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THE UNIVERSITY OF ALBERTA

DEVIATIONS FROM MATCHING IN RATS USING A LONG CHANGEOVER DELAY

BY

SHIRLEY-ANNE HENSCH

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "Deviations from matching in rats using a long changeover delay" submitted by Shirley-Anne Hensch in partial fulfilment of the requirements for the degree of Master of Science.

Supervisor

W. David Pierce

Date: 16 April 1987

ABSTRACT

Six male Long Evans rats were trained to lever press for 45-mg Noyes pellets. After initial training they were placed on concurrent variable-interval 1-min variable-interval 1-min schedules that included a 15-sec changeover delay (COD). One of the schedules was then varied between 15-sec and 2-min across four conditions. The distribution of animals' behavior between two concurrently available schedules of reinforcement has been found, in previous studies, to conform to the generalized matching law: $(B_1/B_2) = k\,(r_1/r_2)^a$. These previous studies have employed a COD that is relatively short in relation to the schedules under consideration. It has been suggested that a longer COD produces a better fit to the matching line. In particular, undermatching, in which a is systematically less than 1.0, has been found to decrease as the COD is increased. The present study was designed to test the effect on concurrent choice behavior when the COD used was allowed to reach 100% of the richer schedule. The results show, contrary to predictions, that when a COD which ranges from 25% to 100% of the richer schedule is used, undermatching of relative response rates and relative time to obtained relative reinforcement rates is found to occur. When performance is evaluated as a difference between the obtained local reinforcement rates on the two schedules, systematic deviations in performance measures occur as the length of the COD approaches the average inter-reinforcement interval of the richer schedule.

Behavioral distribution is consistent with optimality theory. Subjects did not achieve optimal performance levels, but the obtained reinforcement rates indicate no systematic deviations away from optimality.

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I would like to thank Dr. C.D. Heth for his patience in discussing the far too many questions I had, for his helpful editorial comments, and also for his computing skills which were essential to the successful completion of this study. I would like to thank the Province of Alberta for the funding I received during this study, and I would also like to thank Drs. W.F. Epling and W.D. Pierce for providing the equipment and lab space used during the study. Last, but most importantly, I would like to thank Tim, for always being willing to help out in any way he could.

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Introduction

The behavior of animals responding under concurrent variable-interval variable-interval (<u>conc</u> VI VI) schedules of positive reinforcement has been described by several authors (see Catania, 1966; de Villiers, 1977; Wearden & Burgess, 1982; for reviews). Findley (1958) first reported that preference for a given schedule of a pair of concurrently available independent schedules varied inversely with the mean of the inter-reinforcement interval. Herrnstein (1961) obtained similar results and formulated the Matching Law as a quantitative description of pigeons' steady-state behavior in a concurrent choice situation:

$$R_1/(R_1 + R_2) = r_1/(r_1 + r_2) \qquad (1)$$

where R_i is the total number of responses made on schedule i, and r_i is the total number of reinforcers obtained from schedule i. The Matching Law, therefore, relates the proportion of responses emitted on a particular alternative to the proportion of reinforcers obtained from that alternative. Herrnstein found these two proportions to be equal when behavior rates reached steady-state performance. Later Brownstein and Pliskoff (1968) extended the Matching Law to include time matching:

$$t_1/(t_1 + t_2) = r_1/(r_1 + r_2) \qquad (2)$$

where t_i is the total time spent on schedule i.

Baum (1974) found that deviations from these proportional relationships were systematic, and could be accounted for with the addition of two parameters: <u>a</u>, a measure of sensitivity to schedule parameters; and k, a measure of response bias. He incorporated these parameters into a power function which he termed the generalized matching law:

$$B_1/B_2 = k\,(r_1/r_2)^a \qquad (3)$$

where B_i is a measure of behavioral output with respect to schedule i. When proportional matching, as given by the Matching Law, holds both a and k are equal to 1.00. However, if the formula is applied in this form, data points may be lost from conditions where no reinforcement is obtained from one of the alternatives. Expansion of Equation 3 to its equivalent proportional forms (see Appendix A) avoids this problem:

$$R_1/(R_1+R_2) = kr_1{}^a/(kr_1{}^a + r_2{}^a) \qquad (4)$$

$$t_1/(t_1+t_2) = kr_1{}^a/(kr_1{}^a + r_2{}^a) \qquad (5)$$

The major reviews of matching (Catania, 1966; de Villiers, 1977; Wearden & Burgess, 1982) have found both Herrnstein's (1961) original formulation and Baum's (1974) generalized model provide good fits to the obtained data. Recent studies provide support for these results across a wide range of species such as pigeons (e.g. Davison & Ferguson, 1978; Leighland, 1979), humans (e.g. Bradshaw, Szabadi, Bevan & Ruddle, 1979; Pierce & Epling, 1983), rats (e.g. Norman & McSweeney, 1978; Poling, 1978), cows (Matthews & Temple, 1979), and wagtails (Houston, 1986). Appendix B provides a review of studies using rats in concurrent choice paradigms. However, although good fits to obtained data are achieved, both Herrnstein's (1961)

Matching Law and Baum's (1974) Generalized Matching Law are normative models which are silent with respect to the underlying processes.

To describe the process underlying choice behavior, Herrnstein and Vaughan (1980) proposed a model which they termed melioration:

$$R_D = r_1/t_1 - r_2/t_2 \tag{6}$$

R_D represents the difference in obtained reinforcement rates for a pair of concurrently available schedules. Herrnstein and Vaughan state that animals will allocate behavior between two reinforcement sources by shifting to the higher local rate of reinforcement until an equilibrium is reached at $R_D = 0$. At equilibrium, melioration yields the matching relationship:

$$t_1/t_2 = r_1/r_2. \tag{7}$$

If animals showed exclusive preference for one of the alternatives however, R_D could not be set equal to zero. In this case the relative response rate and the relative time spent would match the obtained reinforcement rate, but the process underlying this result could not be described by melioration.

An alternate approach to a process model is to determine optimal behavior strategies. This approach has been studied extensively in zoological literature (for example, Cowie & Krebs, 1979; Krebs, 1978; Lea, 1981, 1982). Houston and McNamara (1981) developed a mathematical model to describe optimal behavior in a concurrent choice situation. They propose that the optimal strategy for a given pair of concurrent VI VI schedules is dependent upon the ratio of the changeover delay

(COD) to the richer schedule. A COD is a delay contingency programmed to separate the reinforcement on one alternative from a response to the other alternative by some minimum time interval. Previous researchers have proposed that the inclusion of a COD is necessary to reduce the rapid alternation between the two schedules that would normally occur (Catania and Cutts, 1963; Herrnstein, 1961). It has been suggested that the sensitivity to reinforcement, as measured by a (Baum, 1974) increases as the duration of the programmed COD is increased from zero to some asymptotic value. Research has indicated that this asymptotic value is between 5.0 and 7.5 seconds in rats, and that increases beyond ~~that~~ value have no reported effect (Allison & Lloyd, 1971; de Villiers, 1977; Norman & McSweeney, 1978). Houston and McNamara (1981) imply this is not necessarily the case; it is not the absolute value of the COD, but the ratio of the COD to the richer schedule that describes behavior allocation. Their model predicts that when the COD is large relative to the richer schedule the animal should never switch away from that schedule. As the duration of the COD decreases relative to the richer schedule one of two other strategies becomes optimal, dependent upon two parameters:

τ: the ratio of the COD to the richer schedule, and

λ: the ratio of the richer schedule to the leaner schedule.

With respect to these two parameters Houston and McNamara (1981) derived two critical values:

$$\tau_c = 0.920703 \qquad \lambda_c = 0.871405$$

Their model divides an animal's response space into three discrete regions which describe how subjects will partition their time between two concurrently available schedules for all possible combintations of COD and variable interval component schedules:

1. NEVER SWITCH: The animal never leaves the schedule with the higher reward rate.
2. STAY-STAY: The animal stays for some positive length of time on each schedule before switching away to the alternate.
3. STAY-SWITCH: The animal should switch into the leaner schedule only to collect a reinforcer and then immediately switch back to the richer schedule.

For $\lambda > \lambda_c$ with $\tau < \tau_c$ stay-stay is the optimal policy, for $\tau \geq \tau_c$ with $\lambda \leq \lambda_c$ never switch is the ~~optimal policy,~~ and for situations where $0 < \lambda \leq \lambda_c$ and $0 < \tau < \tau_c$ a stay-switch policy is optimal. Houston and McNamara (1981, p.383) could not locate any empirical studies which did not fall in the region $0 < \lambda \leq \lambda_c$, $0 < \tau < \tau_c$ (the stay-switch region defined above).

A review of matching studies involving rats (see Appendix B) showed that the ratio of the COD to the richer schedule is generally programmed to be less than or equal to 0.25; two exceptions are studies by Shull and Pliskoff (1967) and Norman and McSweeney (1978). Shull and Pliskoff used a range of COD's and held schedule values constant. The ratio of the COD to the richer schedule varied between 0.00 and 0.33. Norman and McSweeney used a constant COD and varied the conc VI VI components. The ratio of their COD to the richer schedule (τ) varied between 0.08 and 0.33.

