reinforcers, and the fewer extra reinforcers obtained, the wider this range becomes. Those allocations that maximize delay-discounted reinforcement are evidently within that range.

Given a definable behavioral situation, it is impossible for every aspect of behavior to match every aspect of the environment—some aspects will vary in opposite ways. The matching law may be used to discover those aspects of behavior and the environment and their mathematical transformations that do indeed match each other. The matching law has succeeded in many situations because the aspects of the environment and behavior that do match each other are obvious reinforcers and choices. However, as the matching law comes to be applied in situations further removed from its original empirical sphere, the reinforcers and choices that are matched become less and less obvious. In those situations, matching may simply be assumed (Rachlin, 1971) and then used to reveal occult reinforcers or occult choices. In experiments in which choices are clear and obvious, the matching law could be used to reveal occult reinforcers. However, this tactic has not been successful. For instance, with standard concurrent schedules of food versus water reinforcement, animals' choices are *inversely* proportional to reinforcement rate—exactly opposite to what matching predicts (Hursh, 1978; Rachlin, Green, Kagel, & Battalio, 1976). These findings (which seem important because real-world choices are often between qualitatively different reinforcers) remain unexplained by the matching law, yet explicable by maximization.

Matching has been more successful in explaining results of experiments in which reinforcers are clear and obvious. For instance, the experiment of Green *et al.* (1983), which studied response-based *conc VI VR* schedules, failed to find matching between pecks on two differently colored keys and rates of reinforcement contingent on those pecks. Heyman and Herrnstein (1986) explain those results in

terms of the “learning of a new response class.” Herrnstein (1982) has argued that “melioration” (a molecular process said to underlie matching) can explain the learning of new response classes. Thus, the matching law, as a method of analysis of complex choice situations, may reveal complexities of behavioral structure. The results of the present experiment undoubtedly may be explained in structural terms. Even though we make no such attempt here, we do not deny that application of matching (or melioration) to our results might reveal interesting aspects of how pigeons organize their behavior.

An exactly analogous argument may be made about maximization theory. It is impossible for all aspects of behavior to vary so as to maximize all aspects of the environment. However, there will always be some aspect of behavior (or mathematical transformation thereof) that maximizes some aspect of the environment (or mathematical transformation thereof). Like matching, maximizing may be used to discover behavioral structure when function is clear or function when structure is clear. But just as matching mostly has been used to discover structure, maximizing has been used (and we believe to much better effect) to discover function. In economics, maximization theory has derived social values from economic behavior (Becker, 1976). We have used maximization principles to help understand value systems of children playing with toys (Rachlin & Burkhard, 1978), rats choosing among different foods and liquids (Rachlin *et al.*, 1976), and how humans and other animals value leisure versus income (Green, Kagel, & Battalio, 1982). At one point we believed that choice in *conc VI VR* schedules could be explained completely in terms of a trade-off between food and leisure (Green *et al.*, 1983). However, the current explanation, in terms of time discounting, embraces more of the facts. We harbor no illusion that it is the final explanation.

The fact that matching and maximizing, each in its own terms, may be modified to explain virtually any set of choice data, even apparently contradictory data, precludes a decisive test between the two principles. The time has come, therefore, to recognize that neither is a fundamental law of human nature and to view both principles for what they are—useful tools by which the structure and function of behavior may be examined.

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