HUMAN CHOICE IN CONCURRENT RATIO-INTERVAL SCHEDULES OF REINFORCEMENT

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Seven undergraduates participated in a concurrent-choice experiment with monetary reinforcers. Response-independent analogues of variable-interval and variable-ratio schedules were used to assess whether subjects would maximize reinforcement rate. The optimal pattern of behavior, in terms of maximizing reinforcement rate, involved a large bias toward the ratio alternative, with only occasional sampling of the interval schedule. Most experiments with pigeons, however, demonstrate matching of response rates to reinforcement rates, with only slight biases for the ratio schedule. Although subjects in the present experiment allocated more time to the ratio alternative than required by matching, the magnitude of the bias did not approximate that predicted by a maximizing account. After exposure to clock stimuli correlated with the operation of each schedule, 1 subject's behavior did show a substantial level of bias, increasing the total number of reinforcers obtained, and lay at a point between the predictions of matching and maximizing. The other subjects, however, continued to respond less optimally. The present results can be accounted for by a view of matching that incorporates the effects of delayed reinforcement.

Key words: matching, maximizing, concurrent ratio-interval schedules, choice, time allocation, humans

Studies of concurrent choice implicate the matching law as an effective description of behavioral allocation (Herrnstein, 1970). With humans, pigeons, and other species as subjects, data from studies using concurrent-interval schedules show that a subject's ratio of behavior matches the ratio of reinforcement obtained from each alternative (see Davison & McCarthy, 1988, and Williams, 1988, for reviews). Baum (1974) proposed the following equation as a generalized form of the matching law:

$$B_1/B_2 = b(R_1/R_2)^a, \quad (1)$$

where B_1 and B_2 represent the amounts of behavior (in number of responses or time allocated) to each concurrent schedule, and R_1 and R_2 represent the corresponding rates of reinforcement. Parameters a and b are estimated from the data and distinguish between two types of deviation from perfect matching (i.e., when $a = 1$ and $b = 1$). The a parameter

measures sensitivity to varying schedules of reinforcement. Values of a less than 1.0 represent instances of undermatching when the ratio of behavior fails to increase at a rate equal to the ratio of reinforcement. Poor discrimination between alternatives produces undermatching (Baum, 1974). For example, a choice procedure that does not include a changeover delay (COD) to discourage reinforcement of switching between responses tends to result in frequent alternation between the alternatives and, consequently, undermatching. A brief COD (typically 1 to 3 s) decreases the degree of undermatching by extinguishing changeover responses, thus making the reinforcement schedules independent and more discriminable.

The b parameter is a measure of remaining bias toward one of the alternatives when the schedule values are equal in explicitly controlled reinforcement. As typically viewed, the matching relation predicts no bias ($b = 1$) when reward value and response efforts are equated. Thus, any deviation of b from 1.0 results in preference that is unaccounted for.

According to one view (e.g., Green, Rachlin, & Hanson, 1983; Silberberg, Thomas, & Berendzen, 1991), matching occurs because it is the pattern of behavior that maximizes overall rate of reinforcement. Organisms maximize net gain (reward minus response cost) by integrating reinforcement rates from all sources in a situation (Green et al., 1983). According to

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this view, matching is simply the molar by-product of a maximization strategy. Baum's (1981) schedule-feedback analysis of performance on concurrent-interval schedules shows that matching is the optimal pattern of behavior. However, Baum's analysis requires several untested assumptions about responding on interval schedules. Williams (1988) notes that in most concurrent-interval situations, subjects can greatly deviate from matching without losing more than one reinforcer per hour. Thus, to account for matching, a maximizing account must assume that a subject is extremely sensitive to small differences in obtained reinforcement rate. Furthermore, several studies have shown that subjects are insensitive to schedule-feedback functions (e.g., Vaughan & Miller, 1984), thus rejecting the premise on which maximizing rests. Regardless, concurrent-interval schedules do not separate the predictions of maximizing and matching and, therefore, do not provide a clear test of the maximizing hypothesis.