The present study was designed to determine the effects on concurrent choice behavior when τ ranges between 0.25 and 1.00. Four schedule pairs and a COD were selected that would result in values of τ and λ (Table 1) that would predict patterns of behavior falling in each of the regions described by Houston and McNamara (1981). Consistent with Houston and McNamara's model, it was hypothesized that animals would show exclusive preference for the richer schedule when its mean inter-reinforcement interval was equal to the COD ($\tau = 1.00$). It was further hypothesized that animals would show an equal distribution of behavior across the two alternatives when τ was in the range common in concurrent choice experiments ($\tau = 0.25$) and λ was set equal to 1.00. In the two cases where λ is equal to 0.50, τ takes on values of 0.25 and 0.50. In these conditions it was predicted that animals would spend most of their time on the richer schedule, only switching to the leaner schedule to collect a reinforcer, and then immediately returning to the richer schedule. This would result in more extreme response and time partitioning than would be expected from the programmed reinforcement rates when the value of τ is large.

TABLE 1: Schedules used, and predicted behavior allocation based on lambda and tau.

Richer Schedule	Leaner Schedule	COD	Lambda	Tau	Predicted Behavior
VI 15-sec	VI 60-sec	15 sec	0.25	1.00	Never Switch
VI 60-sec	VI 60-sec	15 sec	1.00	0.25	Stay-Stay
VI 30-sec	VI 60-sec	15 sec	0.50	0.50	Stay-Switch
VI 60-sec	VI 120-sec	15 sec	0.50	0.25	Stay Switch

These predicted results are similar to those reported in a study by Shull and Pliskoff (1967) which used a pair of concurrent schedules where λ was equal to 0.33; with their longest COD duration τ also took on a value of 0.33. In this condition they reported that animals spent approximately 90% of their time on the richer schedule, rather than 75% as predicted by the programmed reinforcement rates. They also reported that as time and response ratios increased with respect to the richer schedule, obtained reinforcement ratios also increased, therefore matching to obtained reinforcement ratios continued to hold as observed response and time ratios deviated from programmed reinforcement ratios. Therefore, although animals were expected to partition their time in the manner predicted by Houston and McNamara (1981) there would be no effect on the fit of the matching line to observed behavior.

Method

Subjects

Six experimentally naive male Long Evans rats, approximately 12 weeks old at the start of training, were used. The rats were housed individually under a constant cycle of 12-hours light and 12-hours dark. The rats were fed at the end of each session, and maintained at approximately 80% of their extrapolated normal weight, which was calculated by allowing a 5 gm weight gain per week until the subjects were 16 weeks old. Tap water was freely available at all times in both the home cage and the operant chamber.

Apparatus

An operant chamber measuring 20 cm high by 20 cm wide by 40 cm long was constructed. A food cup was located 4 cm from the floor in the center of the front wall. Directly above the food cup, 6 cm from the floor, was a feeder tube connected to a dispenser that delivered 45-mg Noyes pellets as reinforcement for bar pressing. Above the food cup, 10 cm from the floor, was a drinking tube. Levers were situated 6 cm from the floor in each of the end walls. The chamber was enclosed by sound attenuating material. House lights remained on during each session. A microcomputer, located in an adjoining room, was used for programming and recording.

Procedure

After being reduced to 80% of their ad lib weight, all subjects were trained to lever press in the operant chamber described above. During the first session the subjects were placed in the chamber and 40 45-mg Noyes pellets were delivered on a fixed time (FT) 30-sec schedule. During this initial session the FT 30-sec schedule could be overridden by a single lever press on either of the available levers. During the next two to six days all the subjects were given daily sessions utilizing concurrent CRF CRF schedules (*conc* CRF CRF). These sessions ran for 45 minutes, or until 40 reinforcers had been delivered, whichever occurred first. Subjects #2 and #5 required additional hand shaping. When each subject was able to complete a 40-reinforcer session in less than 15 minutes, the following sessions were conducted to ensure conditioning to both bars had occurred:

(1) 40 45-mg Noyes pellets were delivered on CRF schedule. The previously preferred lever was removed from the chamber so that all responses occurred on the non-preferred lever.

(2) 40 45-mg Noyes pellets were delivered on a *conc* CRF CRF schedule with both levers in place.

(3) 40 45-mg Noyes pellets were delivered on a CRF schedule with the previously non-preferred lever removed from the chamber so that all responses occurred on the preferred lever.

(4) 40 45-mg Noyes pellets were delivered on a conc CRF CRF schedule with both levers in place.

Four additonal sessions were run, utilizing a conc FR5 FR5 schedule, during which the session length was extended until 80 reinforcers had been delivered. At this point the subjects began a series of concurrent variable-interval schedules containing a 15-sec COD.

The schedules and the number of days for each subject to meet the stability criterion are presented in Table 2. Stability was achieved when the response rates on both schedules fell within the previous range for five consecutive days (Norman & McSweeney, 1978, p. 455). An example of this calculation is reproduced in Appendix C.

The main part of the experiment consisted of the presentation of five separate pairs of conc VI VI schedules. The first pair consisted of conc VI 1-min VI 1-min schedules. After stability was achieved on this pair, the second set of schedules (conc VI 15-sec VI 1-min) were presented. For half the subjects (1, 3, and 5) the VI 15-sec component was associated with the right lever, as the subject faced the food cup; for the remaining subjects (2, 4, and 6) the left lever was used. During the third phase of the experiment (conc VI 30-sec VI 1-min) the richer schedule was presented on the left lever for subjects 1, 3, and 5, and on the right lever for subjects 2, 4, and 6. The leaner schedule of the fourth set of schedules (conc VI 1-min VI 2-min) was presented on the same lever as the VI 30-sec schedule of the previous pair for all subjects. In the final phase conc VI 1-min VI 1-min schedules were repeated. This presentation

Table 2: The number of sessions on each concurrent schedule by subject.

	Schedule		Subject					
	60-sec	Alternate	1	2	3	4	5	6
<u>conc</u>	VI 60-sec	VI 60-sec	16	36	32	25	12	21
<u>conc</u>	VI 60-sec	VI 15-sec	25	17	13	17	20	41
<u>conc</u>	VI 60-sec	VI 30-sec	16	13	31	26	13	24
<u>conc</u>	VI 60-sec	VI 120-sec	12	11	15	18	20	28
<u>conc</u>	VI 60-sec	VI 60-sec	17	33	17	17	16	11

ordering was undertaken to control for hysteresis effects (Baum, 1974; de Villiers, 1977; Stevens, 1957) that have been found when the richer schedule is always programmed on the same lever or key.

For all schedules the interreinforcement intervals were constructed as a 12-interval series as described by Catania and Reynolds (1968, p. 381). Each completion of the block of 12 intervals initiated a new random presentation of the series. Sessions took place daily, and were terminated when 81 reinforcers had been delivered, or when 60 min had elapsed, whichever occurred first. 81 Noyes pellets represent approximately 20% of the animals' total daily food intake, therefore cumulative records from all conditions were randomly checked for any signs of satiation during the experimental session. No decrease in overall response rates across the sessions was detected for any of the animals. Daily sessions started at 0530 MST, seven days per week. Within the daily time block, the running order for individual subjects was randomized.

Results and Discussion

The data obtained from the last five days in each condition for each subject (see Appendix D for a full listing) were used to evaluate each of the four models discussed earlier. In the conc VI 15-sec VI 1-min and the conc VI 30-sec VI 1-min all sessions were terminated when 81 reinforcers had been delivered. In the conc VI 1-min VI 1-min and the conc VI 1-min VI 2-min the sessions were terminated after 60 minutes had elapsed. As a result, subjects received less overall reinforcement in the latter two conditions across the five stability sessions.

Normative Models

Proportional Matching (Herrnstein, 1961).

A linear least-squares regression line was fit to the data points from each subject (see Figure 1, and Table 3). Proportional response and time measures were calculated according to equations 1 and 2. The data points from each individual session were used, rather than averages from each condition, to provide a more accurate estimate of the residual sum of squares (SSE). Averaging of values prior to the fitting of a regression line can reduce the SSE and result in inflated values of R^2. The R^2 values from these plots ranged from 0.957 to 0.993 across all subjects. The associated slopes and intercepts ranged from 0.863 to 1.05 and from 0.003 to 0.045 respectively. Herrnstein's (1961) model predicts that when proportional matching holds the slope of the regression line will be 1.00 and the intercept will be 0.00. Setting the alpha level at 0.05 and testing for variations in the intercept and slope