Evidence from other paradigms suggests that matching behavior often persists at the expense of reinforcement (Herrnstein, 1990). For example, concurrent ratio-interval schedules have been used to separate the predictions of matching and maximizing (e.g., DeCarlo, 1985; Heyman & Herrnstein, 1986). In this situation, matching does not maximize reinforcement. An interval schedule elapses with time, whereas the ratio schedule advances only when the subject responds to it. Thus, a subject may gain reinforcement by allocating most of its time to the ratio schedule, while the interval schedule times down independently. Ideally, the subject should only occasionally sample the interval schedule to obtain any reinforcers that might have been earned. Thus, a maximizing strategy requires a consistent preference for the ratio alternative that is not predicted by matching.

Baum (1981) offered the following quantitative prediction of such optimal behavioral allocation in concurrent ratio-interval situations:

$$B_{VR}/B_{VI} = n^{0.5}(R_{VR}/R_{VI})^a, \quad (2)$$

where n replaces b of Equation 1 as the bias term and equals the square root of the scheduled ratio value. Terms R_{VR} and R_{VI} represent the rates of reinforcement for responding on

variable-ratio (VR) and variable-interval (VI) schedules, respectively. Here, a maximizing strategy requires a bias toward the ratio alternative. As long as the ratio requirement remains constant, bias for the ratio alternative should not change when varying the interval schedule requirement. Equation 2, however, does require increased bias for the ratio schedule (as well as undermatching) as the ratio requirement is increased in successive conditions (Baum, 1981).

Several experiments with rats and pigeons have used concurrent VI VR schedules or their response- or time-dependent analogues (see Vyse & Belke, 1992, for a review). Results are more consistent with the matching law than with maximizing (DeCarlo, 1985; Herrnstein & Heyman, 1979; Heyman & Herrnstein, 1986; Vyse & Belke, 1992; Williams, 1985, 1992). That is, data lie closer to the matching predictions of no bias ($b = 1$) and a constant slope ($a = 1$) in Equation 1 as schedule values vary. The pertinent studies are discussed below.

Silberberg et al. (1991) conducted the only previous study of human choice in concurrent ratio-interval schedules. They reported that subjects maximized by showing preference (in relative response rate) for a VR over a VI alternative, an outcome not obviously predicted by matching. However, the ratio preference was shown only in subjects who received prior discrimination training with each of the component schedules. Discrimination training consisted either of presentations of a multiple VI VR schedule or sessions in which each of the schedules was presented independently on alternate days. Subjects not exposed to a discrimination procedure prior to choice matched relative response rates to relative reinforcement rates. The discrimination training distinguishes this experiment from those in the literature on nonhumans. Pigeons might also prefer the ratio alternative given this training. Second, as Heyman and Herrnstein (1986) noted, relative response rate may not be an adequate measure of preference because ratio schedules evoke higher local response rates than interval schedules do. Essentially, new response units may have developed to the ratio schedule (Schwartz, 1981), thus producing a response bias for that alternative.

Finally, in defining maximization ordinally,

Silberberg et al. (1991) did not report bias parameter values. Thus, the magnitude of the observed bias and whether subjects did in fact maximize obtained reinforcement are unknown. The authors concluded that there is a phyletic difference between humans and non-humans in performance on concurrent ratio-interval schedules. Perhaps humans maximize reinforcement, whereas pigeons match in ratio-interval situations. For these reasons, human choice in concurrent ratio-interval schedules warrants further investigation.

One purpose of the present experiment was to extend the meager data base of human performance on concurrent ratio-interval schedules. The procedure employed Heyman and Herrnstein's (1986) response-independent VR VI analogue schedules. These variable-time (VT) variable-ratio-time (VRT) schedules provide reinforcement contingent on time allocation, not responding. Subjects simply choose between allocating time to each of the alternatives. Thus, concurrent VT VRT improves upon standard concurrent VR VI by equating response cost for both alternatives and by providing a less contestable time-allocation measure. However, the schedules retain the essential feature of concurrent ratio-interval schedules; namely, both schedules operate when the subject chooses the VRT schedule, but only the VT operates when the subject chooses the VT schedule. In order to maximize, Heyman and Herrnstein's (1986) pigeons should have spent most of their time on the VRT schedule, but they did not. Choice conformed to matching, although matching led to lower overall reinforcement rates. The present study assessed whether human subjects also behave nonoptimally in a comparable procedure.

Second, the present study investigated stimulus conditions under which humans may respond optimally. When a subject has been in the presence of the ratio schedule for only a brief time, switching to the interval schedule yields a low probability of reinforcement. As time progresses, the probability of reinforcement improves. Perhaps enhancing the salience of this feature of ratio-interval schedules would improve performance. A visible indication of an elapsing interval schedule might cue the subject to this contingency and increase the amount of time allocated to the ratio schedule, thus leading to more optimal behavior.

The specific manipulation consisted of the presentation of two visible running-time meters correlated with the operation of the respective schedule components. Thus, when a subject chose the VRT, both the VRT timer and the VT timer operated. Alternately, when the VT schedule was chosen, only the VT timer operated. If this cue shifts choice in the direction of maximizing, it will suggest that the presence of adequate discriminative stimuli correlated with the effective contingencies may be necessary for the occurrence of optimal behavior.

METHOD

Subjects

Seven undergraduates (4 female, 3 male) served. Posted fliers offered two research-credit hours and 13.5 paid hours in exchange for participation in a human choice experiment. Payment consisted of monetary reward. Each point earned in the task was worth 5 cents. Subjects, either 1st- or 2nd-year students, agreed to 31 half-hour sessions, each conducted on a different weekday. S5 did not return after Session 9 and could not be reached later for payment or debriefing. Her data are not included.

Apparatus

Sessions were conducted in a small, isolated room. A desk and chair faced a wall. The only door opened from the wall on the right and contained a small observation window. Fluorescent lights provided overhead lighting. An intelligence panel was placed on the desk throughout the experiment. Three 28-V light bulbs with colored covers centered on the panel signaled reinforcers (green, center) and whether a subject was in the presence of the VT schedule (right) or the VRT schedule (left). A SO-DECO counter (Type TCeBZ4E) displayed the cumulative reinforcers. A changeover (CO) button was attached to the control panel by a cable that could be moved around by the subject. Two running-time meters (Automatic Timing and Controls, Inc., 120-60) were placed on top of the control panel during time-cue conditions. Aside from these items and a wall clock, no other equipment or furniture remained inside the room. An adjacent room

Table 1

Conditions, schedule values, and results by subject. Time allocated, reinforcers obtained from each schedule, and number of changeovers (CO) represent means of the last three sessions in each condition.

Subject	Condition	Schedules		Time (s)		Reinforcers		CO
		VT	VRT	VT	VRT	VT	VRT	
S1	No cue	30	30	610	377	36	12	1,595
		30	60	785	180	43	3	1,727
	Time cue	30	30	605	566	37	22	1,233
		30	60	762	527	41	6	770
		60	30	754	626	24	19	663
S2	No cue	30	60	1,012	615	41	10	77
		60	30	720	934	21	31	53
	Time cue	30	30	831	798	36	25	59
		30	60	879	744	43	13	38
		60	30	800	862	21	29	68
S3	No cue	30	30	792	846	33	23	243
		60	30	747	851	23	32	66
	Time cue	30	30	780	780	47	22	346
		30	60	881	664	47	7	127
		60	30	390	1,267	12	39	354
S4	No cue	30	30	718	922	26	30	26
		60	30	414	1,256	10	39	32
	Time cue	30	30	761	867	33	31	38
		30	60	914	693	42	8	130
		60	30	643	1,012	18	34	52
S6	No cue	30	60	757	832	41	13	111
		60	30	650	965	23	32	165
	Time cue	30	30	778	795	44	24	142
		30	60	826	761	44	11	154
		60	30	778	848	25	26	139
S7	No cue	30	30	739	872	34	31	53
		30	60	1,167	455	46	8	49
	Time cue	30	30	608	1,018	29	29	55
		30	60	511	1,149	28	18	53
		60	30	163	1,487	14	45	61

contained a DATEL 286 computer and customized digital interfacing that were used to control experimental events and collect data.