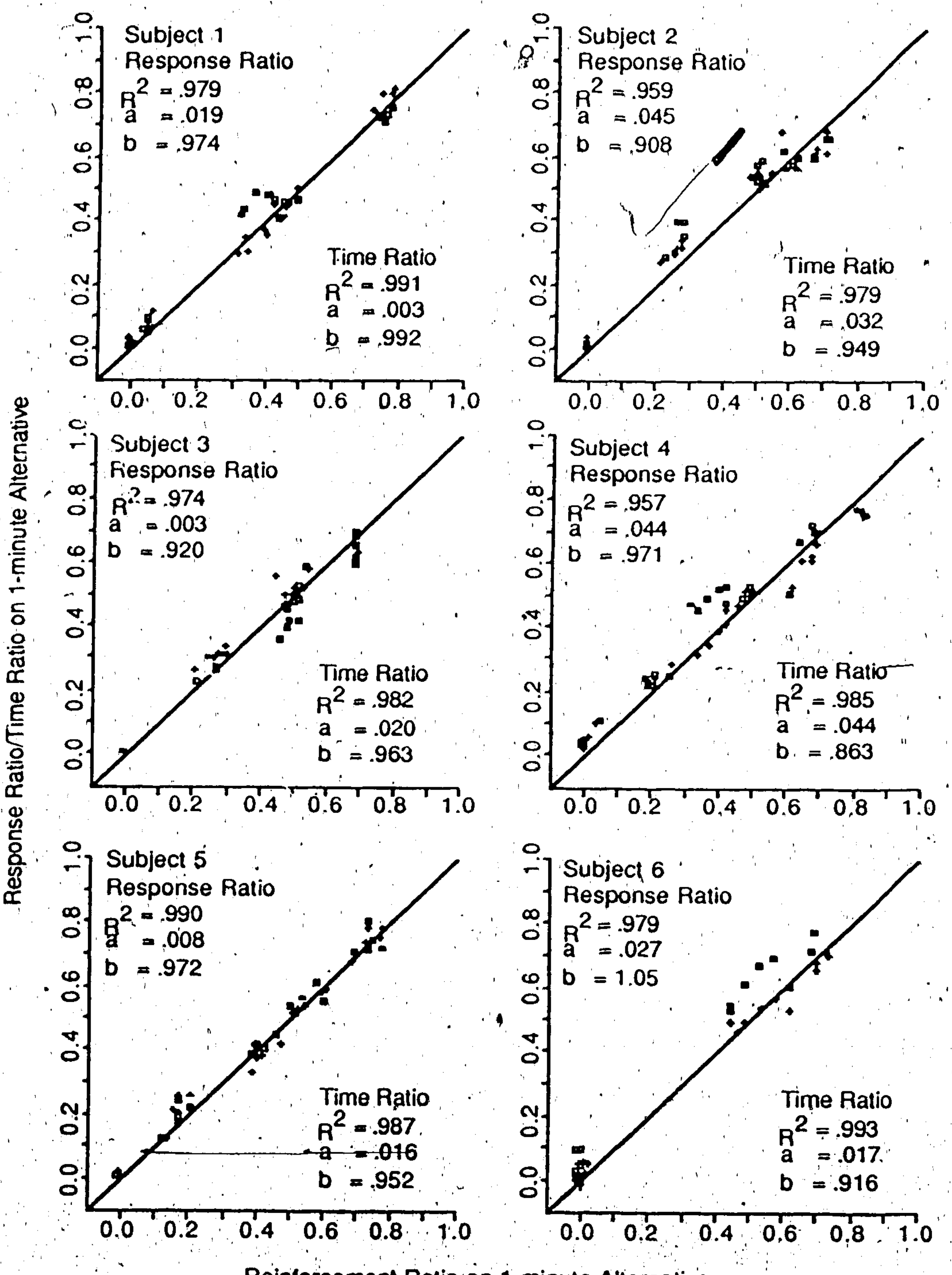

Figure 1: Response (□) and time proportions (+) on the 1-minute alternative as a function of obtained reinforcement rate. The obtained intercept (a), slope (b) and R^2 value from a least-squares regression are given for each subject.

Table 3: Total seconds spent responding under, total responses emitted to, and total reinforcers obtained from each component of each concurrent schedule. All statistics have been averaged over the last five sessions of each schedule, the two presentations of concurrent VI 1-min VI 1-min have been averaged together. Standard errors are given in parenthesis.

Subject	Measure	VI 15-sec	VI 1-min	VI 30-sec	VI 1-min	VI 1-min	VI 1-min	VI 2-min	VI 1-min
1	Seconds	1328(13)	2(4)	2536(40)	164(110)	2196(238)	1396(231)	787(98)	2810(95)
	Responses	1796(40)	1(2)	4187(460)	175(157)	2016(700)	1583(519)	1204(131)	3481(102)
	Reinforcers	81(0)	0(0)	78(2)	3(2)	43(3)	30(6)	15(2)	48(4)
2	Seconds	1636(69)	8(11)	1945(135)	895(88)	1558(153)	2036(157)	1306(167)	2293(167)
	Responses	916(204)	5(8)	1453(194)	735(155)	1011(121)	1277(143)	1258(139)	2022(230)
	Reinforcers	81(0)	0(0)	60(2)	21(2)	34(4)	40(3)	20(3)	43(4)
3	Seconds	1410(51)	0(1)	1788(94)	751(86)	1716(118)	1617(162)	1223(121)	2376(120)
	Responses	2154(44)	0(0)	3160(411)	1135(54)	2443(290	2066(555)	1848(273)	3369(382)
	Reinforcers	81(0)	0(0)	60(2)	21(2)	40(3)	40(2)	22(1)	47(1)
4	Seconds	1437(21)	87(41)	1952(80)	614(28)	2068(283)	1505(272)	1435(145)	2159(144)
	Responses	1079(71)	57(41)	2317(281)	722(44)	1688(513)	1655(543)	1497(356)	2879(368)
	Reinforcers	79(1)	2(1)	63(18)	18(2)	42(2)	32(7)	21(2)	42(3)
5	Seconds	1381(45)	10(9)	2140(64)	609(160)	1934(347)	1661(345)	921(156)	2671(151)
	Responses	688(21)	2(1)	1546(221)	342(72)	907(360)	794(87)	532(79)	1486(190)
	Reinforcers	81(0)	0(0)	66(2)	14(2)	37(9)	35(4)	16(2)	48(5)
6	Seconds	1443(63)	11(19)	2596(39)	31(67)	2615(891)	979(893)	1340(264)	2259(264)
	Responses	1118(113)	2(4)	1867(217)	30(66)	1063(146)	907(905)	1012(252)	2454(224)
	Reinforcers	81(0)	0(0)	81(1)	0(1)	45(9)	19(19)	19(3)	43(5)

indicates that none of the intercepts differ signficantly from 0.00. However, the slopes for the response ratios for Subjects #2 (t=-2.34) and #3 (t=2.58), and for the time ratios for Subjects #4 (t=-6.27), #5 (t=-2.13) and #6 (t=-5.26) vary significantly from 1.00.

The remaining seven least-squared fits appear to be well described by Herrnstein's model. The linear regressions on the data therefore shows that, although a linear model fits the data well, there are some deviations from predicted slope values in five of the twelve linear fits.

Generalized Matching Law (Baum, 1974).

It could not be concluded that the slopes of response and time ratios, plotted as a linear function of obtained reinforcement ratios, did not differ from 1.00 for some subjects, therefore, a non-linear regression curve was fit to estimate the parameters a and k used by Baum (1974) to describe deviations from matching (equations 4 and 5). The data were read into a BMDP command file (Ralston, 1979) and a derivative-free non-linear regression was carried out to estimate the parameters a and k for each subject (Table 4). The R^2 values of the resulting curves range from 0.963 to 0.995; therefore it can be concluded that the estimated parameters provide an extremely good fit to the data. The estimates of a range from 0.668 to 1.087, and the estimates of k range from 0.853 to 1.487. Previous studies have concluded that in concurrent choice procedures involving rats, a increases to 1.00 as the COD is increased from 0.0 seconds to an asymptotic level (approximately 7.5 seconds); increases in the COD beyond this asymptotic level have no reported effect (Allison & Lloyd, 1971; de Villiers, 1977; Norman & McSweeney, 1978). Based on these studies, a was not

TABLE 4: Estimation of Baum's (1974) parameters using non-linear least squares. For each parameter the standard error of the estimate is given in brackets.

Response Ratios

Subject	a		k		R^2
1	0.838*	(0.049)	1.066	(0.042)	0.986
2	0.668*	(0.044)	1.056	(0.030)	0.984
3	0.913	(0.061)	0.853*	(0.030)	0.976
4	0.861*	(0.059)	1.143*	(0.052)	0.963
5	0.944	(0.037)	0.980	(0.028)	0.990
6	0.715*	(0.053)	1.487*	(0.071)	0.990

Time Ratios

Subject	a		k		R^2
1	1.087	(0.044)	0.960	(0.029)	0.993
2	0.780*	(0.036)	1.073*	(0.025)	0.991
3	0.839*	(0.042)	1.027	(0.026)	0.989
4	0.800*	(0.034)	0.901*	(0.023)	0.985
5	0.916*	(0.038)	0.960	(0.029)	0.988
6	0.733*	(0.041)	0.974	(0.029)	0.995

*t-tests indicate that these values are significantly different from 1.00 at the alpha 0.05 level. R^2 values were calculated as SSR/SST.

expected to differ significantly from 1.00 when a 15-second COD was in effect across all conditions. With an alpha level of 0.05 (and assuming a t-distribution) the conclusion from the regression results is that subjects 1, 2, 4, and 6 are undermatching response ratios, and subjects 2, 3, 4, 5, and 6 are undermatching time ratios. This is counter to predictions that using a COD larger than 7.5 seconds will not produce over or undermatching; the results show instead clear evidence of undermatching of both time and response ratios.

Both normative models provided a good fit to the data, but the predictions they make were not well supported. Therefore the two process models described earlier, melioration (Herrnstein & Vaughan, 1980) and optimization (Houston & McNamara, 1981), were evaluated to determine if they could provide a description of the processes underlying the obtained data.

Process Models

Melioration (Herrnstein & Vaughan,1980).

Herrnstein and Vaughan (1980) proposed that animals in a concurrent choice procedure would distribute their behavior between the concurrently available sources of reinforcement by shifting to the schedule with the higher local rate of reinforcement. This behavioral adjustment would continue until an equilibrium point was reached and the local reinforcement rates from the two schedules were equated. Their descriptive measure (R_D) represents the difference in the local reinforcement rates. When the distribution of an animal's behavior is described by the process of

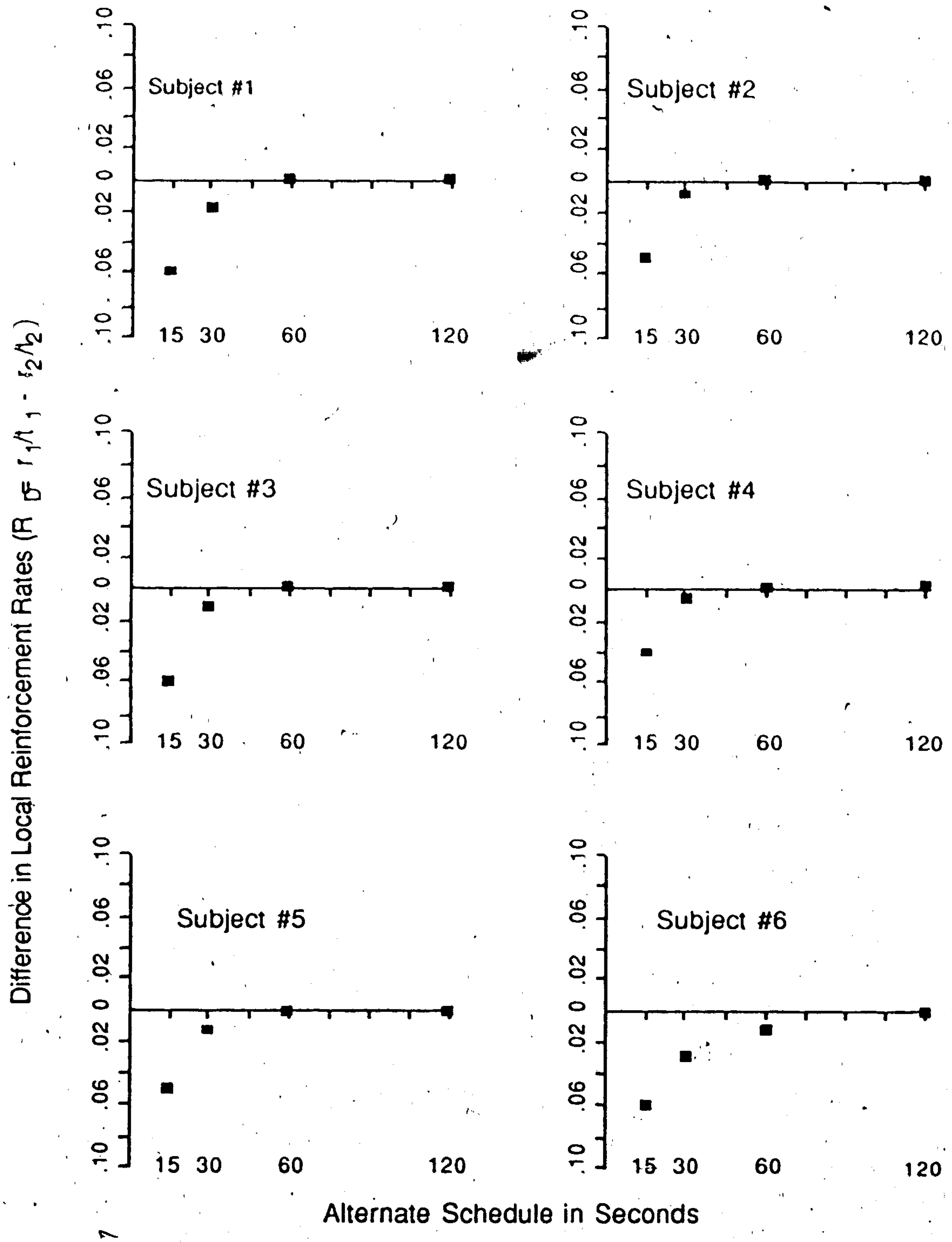

Figure 2: R_D as a function of the alternately available schedule. For each subject R_D is averaged over the last five sessions that each schedule was in effect

melioration, R_D is equal to 0.00. Figure 2 shows R_D plotted as a function of the average interreinforcement interval (IRI) on the alternate schedule.

For all subjects, R_D differs significantly from 0.00 when the IRI of the alternately available schedule is equal to the COD (alpha = .05). For subjects #2, #3, and #6 the difference between the local rates is also significant when the IRI of the alternate schedule is twice the COD, and for subjects #2, #4, and #6 there are significant differences in the local rates in the <u>conc</u> VI 1-min VI 2-min condition (alpha = .05).

The most striking aspect of Figure 2 is the regularity of the deviations. The difference between the local rates of reinforcement is largest in the <u>conc</u> VI 15-sec VI 1-min condition (range -.0610 to -.0357). R_D is intermediate in the <u>conc</u> VI 30-sec VI 1-min condition (range -.0284 to -.0052), and R_D is smallest in either the <u>conc</u> VI 1-min VI 1-min or <u>conc</u> VI 1-min VI 2-min condition (range -.0066 to .0046). It would appear that there is some regularity in performance that is not reflective of the process inferred by melioration. To measure the systematic reliability of these inter-subject deviations, Kendall's coefficient of concordance (Siegal, 1956) was calculated. The result ($W_{4,6} = 0.911$, $p < .01$) indicates the deviations observed are systematic; that is, each subject appears to be responding to the set of schedules in the same way. This systematic deviation in R_D results from the reduction in switching behavior that occurs as the length of the COD increases relative to the average IRI of the richer schedule. Continuing to switch into the leaner schedule as the COD approaches the IRI of the richer schedule would result in a decrease in the overall obtained rate of reinforcement. Herrnstein and Vaughan (1980, p. 170) suggest that animals will equate the reward rates rather than show exclusive preference, even if it results in departures from optimal behavior: "...melioration does not entail overall maximization as a general principle." However, this departure from optimality doesn't occur. Instead, all subjects exhibit an optimal behavior strategy, exlusive or near exclusive preference for the richer alternative, that does not correspond to the process described by melioration.

Therefore, while melioration provides a good description of the data when high switch rates between the schedules are required to maximize overall reinforcement rates, it does not account for the data from conditions where the optimal response pattern is to never switch, or to switch infrequently, from the richer schedule to the leaner schedule.

Houston and McNamara's (1981) optimization model anticipated this reduction in switch rates as the duration of the COD increased relative to the richer of the two alternatives.

Optimization (Houston & McNamara, 1981):

The initial predictions of Houston and McNamara's (1981) optimization model are with respect to the allocation of behavior based on the values of τ and λ. For values of τ greater than τ_c the optimal behavior is exclusive preference for the richer schedule, for values of λ greater than λ_c the optimal strategy is to stay for approximately equal times on both alternatives, and for values of τ less than τ_c and λ less than λ_c the optimal strategy is to stay longer on the richer schedule, only switching into the leaner schedule to pick-up a reinforcer.

The results in Table 3 provide empirical support for Houston and McNamara's division of an animal's response space. In the <u>conc</u> VI 15-sec VI 1-min condition τ is equal to 1.00, and all subjects show near exclusive preference for the richer schedule. Average response ratios with respect to the 15-sec alternative range from 0.95 to 1.00 and average time ratios range from .94 to 1.00. In the <u>conc</u> VI 1-min VI 1-min condition, λ is equal to 1.00 and subjects' response ratios (with respect to the preferred response alternative) range from 0.50 to 0.56 with time ratios between 0.51 and 0.73. This shows some deviation from the prediction of approximately equal distributions for the time measure, however Subject #6 showed almost exclusive preference for one alternative during the initial baseline presentation of the <u>conc</u> VI 1-min VI 1-min schedules. This biased responding was not evident when the schedules were re-presented at the conclusion of the study. If this subject's data from the first <u>conc</u> VI 1-min VI 1-min presentation are removed, the range on time ratios is lowered to between 0.50 and 0.61.

As predicted, in the <u>conc</u> VI 30-sec VI 1-min condition ($\lambda = 0.50$, $\tau = 0.50$) the subjects showed more extreme partitioning of behavior with respect to the richer schedule than would be predicted by the programmed reinforcement rates. Response ratios range from 0.66 to 0.98 and time ratios range from 0.68 to 0.99. In the _conc_ VI 1-min VI 2-min condition ($\lambda = 0.50$, $\tau = 0.25$) the extreme behavior evident in the _conc_ VI 30-sec VI 1-min condition does not appear. Response ratios range from 0.62 to 0.74 and time ratios range from 0.60 to 0.78 with respect to the 1-min schedule. Behavior in these ranges approximates the allocation predicted by programmed reinforcement rates (0.67 with respect to the 1-min schedule).

These results provide empirical support for Houston and McNamara's (1981) division of an animal's response space based on the values on τ and λ. The results also indicate that, when the ratio of the COD to the richer schedule is within the range normally studied ($\tau \leq 0.25$), response partitioning approximates scheduled reinforcement values.

One implication of the optimization model is that the predicted strategies will result in performance that optimizes obtained reward rates. The model evaluates performance on two measures:

$\underline{S}$ the switching rate (changeovers per minute), and

$\underline{R}_i$ the reward rate on schedule i (i=1,2) where 1 refers to the richer schedule.

The results predicted by optimization (Houston & McNamara, 1981), together with the observed values, are presented in Table 5 and Figure 3. The plot of obtained reinforcement rates as a function of the alternate schedule shows that, although none of the animals was able to achieve optimal performance on any of the presented

TABLE 5: Optimal and observed values of Houston and McNamara's (1981) parameters. S^* is the optimal number of switches per minute, $R1^*$ and $R2^*$ are the optimal number of reinforcers per minute obtainable from the richer and leaner schedules respectively. For each subject the observed switch rate and the obtained reinforcement rates are averaged over the last five sessions the schedule was in effect.