Procedure

The study consisted of five conditions in a within-subject design. Three concurrent-schedule values were used: VT 30 s, VRT 30 s; VT 30 s, VRT 60 s; and VT 60 s, VRT 30 s. Two stimulus conditions included "no-cue" and "time-cue" conditions. Each condition consisted of five sessions. Although no stability criterion was set, performance in the last three sessions was judged to be visually stable on 26 of 30 conditions. Table 1 lists the conditions presented to each subject.

Prior to these sessions, each subject had two baseline sessions with each of the three schedule pairs and without time cues. Because behavior was not sufficiently stable during baseline, these data are not reported. No-cue

conditions lasted 10 sessions, five with each of two of the three schedule values.

Timer cues. This phase of the experiment consisted of 15 sessions (five with each of the three schedule pairs) in which timer cues were provided. Two running-time meters faced the subject. One timer was associated with the VT schedule and operated in the presence of either (VT or VRT) light. The other timer operated only when the VRT light was on; thus, it signaled the operation of the VRT schedule. Neither timer operated during reinforcement. The order of schedule values and the color light associated with each schedule were counter-balanced, but for technical and practical reasons, order of stimulus conditions was not. Possibly, timer stimuli could have been more salient to subjects and thus more effective in controlling behavior if they had been presented near the beginning of the experiment rather than near the end.

Each session began when both red and white lights on the control panel were illuminated. The subject's first CO press began the session timer and randomly selected either the VT or VRT light to remain illuminated while the other light was turned off. Each subsequent CO press turned off the light previously illuminated while the other light was turned on. In addition, each CO press began a 3-s COD, during which no reinforcers were delivered. The lights signaled which reinforcement contingency was in effect. In the presence of the VT light, only the VT schedule elapsed. Any point earned during this time was delivered immediately. Conversely, when the VRT light was on, both the VT and VRT schedules operated. A point earned on the VRT schedule was delivered immediately. However, a point earned on the VT schedule was held until the next changeover switched the subject back to the VT light and the COD had elapsed. The green reinforcer light flashed briefly when a point was delivered. A counter below this light tallied the number of reinforcers accumulated in a session. All sessions ended after 30 min, whereupon both outer lights on the control panel became dark.

Prior to the first session, subjects read the following instructions:

Your task in this experiment is to assume that points are good. Remember, each point is exchangeable for money. Points are signaled by the green light at the center of your control panel. This light will remain dark until you have received a point. At that time, the green light will flash, and the counter will be incremented by one. The experiment will be set to start when both the red and white lights on your control panel are illuminated. Your first press on the push button will begin the session by turning off one of these outer lights, while the other light remains illuminated. Each subsequent press will turn off whichever light was previously illuminated and turn the other one on. In other words, the push button will allow you to remain in the presence of either the red light or the white light. The experiment will end when both outer lights become dark.

Copies of the instructions remained available on the subject's desk throughout the experiment. Before each session, subjects were asked to leave watches and other personal belongings outside the experiment room.

Questionnaire and debriefing. After all sessions were completed, subjects were given

questionnaires from which verbal reports of their performance were obtained. Subjects were later debriefed about the experiment.