OPTIMAL VALUES:	Schedule	S^*	$R1^*$	$R2^*$
	15/60	0.0000	4.0000	0.0000
	30/60	0.7803	1.7129	0.5637
	60/60	3.6923	0.7908	0.7908
	60/120	1.8215	0.9030	0.3848

OBSERVED VALUES:	Subject	Schedule	S	R+ Rich	R+ Lean
	1	15/60	0.0454	3.6530	0.0000
	1	30/60	0.5443	1.7424	0.0578
	1	60/60	1.1630	0.7150	0.5062
	1	60/120	0.9209	0.8008	0.2503
	2	15/60	0.1028	2.9573	0.0000
	2	30/60	0.8563	1.2593	0.4522
	2	60/60	1.0551	0.5643	0.6678
	2	60/120	1.3670	0.7202	0.3334
	3	15/60	0.0175	3.4453	0.0000
	3	30/60	1.2317	1.4132	0.5010
	3	60/60	1.4819	0.6725	0.6827
	3	60/120	1.4737	0.7869	0.3601
	4	15/60	0.4461	3.1181	0.0709
	4	30/60	1.1548	1.4825	0.4115
	4	60/60	1.6005	0.7053	0.5407
	4	60/120	2.0802	0.7045	0.3572
	5	15/60	0.1376	3.4858	0.0086
	5	30/60	0.6329	1.4493	0.3099
	5	60/60	1.1282	0.6175	0.5775
	5	60/120	0.8383	0.8084	0.2672
	6	15/60	0.0535	3.3434	0.0000
	6	30/60	0.0228	1.8412	0.0091
	6	60/60	1.0898	0.7445	0.3088
	6	60/120	1.3906	0.7236	0.3235

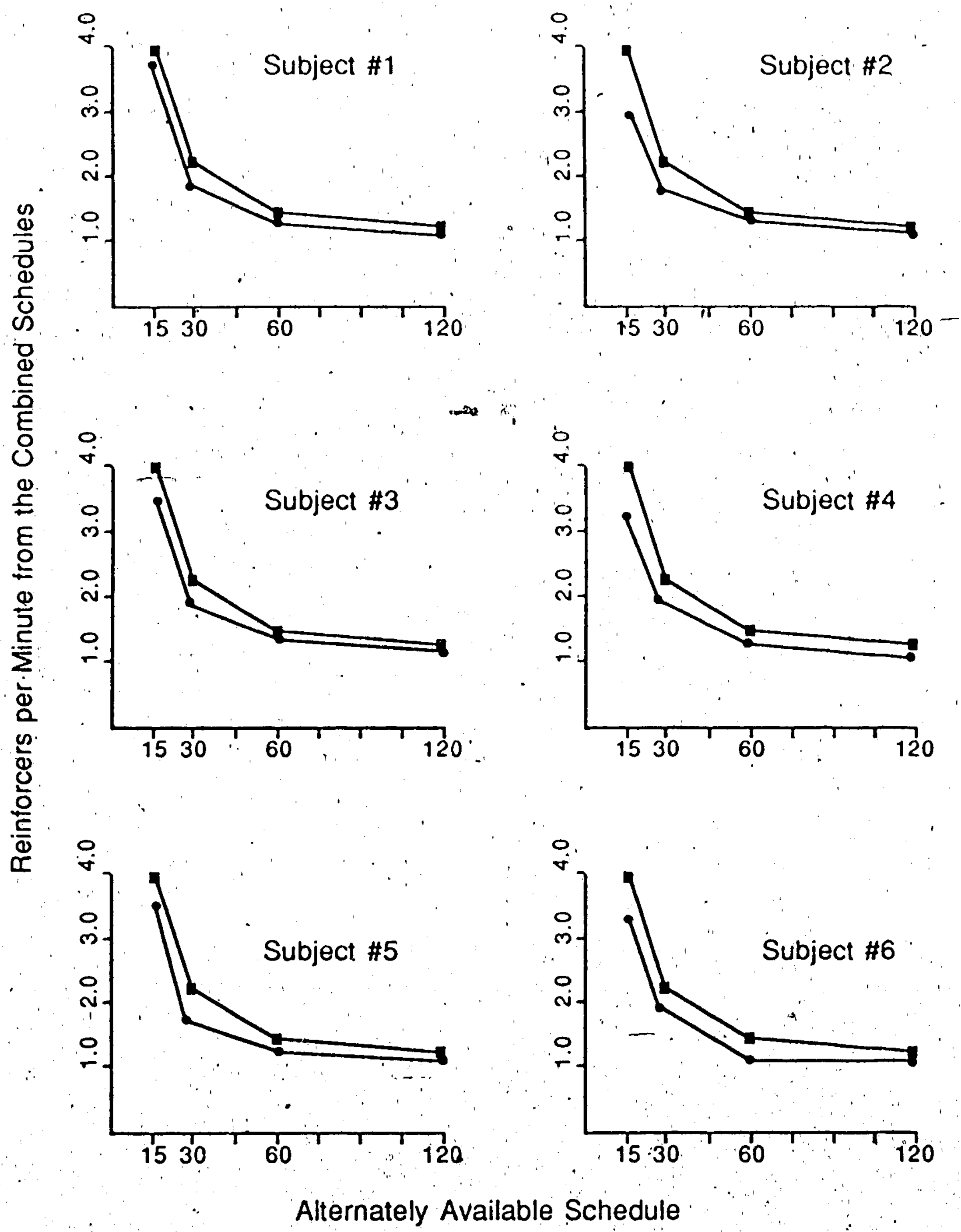

Figure 3: Optimal reinforcers per minute (■) and obtained reinforcers per minute (●) as a function of the alternately available schedule. For each subject the obtained reinforcement rate is averaged over the last five sessions for each schedule.

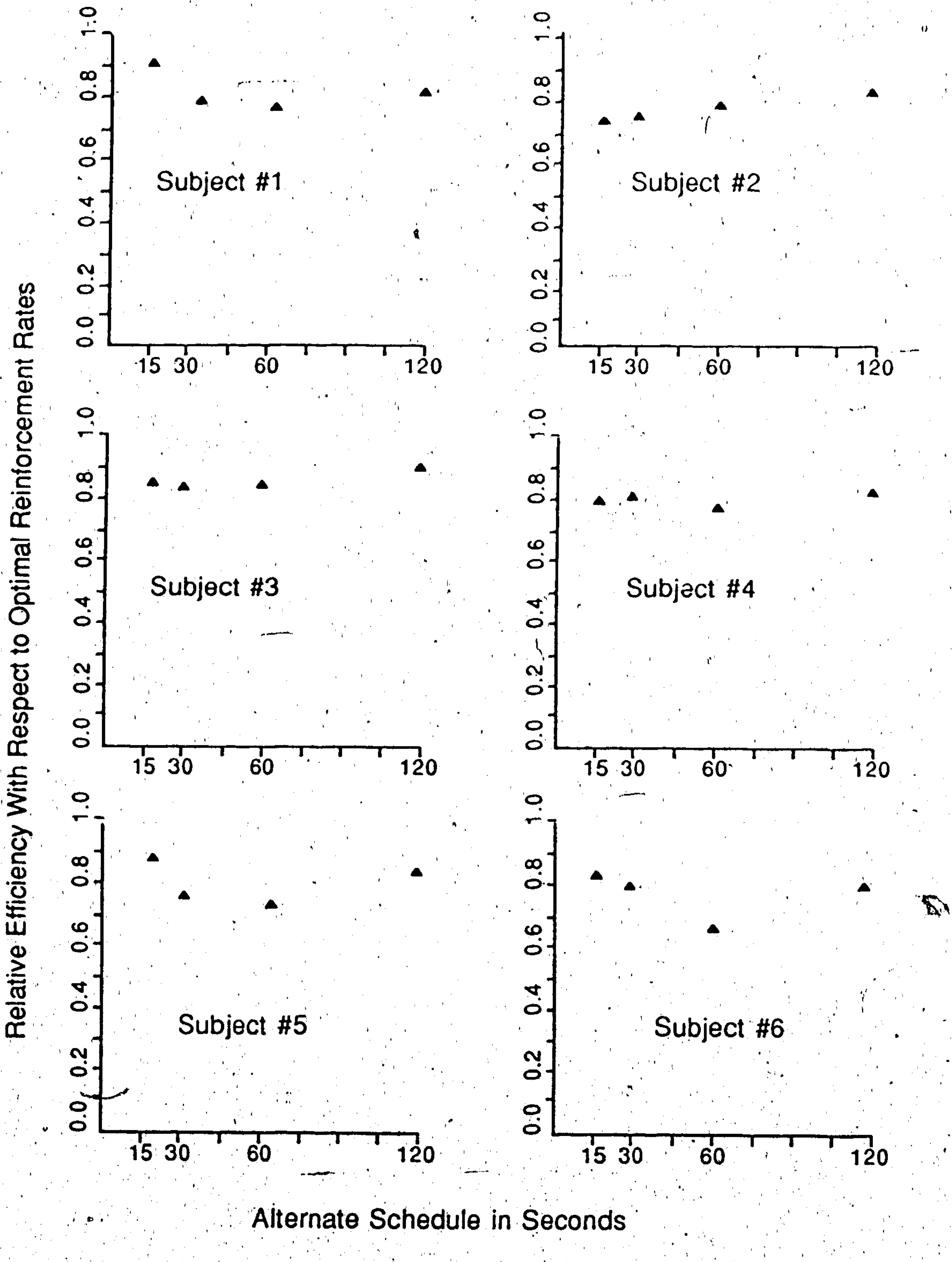

Figure 4: Relative efficiency $[(R_1 + R_2)/(R_1{}^* + R_2{}^*)]$ as a function of the alternatively available schedule. For each subject the values have been averaged over the last five sessions each schedule was in effect.

schedules, observed behavior tracks optimal behavior. To test for systematic departures from optimal performance, a measure of relative efficiency was constructed by dividing the obtained reinforcement rates by the total of the predicted optimal reinforcement rates available on the two schedules. This ratio measure was plotted as a function of schedule values (Figure 4), and Kendall's coefficient of concordance was calculated (Siegal, 1956). The result indicates that the deviations in efficiency are not systematically related to the underlying schedule parameters ($W_{4,6} = 0.411$, $p > .10$). The relative efficiency ranges from 0.6859 to 0.9133 across subjects, but the largest absolute deviation for a single subject (#1) is 0.1728. This variation in performance is not significant at an alpha level of .05.

When performance is evaluated in terms of Houston and McNamara's predicted switch rates, the results indicate all subjects switched significantly less than predicted by the model in the <u>conc</u> VI 1-min VI 1-min condition (alpha = .05). Subjects #1, #5, and #6 also switched significantly less than predicted in the <u>conc</u> VI 1-min VI 2-min condition (alpha = .05). In the <u>conc</u> VI 30-sec VI 1-min condition, subjects #3 and #4 overswitched, and subjects #5 and #6 underswitched relative to the predicted switch rate (alpha = .05).

The tendency of all the animals to switch less in conditions which have high switch rates predicted by the model may highlight one of the constraints imposed on mathematical formulations of naturally occurring behavior, such as foraging. Houston and McNamara (1981, p.388) state:

> "The optimal policies we have obtained maximize the reward rate rather than the net rate of energy intake. If the rate at which energy is expended during switching is the same as the rate while on a schedule, maximizing net reward rate is equivalent to maximizing net rate of energy intake. This equivalence is likely to hold for performance in a Skinner box, but not for traveling between patches in the wild. In general, if switching is energetically more costly than staying, the stay times that maximize net rate of energy intake will be longer than those that maximize reward rate."

The results of this study indicate that the equivalence they mention may not hold, even within the operant chamber. When response alternatives are spatially separated, and conditions require a high rate of switching to maximize the overall reward rate, switch rates fall below those predicted by the model.

Therefore, Houston and McNamara's (1981) optimization model is able to predict the pattern of behavior allocation across a wide range of <u>conc</u> VI VI settings, and the model's calculated optimal reinforcement rates provide evidence that animal's behavior tracks optimality. However, specific predictions with regard to switch rates are not well supported. This may be due, in part, to the differential energy cost that exists between staying on an alternative, and switching away from that alternative.

Conclusion

The optimization model (Houston & McNamara, 1981) accounts for the pattern of behavior allocation under a variety of conditions, some of which fall outside the bounds normally studied (e.g. proportionately long COD's), however the model does not adequately predict observed behavior when switching between alternatives is costly in terms of net energy consumption. Melioration (Herrnstein & Vaughan, 1980), is unable to explain behavior allocation in situations where low switch rates, or exclusive responding to one alternative is the optimal behavior pattern.

The net result is that optimization provides good prediction of all aspects of behavior when a proportionately long COD is in effect, but loses some of its predictive power when the duration of the COD with respect to the richer schedule falls in the range normally employed in concurrent choice studies ($\tau \leq 0.25$). In this range, melioration provides better predictions of the processes underlying behavioral allocation.

Counter to predictions of the Matching Law (Herrnstein, 1961), in five of the twelve linear fits the slope of the regression line was found to differ significantly from 1.00. And, counter to predictions of the Generalized Matching Law (Baum, 1974), all subjects exhibited clear evidence of undermatching of time and/or response measures with the 15-sec COD used in this study. This suggests that the role of the COD in choice behavior, in relation to the schedules under consideration, may be a much more complex one than indicated by previous studies.

It has been suggested the concurrent choice paradigm can provide a useful analogy for foraging behavior in patchy environments (Baum, 1983). One manipulation that may result in a closer approximation to a natural foraging situation is the inclusion of a programmed changeover delay, or a changeover procedure, that is representative of the real cost incurred through travel between patches. This study provides some important data relevent to this type of manipulation.

References

Allison, J. (1981). Paired baseline performance as a behavioral ideal. Journal of the Experimental Analysis of Behavior, 35, 355-366.

Allison, T.S., & Lloyd, K.E. (1971). Concurrent schedules of reinforcement: Effects of gradual and abrupt increases in changeover delay. Journal of the Experimental Analysis of Behavior, 16, 67-73.

Barrett, J.E., & Stanley, J.A. (1980). Maintenance of responding by squirrel monkeys under a concurrent shock-postponement, fixed-interval shock-presentation schedule. Journal of the Experimental Analysis of Behavior, 34, 117-129.

Baum, W.M. (1974). On two types of deviation from the matching law: Bias and undermatching. Journal of the Experimental Analysis of Behavior, 22, 231-242.

Baum, W.M. (1976). Time-based and count-based measurement of preference. Journal of the Experimental Analysis of Behavior, 26, 27-35.

Baum, W.M. (1979). Matching, undermatching, and overmatching in studies of choice. Journal of the Experimental Analysis of Behavior, 32, 269-281.

Baum, W.M. (1982). Choice, changeover, and travel. Journal of the Experimental Analysis of Behavior, 38, 35-49.

Baum, W.M. (1983). Studying Foraging in the Psychological Laboratory. In R.L. Mellgren (Ed.) Animal Cognition and Behavior (pp. 253-283). Amsterdam: North Holland Press.

Bradshaw, C.M., Szabadi, E., Bevan, P., & Ruddle, H.V. (1979). The effect of signaled reinforcement availability on concurrent performances in humans. Journal of the Experimental Analysis of Behavior, 32, 65-74.

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

Catania, A.C. (1963). Concurrent performances: reinforcement interaction and response independence. Journal of the Experimental Analysis of Behavior, 6, 253-263.

Catania, A.C. (1966). Concurrent operants. In W.K. Honig (Ed.), Operant behavior: Areas of research and application (pp. 213-270). Englewood Cliffs, N.J.: Prentice-Hall, Inc.

Catania, A.C., & Cutts, D. (1963). Experimental control of superstitious responding in humans. Journal of the Experimental Analysis of Behavior, 6, 203-208.

Catania, A.C., & Reynolds, G.S. (1968). A quantitative analysis of the responding maintained by interval schedules of reinforcement. Journal of the Experimental Analysis of Behavior, 11, 327-383.

Cowie, R.J., & Krebs, J.R. (1979). Optimal foraging in patchy environments. In R.M. Anderson, B.D. Turner and R.L. Taylor (Eds.) Population Dynamics (pp. 183-205). Oxford: Blackwell Scientific Publications.

Davison, M. (1982). Preference in concurrent variable-interval fixed-ratio schedules. Journal of the Experimental Analysis of Behavior, 37, 81-96.

Davison, M.C., & Ferguson, A. (1978). The effect of different component response requirements in multiple and concurrent schedules. Journal of the Experimental Analysis of Behavior, 29, 283-295.

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

Fantino, E., & Logan, C.A. (1979). The experimental analysis of behavior: A biological perspective. San Francisco: W.H. Freeman and Company.

Findley, J.D. (1958). Preference and switching under concurrent scheduling. Journal of the Experimental Analysis of Behavior, 1, 123-144.

Graft, D.A., Lea, S.E.G., & Whitworth, T.L. (1977). The matching law in and within groups of rats. Journal of the Experimental Analysis of Behavior, 25, 183-194.

Green, L., Rachlin, H., & Hanson, J. (1983). Matching and maximizing with concurrent ratio-interval schedules. Journal of the Experimental Analysis of Behavior, 40, 217-224.

Griffiths, R.R., Wurster, R.M., & Brady, J.V. (1981). Choice between food and heroin: Effects of morphine, naloxone, and secobarbital. Journal of the Experimental Analysis of Behavior, 35, 335-351.

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

Herrnstein, R.J., & Loveland, D.H. (1975). Maximizing and matching on concurrent ratio schedules. _Journal of the Experimental Analysis of Behavior, 24,_ 107-116.

Herrnstein, R.J., & Vaughan, W. (1980). Melioration and behavioral allocation. In J.E.R. Staddon (Ed.) _Limits to action: The allocation of individual behavior_ (pp. 143-176). New York: Academic Press.

Houston, A. (1986). The matching law applies to wagtails' foraging in the wild. _Journal of the Experimental Analysis of Behavior, 45,_ 15-18.

Houston, A.I., & McNamara, J. (1981). How to maximize reward rate on two variable-interval paradigms. _Journal of the Experimental Analysis of Behavior, 35,_ 367-396.

Hursh, S.R. (1978). The economics of daily consumption controlling food- and water-reinfoced responding. _Journal of the Experimental Analysis of Behavior, 29,_ 475-491.

Hursh, S.R. (1980). Economic concepts for the analysis of behavior. _Journal of the Experimental Analysis of Behavior, 34,_ 219-238.

Killeen, P. (1972). A yoked-chamber comparison of concurrent and multiple schedules. _Journal of the Experimental Analysis of Behavior, 18,_ 13-22.

Krebs, J.R. (1978). Optimal foraging: Decision rules for predators. In J.R. Krebs, & N.B. Davies (Eds.) _Behavioural ecology: An evolutionary approach_ (pp. 23-63). Oxford: Blackwell Scientific Publications.

LaBounty, C.E., & Reynolds, G.S. (1973). An analysis of response and time matching to reinforcement in concurrent ratio-interval schedules. Journal of the Experimental Analysis of Behavior, 19, 155-166.

Lea, S.E.G. (1978). The psychology and economics of demand. Psychological Bulletin, 85, 441-466.