RESULTS

Figure 1 shows data plots for each subject during no-cue conditions. The last three sessions in each condition were included in the analysis. The dependent measure was the ratio of times spent in the presence of each alternative. This time-allocation ratio was plotted with respect to the VT schedule against the corresponding reinforcement ratio. Equation 1 was transformed into a linear function by using logarithmic coordinates:

$$\log(B_{VT}/B_{VRT}) = a \log(R_{VT}/R_{VRT}) + \log b. \quad (3)$$

Perfect matching occurs when the slope (a) is 1.0 and the intercept ($\log b$) is 0. The slope reflects the sensitivity of behavior to relative reinforcement. A positive b value indicates a bias for the interval schedule, and a negative value measures bias for the ratio alternative. A least squares fit of Equation 3 provided a measure of variance accounted for.

The bias parameter is of primary interest. However, the adequacy of the value depends on sensitivity to the schedules. A bias measure is uninformative if behavior is not sensitive to the schedule parameters. Likewise, the maximizing prediction is based on the matching of behavior to reinforcement parameters. Thus, bias values are not discussed for subjects whose slope was less than 0.40. As seen by the nearly flat slope ($a = 0.26$) in Figure 1, the choice ratio of S6 did not vary with the reinforcement schedules. His data are not included in the data analysis below.

During no-cue conditions, Equation 3 accounted for more than 90% of the variance for all 5 subjects. All subjects showed bias for the ratio schedule. The b values ranged from -0.03 to -0.17 , with a mean of -0.10 . Sensitivity measures (a) ranged from 0.41 to 0.93.

As Herrnstein and Heyman (1979) noted, assessing parameter values for a small number of individual subjects may not be adequate with a narrow range of reinforcement ratios. Pooling individual-subject data provides a more powerful statistic by allowing a greater log-unit coverage of the independent variable and increasing sample size. Figure 2 shows the pooled time ratios for no-cue conditions and

Fig. 1. Results for each subject are shown for no-cue conditions. Log ratio of time allocation to the VT over the VRT as a function of the log ratio of reinforcement from the VT over the VRT. Dashed lines represent strict matching, and solid lines are fitted least squares regression lines. Estimates of bias, sensitivity, and percentage of variance accounted for (VAC) are provided.

their fit to Equation 3. The a value of 0.74 reflects some undermatching, whereas the negative b value (-0.13) shows a small bias to the VRT. Equation 3 accounts for 90% of the variance.

Figure 3 plots data for each subject during time-cue conditions. Only 2 subjects (S3 and S7) maintained sensitivity. S3 showed only a slight increase in bias (-0.22 from -0.16) to the VRT. S7, on the other hand, showed a marked increase in bias (-0.44 from -0.10) for the VRT schedule. However, this value did not reach the optimal levels (-0.74 for VRT 30 s; -0.89 for VRT 60 s) predicted by Equation 2.

Table 1 shows the number of reinforcers earned by each subject in each condition. The more biased distribution of behavior shown by S7 produced a greater number of reinforcers. S7 averaged 59 points per session in the last time-cue condition, a mean increase of 10 points relative to the other 5 subjects in that condition.

DISCUSSION

The present results show that reinforcement maximization did not control human performance in concurrent ratio-interval schedules of reinforcement. In no-cue conditions, 1 subject (S6) showed no sensitivity to changes in schedule values. The remaining subjects all showed undermatching and a small, although consistent, bias for the ratio schedule. However, the degree of bias did not approach that predicted by a maximizing view. Whereas the predicted bias was -0.89 when the VRT value was 60 s and -0.74 when it was 30 s (Equation 2), obtained biases ranged between -0.03 and -0.17 , with a pooled value of -0.13 . Thus, to maximize total reinforcement in a session, subjects should have allocated more time to the VRT schedule than they actually did.

In time-cue conditions, 4 of 6 subjects showed insufficient sensitivity to reinforcement schedules. Basically, these subjects remained indifferent between the alternatives. Although speculative, two factors may account for this severe undermatching. Keller and Gollub (1977) demonstrated a type of discriminative interference in sensitivity between successive experimental conditions. They observed strict matching when a single relative reinforcement

Fig. 2. Pooled data are shown for all subjects in the no-cue condition. Log ratio of time allocation to the VT over the VRT as a function of the log ratio of reinforcement from the VT over the VRT. The dashed line represents strict matching, and the solid line is the fitted least squares regression line. Estimates of bias, sensitivity, and percentage of variance accounted for (VAC) are provided.

rate was presented to each subject, whereas substantial undermatching occurred when each subject received various different relative rates of reinforcement. Thus, in the present experiment, an effect of successive conditions may have reduced sensitivity and produced undermatching.