Lea, S.E.G. (1981). Correlation and contiguity in foraging behavior. In P. Harzem, & M.D. Zeiler (Eds.) Predictability, correlation, and contiguity (pp. 355-406). New York: John Wiley, & Sons.

Lea, S.E.G. (1982). The mechanism of optimality in foraging. In M.L. Commons, R.J. Herrnstein and H. Rachlin (Eds.) Quantitative analyses of behavior: Matching and maximizing accounts (pp. 169-188). Cambridge: Ballinger Publishing Company.

Leigland, S.M. (1979). Deviations from matching as a measure of preference for alternatives in pigeons. Journal of the Experimental Analysis of Behavior, 32, 1-13.

Lobb, B., & Davison, M.C. (1975). Performance in concurrent interval schedules: A systematic replication. Journal of the Experimental Analysis of Behavior, 24, 191-197.

Matthews, L.R., & Temple, W. (1979). Concurrent schedule assessment of food preference in cows. Journal of the Experimental Analysis of Behavior, 32, 245-254.

Myers, D.L., & Myers, L.E. (1977). Undermatching: A reappraisal of performance on concurrent variable-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior, 27,* 203-214.

Nevin, J.A. (1971). Response strength in multiple schedules. *Journal of the Experimental Analysis of Behavior, 21,* 241-247.

Norman, W.D., & McSweeney, F.K. (1978). Matching, contrast, and equalizing in the concurrent lever-press responding of rats. *Journal of the Experimental Analysis of Behavior, 29,* 453-462.

Pierce, W.D., & Epling, W.F. (1983). Choice, matching and human behavior: A review of the literature. *The Behavior Analyst, 6,* [illegible]7-76.

Poling, A. (1978). Performance of rats under concurrent variable-interval schedules of negative reinforcement. *Journal of the Experimental Analysis of Behavior, 30,* 31-36.

Rachlin, H.C. (1973). Contrast and matching. *Psychological Review, 80,* 217-234.

Ralston, M. (1979). Par: Derivative-free nonlinear regression. In W.J. Dixon, M.B. Brown (Eds.) *BMDP: Biomedical computer programs P-series, 1979* (pp. 484-498). Los Angeles: University of California Press.

Rider, D.P. (1981). Concurrent fixed-interval variable-ratio schedules and the matching relation. *Journal of the Experimental Analysis of Behavior, 36,* 317-328.

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

Siegal, S. (1956). Nonparametric statistics for the behavioral sciences. New York: McGraw Hill.

Staddon, J.E.R. (1980). Optimality analyses of operant behavior and their relation to optimal foraging. In J.E.R. Staddon (Ed.) Limits to action: The allocation of individual behavior (pp. 101-141). New York: Academic Press.

Stevens, S.S. (1957). On the psychophysical law. Psychological Review, 64, 153-181.

Wearden, J.H., & Burgess, I.S. (1982). Matching since Baum (1979). Journal of the Experimental Analysis of Behavior, 38, 339-348.

White, A.J., & Davison, M.C. (1973). Performance in concurrent fixed-interval schedules. Journal of the Experimental Analysis of Behavior, 19, 147-153.

Appendix A: Expansion of Baum's (1974) Power Function

Starting with:

$$B_1/B_2 = k(r_1/r_2)^a$$

Expand the right-hand side:

$$B_1/B_2 = kr_1^a/r_2^a$$

Invert and add one to each side:

$$B_1/B_1 + B_2/B_1 = kr_1^a/kr_1^a + r_2^a/kr_1^a$$

Reduce to a common denominator:

$$(B_1 + B_2)/B_1 = (kr_1^a + r_2^a)/kr_1^a$$

Re-invert:

$$B_1/(B_1 + B_2) = kr_1^a/(kr_1^a + r_2^a)$$

Appendix B: Literature Review

Introduction

One area of research in the experimental analysis of behavior concerns the mechanisms that underlie choice behavior in animals. The concept of choice in animals is perhaps best exemplified in animals foraging for food in a natural setting. The animal is continually making choices regarding where to hunt, what to consume, and movement between and within areas (Krebs, 1978).

The study of foraging within a laboratory setting allows for the control of factors such as differences in risk due to predation, differences in food quality and quantity, and differences in travel requirements between areas. This control allows researchers to study choice between alternatives that vary along a single dimension. Various studies have examined the effects on choice behavior of such variables as: quality of the reinforcers (e.g. Griffiths, Wurster & Brady, 1981; Hursh, 1978; Lea, 1978); quantity of the reinforcers (e.g. Catania, 1963); duration of the changeover delay (e.g. Shull & Pliskoff, 1967); different manipulanda (e.g. Barrett & Stanley, 1980); different types of reinforcement schedules (e.g. Herrnstein & Vaughan, 1980); and different rates of reinforcement (see Baum, 1979; Myers & Myers, 1977; Wearden & Burgess, 1982, for reviews).

The most commonly used experimental procedure in this type of research is a paradigm that employs two separate but concurrent reinforcement schedules associated with spatially separated response mechanisms. The two manipulanda are usually the same to control for differences in response partitioning due to factors related to response topography (Fantino & Logan, 1979, p.209). Hursh (1980) reported that, in situations where the quality or quantity of reinforcement differs between the response alternatives, there is no single unidimensional rule capable of describing the resultant behavior. An animal's choice behavior is a function of the degree to which the differing reinforcers can be considered substitutes or complements. When the differing reinforcers are substitutes for each other, an increase in choice responding for one is accompanied by a decrease in choice responding for the other. When the two reinforcers are complementary, an increase in responding for one is accompanied by an increase in responding for the other (Hursh, 1980). Therefore, the same type and quantity of reinforcement is generally delivered for each reinforced response, regardless of the response alternative. Also, both response alternatives generally remain available throughout the procedure so that rate of response and time spent responding is under the control of the subject.

The researcher controls the availability of reinforcement through the programming of the underlying schedules. While ratio schedules have been employed by some researchers (e.g. Allison, 1981; Davison, 1982; Rider, 1981), variable interval schedules are more common. The use of concurrent variable-interval variable-interval (conc VI VI) schedules allows the probability of reinforcement from one alternative to be independent of responses made to the other alternative. Both schedules run continuously, and both schedules advance as time elapses, no matter how the animal allocates its responses. However, reinforcers scheduled on the non-current alternative are held until the animal returns to that alternative. This leads to an increase in the probability of reinforcement from a given alternative the longer the animal has been away from it.

For this reason, it is common in choice experiments to program a changeover delay (COD). This is a time interval, following a switch from one alternative to the other, during which no reinforcers are delivered. The COD prevents the animal from being reinforced for merely alternating its responses. It has been suggested that tendencies to respond in a random manner, regardless of the programmed reinforcement rates, are decreased through the introduction of a COD. As the duration of the COD is lengthened animals become increasingly sensitive to the underlying schedules of reinforcement. With a COD of sufficient duration animals' response rates tend to match the programmed reinforcement rates (Baum, 1974). Research into the most effective COD duration has suggested that the minimum time interval required to override simple alternation between response alternatives is species dependent (de Villiers, 1977, p.243). With pigeons, a delay of 1 to 3 seconds appears to be sufficient to produce matching of response rates to reinforcement rates (Catania, 1966; Herrnstein, 1961), however rats require a longer COD (5.0 to 7.5 seconds) before response rates reliably match reinforcement rates. Increases beyond these asymptotic values have no reported effects (Allison & Lloyd, 1971; de Villiers, 1977; Norman & McSweeney, 1978).

One issue that is overlooked is, with a sufficiently long COD the animal would be expected to respond exclusively to one of the alternatives. Although this behavior conforms to the matching relation by definition, it indicates a sensitivity to the cost incurred by switching between schedules, rather than a sensitivity to the underlying schedule parameters. Therefore, an alternate method of predicting behavior relative to the duration of the COD has been proposed by Houston and McNamara (1981). They suggest that it is not the absolute value of the COD, but rather the ratio of the COD to the richer of two available schedules (τ) that determines choice behavior. When the duration of the COD is long relative to the mean inter-reinforcement interval of the richer schedule, the optimal strategy for an animal is to never switch into the leaner schedule. As the ratio of the COD to the richer schedule decreases, a distribution of responses will be observed that is a function of the ratio of the richer schedule to the leaner schedule.

There are two methods with which to test Houston and McNamara's predictions. One method is to hold the richer schedule constant while varying the COD, the other method is to employ a constant COD while varying the richer schedule. Both these research designs have been utilized in previous studies of choice behavior (e.g. Norman & McSweeney, 1978; Shull & Pliskoff, 1967); however, no existing empircal studies have focused on behavioral distribution as a function of the proportional relationship between the COD and the underlying schedules.

The present study was designed to determine behavior patterns in a concurrent choice setting which employed a constant COD duration that would be comparable to actual travel time between discrete food patches. Baum (1979) reviewed 103 data sets from 23 concurrent choice studies, and Wearden and Burgess (1982) reviewed 120 data sets from 13 additional studies. In the studies that they reviewed, those using pigeons employed short COD's (1 to 3 seconds). Studies utilizing COD's of a sufficient duration to be equated to actual travel time involved rats. Therefore, the data from studies utilizing rats in a concurrent choice paradigm were evaluated to determine: (1) whether or not rats show evidence of matching response and time ratios to reinforcement ratios, and (2) if rats show evidence of matching, how this behavior is affected by the inclusion of a changeover delay. Studies relevent to these two questions are reviewed below (See also Table B-1).