A second possibility involves issues of motivation. Subjects may have been indifferent between the alternatives because they did not learn that they could increase their rate of reinforcement significantly depending on their performance. This possible factor is consistent with subjects' verbal reports between sessions and following the experiment. Subjects also reported increasing boredom with the task as sessions progressed, adding that they "did not care about getting points" and "just wanted to finish" by the end of the 31 sessions.

Two subjects (S3 and S7) did remain sensitive to schedule values throughout time-cue conditions. S3 showed only a slight increase in bias (from -0.16 to -0.22), whereas S7 showed significantly increased bias (from -0.10 to -0.44), thus obtaining more reinforcers when time cues were operated. These results parallel remarks made by subjects at the end of the experiment. Although S3 did not report a change in strategy when the time cues were

Fig. 3. Results for each subject are shown for time-cue conditions. Log ratio of time allocation to the VT over the VRT as a function of the log ratio of reinforcers from the VT over the VRT. Dashed lines represent strict matching, and solid lines are fitted least squares regression lines. Estimates of bias, sensitivity, and percentage of variance accounted for (VAC) are provided.

presented, S7 described her new strategy during the last (VT 60 s, VRT 30 s) condition: "I stayed on the red light [VRT] for 30 seconds, and if I hadn't gotten a point, I would then switch to white [VT] for 5 seconds, get a point, and then go back to red." Although tending toward optimal performance, S7 also failed to show the degree of bias required to maximize reinforcement rate.

Given that maximizing principles do not account for the data, to what extent does the matching law describe the present data? Results from no-cue conditions replicated a small (although consistent and often ignored) bias for the ratio schedule. Except for the study by Herrnstein and Heyman (1979), previous experiments using concurrent ratio-interval schedules have all reported small biases for the ratio alternative (DeCarlo, 1985; Heyman & Herrnstein, 1986; Vyse & Belke, 1992; Williams, 1985, 1992). Table 2 shows pooled bias values from each of these experiments. Although these studies concluded that matching describes the data more accurately than a maximization strategy does, the common view of matching does not predict any bias and thus cannot describe the results reported in the literature. The ratio of behavior should strictly equal the ratio of reinforcement, given equal hedonic values and response efforts associated with each alternative.

Williams (1992) proposed a view of matching that incorporates the effects of delayed reinforcers to account for the small bias in his data. He varied length of the intertrial interval (ITI) in a discrete-trial procedure to assess the role of temporal separation between responses and reinforcers. The ITI was analogous to the COD in concurrent schedules. With a 5-s ITI, subjects showed substantial bias for the VR alternative (ranging from -0.10 to -0.23 , with a pooled value of -0.15). As the ITI increased to 30 s, biases for the VR decreased significantly (ranging from no bias to -0.11 , with a pooled value of -0.05). Sensitivity, as measured by a , increased towards 1.0 with ITI. Thus, both matching parameters approached strict matching ($a = 1.0$ and $b = 0$ in Equation 3) when the consequences were temporally more separated from the choice response that produced them. Because choosing the VR alternative was followed differentially by delayed VI reinforcers on subsequent trials, we might expect a bias for the VR alternative.

Table 2

Pooled bias and sensitivity values in concurrent ratio-interval experiments.

Experiment	COD (s)	Sensitivity (a)	Bias (b)
DeCarlo (1985)	2.5	0.92	-0.06
Williams (1985) ^a	6 ^b	0.77	-0.02
Heyman and Herrnstein (1986)	1.5	0.94	-0.07
Vyse and Belke (1992)	2	1.02	-0.12
Williams (1992)	5 ^b	0.71	-0.15
Williams (1992)	30 ^b	0.84	-0.05
Present study	3	0.74	-0.13

^a Only mean values reported.

^b ITI values in discrete-trial choice procedure.

A view of matching that includes the effects of delayed reinforcement of ratio choice may help to interpret past and present results in concurrent ratio-interval experiments. As mentioned above, probability of reinforcement is highest when switching from the ratio to the interval schedule. Although delayed by the COD, interval reinforcers obtained after a changeover may reinforce choice of the ratio alternative, thus producing a bias for the ratio schedule. Indeed, studies have shown delay-of-reinforcement effects spanning at least 3 s (e.g., Sizemore & Lattal, 1978; Williams, 1976). The "bias" created may simply reflect matching to an increase in the rate of ratio reinforcement, which is mistakenly measured as interval reinforcement. As noted above, previous studies have produced a bias for the ratio alternative similar to that shown by our subjects (Table 2). Although the small bias may reflect an imperfect maximizing strategy (Rachlin, Green, & Tormey, 1988), considering the role of delayed reinforcement in matching provides a more parsimonious interpretation of the results.

The delay-of-reinforcement effects suggest that the typical COD is ineffective in establishing independence between the alternatives. As mentioned above, choice procedures with short or no COD produce high rates of alternation and severe undermatching. In concurrent-interval procedures, pigeons' responding approaches strict matching as the COD increases (Shull & Pliskoff, 1967). If delayed reinforcers control changeover behavior and the schedules are not entirely independent, we would expect undermatching to occur in ratio-

interval experiments that have used relatively short CODs. Table 2 shows this was indeed the case. Furthermore, reviews of concurrent-interval experiments concluded that undermatching is the most frequent finding (Baum, 1979; Myers & Myers, 1977; Wearden & Burgess, 1982). Williams (1988) suggested using CODs longer than the typical 1 to 3 s.

With human subjects, the role of instructions becomes an issue. Catania (1992) suggests that instructions often disrupt humans' sensitivity to scheduled contingencies. Although we attempted to devise instructions that would prevent a bias for any one pattern of switching, the insensitivity and variability shown during the baseline sessions may have been caused by the instructions given at the start of the experiment. Subjects' reports following the experiment suggested that the instructions were not misleading. (In particular, no subject reported interpreting the phrase "the push button will allow you to remain in the presence of either the red light or the green light" as a suggestion not to switch between lights.) In any event, after the baseline sessions and extended exposure to each condition, subjects' choice proportions usually came under the control of the relative rates of reinforcement.

In conclusion, the present experiment did not support a maximizing account of the molar matching phenomenon. Subjects did not maximize reinforcement rate in this situation. Although 2 subjects behaved more optimally in the presence of time cues, any conclusions regarding the effects of time-cue exposure are tentative because of the insensitivity shown by 4 subjects in time-cue conditions. Moreover, even these 2 subjects' choices were far from that required by a fully effective maximizing strategy. It is not clear whether nonhuman subjects would respond differently to our time-cue manipulation. Other research (e.g., Williams, 1992) shows that pigeons and rats respond more optimally when the consequences of responding are made salient, suggesting that optimal behavior, when observed, depends on stimulus-control factors. Presumably, if sufficiently directive cues were provided, humans (and pigeons) would eventually adopt a maximizing strategy. For example, in the extreme case, instructions to humans that specified a maximizing strategy would probably produce one. However, the present results suggest that

human subjects are similar to their pigeon counterparts in not having a strong tendency to deviate from matching in the direction of maximizing. We undertook this study, in part, to see whether college students would be more likely to maximize reinforcement rate than were the pigeons in Heyman and Herrnstein's (1986) study with a comparable procedure. Instead, we obtained support for the generality of their findings. As in previous experiments with nonhumans, our humans showed only a small bias for the ratio schedule. Moreover, even this bias may be interpreted by a view of matching that incorporates delay-of-reinforcement effects.

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