Review of Related Studies

Shull and Pliskoff (1967) first used rats in a concurrent operant procedure, in which electrical brain stimulation served as the reinforcer. Their objective was to evaluate the effect of different COD durations on relative response rates. Their procedure of scheduling reinforcement was first described by Findley (1958). This procedure differs from the procedure outlined previously in that both schedules are associated with a single lever; a response to the second lever in the chamber alternates the schedules associated with the main response lever. In their procedure "...successive responses on the changeover lever produced only one schedule change. However, the COD interval began anew with each perseverative response on the changeover lever." (Shull & Pliskoff, 1967, pp. 518-519). This manipulation ensures that the COD respresents the minimum interval between a changeover response and a reinforced response. In this study the COD ranged from 0 to 20 seconds in duration, and two concurrent schedule pairs were used: conc VI 1-min

Table B-1: Studies of concurrent choice behavior in rats

Study	Subjects	Schedules	COD Duration	Reinforcer
Shull and Pliskoff (1967)	4 male albino rats	VI 1-min VI 3-min VI 1.5-min VI 1.5-min	0 to 20 sec	Electrical Brain Stimulation
Baum (1976)	5 male brown rats	VI 30-sec VI 2-min VI 45-sec VI 2-min VI 60-sec VI 2-min VI 90-sec VI 2-min VI 2-min VI 2-min VI 30-sec EXT.	7.5 sec	Sweetened Condensed Milk
Graft, Lea & Whitworth (1977)	5 female hooded rats	VI 15-sec VI 15-sec VI 15-sec VI 30-sec VI 15-sec VI 45-sec VI 30-sec VI 30-sec VI 30-sec VI 45-sec VI 45-sec VI 45-sec	N/A	Food Pellets
Norman & McSweeney (1978)	5 male hooded rats	VI 15-sec VI 1-min VI 30-sec VI 1-min VI 1-min VI 1-min VI 2-min VI 1-min	5.0 sec	Food Pellets
Poling (1978)	3 male S.D. rats	VI 30-sec VI 30-sec VI 1-min VI 1-min	6.0 sec	Time-out from shock
Rider (1981)	5 male albino rats	FI 50-sec VR 30 FI 50-sec VR 90 FI 50-sec VR 180 FI 50-sec VR 360 FI 100-sec VR 90 FI 100-sec VR 180 FI 200-sec VR 90 FI 200-sec VR 180 FI 300-sec VR 60 FI 300-sec VR 90 FI 300-sec VR 180 FI 300-sec VR 360	5.0 sec	Food Pellets

VI 3-min and conc VI 1.5-min 1.5-min. Therefore, the COD ranged up to 33% of the richer schedule under consideration. Shull and Pliskoff's major finding was that at all durations of COD the subjects matched relative response rates to obtained reinforcement ratios. However, as the COD was increased the obtained reinforcement ratio diverged from the programmed reinforcement ratio. At the longest COD duration subjects obtained 90% of their reinforcers from the 1-min alternative of a conc VI 1-min VI 3-min schedule. However, Shull and Pliskoff did not fit either Herrnstein's (1961) or Baum's (1974) matching lines to their data, so the amount of variance in their data explained by these models is not known. They found an inverse relationship between the rate of changeovers and the duration of the COD. As the COD was increased, they found a tendency for animals to switch more quickly from the VI 3-min schedule and to stay longer on the VI 1-min schedule. Shull and Pliskoff's study pre-dates Houston and McNamara's (1981) optimality model, but their findings show support for optimality theory. As the ratio of the COD to the richer schedule (τ) was increased, the animals tended to remain on the richer schedule for longer periods and switch into the leaner schedule for shorter periods.

The next study using rats was reported by Baum (1976). His goal was to determine if time spent responding would relate to reinforcement rates in the same manner as response rates did. This study introduced a unique measure of responding. The standard pulseformer was bypassed allowing the continued holding of a response lever to be reinforced. In this way, time spent engaged in responding on each alternative could be directly measured. Baum used a 7.5-sec COD. His richest schedule pair was a conc VI 30-sec VI 2-min, and his leanest was a conc VI 2-min VI 2-min. Therefore, in this study, the COD ranged from 6.25% to 25% of the richer alternative. He found that behavioral frequency varied directly with reinforcement for a given alternative and inversely with the reinforcement on the other alternative. Baum did not report the variance accounted for in the data by Herrnstein's (1961) Matching Law, nor does he use the parameters a and k from the Generalized Matching Law (Baum, 1974) to describe the data. The analysis instead focused on changeover behavior. Baum (1976) found that the rates of changeover were more orderly than behavior ratios when both measures were graphed as a function of reinforcement ratios.

Graft, Lea and Whitworth (1977) designed a variation on previous studies and had a group of rats bar press for all of their daily food pellets in a chamber where the alternatives were spatially discrete and required physical travel and hence "real" travel time. The animals lived in the operant chamber 24 hours a day during the course of the study. Graft et al.'s richest schedule pair was a conc VI 15-sec VI 15-sec, and their leanest schedule pair was a conc VI 45-sec VI 45-sec. Because they had no explicit COD it is not possible to calculate an appropriate range for τ in this study. They found two results of note. First, they found that the rats adjusted their food intake and consumed less as the average cost per pellet increased. They did not fit Herrnstein's (1961) model to their data, but they found evidence of undermatching using obtained reinforcement rates when Baum's (1974) generalized matching law was fit to both group and individual data. In the group data the slope of the regression line fit to the log of the response ratio plotted as a function of the log of the obtained reinforcement ratio was 0.80. The data for individual subjects are discussed but no individual regression slopes are reported. Undermatching means that the parameter a in the generalized matching law is less than 1.0 (Baum, 1974). The COD's used in standard concurrent choice paradigms have been found to reduce undermatching and result in values of a closer to 1.0. It has been suggested by some authors (e.g. Baum, 1982, 1983; Krebs, 1978; Staddon, 1980) that the COD can be functionally equated to travel time between discrete food sources. In Graft et al's. (1977) study no COD was used other than the travel time between food sources. The results of their study imply that undermatching is the expected result in a natural foraging situation.

Norman and McSweeney (1978) used rats in a conc VI VI procedure to determine whether steady-state behavior under these schedules was best described by the equalizing principle (Killeen, 1972), the Matching Law (Baum, 1974; Herrnstein, 1961), or behavioral contrast (Catania, 1963; Rachlin, 1973). Their procedure was a standard concurre[illegible]ice paradigm with a constant 5-sec COD programmed across all conditions. However, their design failed to control for hysteresis effects (Baum, 1974; de Villiers, 1977; Stevens, 1957) which have been reported when the richer schedule is always programmed on the same response alternative. These effects can result in systematic deviations from matching (Baum, 1974; de Villiers, 1977). Norman and McSweeney used a 5-sec COD which ranged from 8.33% of the richer schedule in the conc VI 1-min VI 2-min condition to 33% of the richer schedule in the conc VI 15-sec VI 1-min condition. Their data supported

Baum's (1974) formulation of the Matching Law (86-99% of the variance explained). The slopes of the regression lines ranged between 0.78 and 1.17 for response matching, and between 0.72 and 1.08 for time matching. The intercepts (k) range from -0.18 to 0.09 and from -0.13 to 0.16 for response ratios and time ratios respectively. They do not report the slopes for Herrnstein's (1961) matching line, however they felt that there may have been systematic deviations from Herrnstein's matching line for individual subjects. These individual deviations from matching may have resulted from a failure to balance the schedules across the response alternatives. Their study does not address the issue of changeover behavior.

Poling (1978) also used conc VI VI schedules, but studied rats working for negative reinforcement (time-out from shock) rather than positive reinforcement. In this study the only response requirement to change between the two schedules was movement from one side to the other of the operant chamber. For this reason the response measure utilized was the time the subjects spent under each component schedule. However, although Poling describes the arrangement of reinforcers as a conc VI VI procedure, it is conceptually similar to a discrete trials procedure. A single VI program was used and each scheduled reinforcer was arranged probabilistically to one of the two response alternatives. Another reinforcer did not become available until the initial reinforcer had been delivered. This means that the animals must pick up all reinforcers in the order they are assigned during the session. In continuous concurrent choice procedures a reinforcer that becomes available on the non-current alternative is held until the animal begins responding on that alternative, however reinforcers continue to become available on the alternative to which an animal is currently responding. With a constant 6-sec COD, the leanest condition (conc VI 1-min VI 1-min) had a COD equal to 10% of the individual component schedules, and the richest condition (conc VI 30-sec VI 30-sec) had a COD equal to 20% of the individual component schedules. Poling reported that the relative time spent under each component varied directly and linearly with the relative reinforcement rate from that component schedule. Herrnstein's (1961) formulation of the matching law accounted for more than 88% of the variance. Baum's (1974) generalized matching law was not fit to the data, therefore the small deviations from proportional matching that were evident cannot be assessed as to the degree of undermatching or bias that is present. Poling (1978) did not report patterns of changeover behavior.

Rider (1981) utilized conc FI VR schedules. It is not possible to determine the ratio of the COD to the richer schedule in this study due to the inclusion of a ratio component. Herrnstein's (1961) model was not fit to the data. Linear regression lines were fit to the Generalized Matching Law (Baum, 1974). The log of response ratios as a function of the log of reinforcement ratios yielded slopes ranging between 0.69 and 0.86, and intercepts ranging from -1.04 to -0.35. The log of time ratios as a function of the log of reinforcement ratios yielded slopes ranging between 0.51 and 0.83, and intercepts ranging from -0.27 to -0.13. The results of this study indicate that each subject undermatched both response ratios and time ratios relative to reinforcement ratios, and displayed systematic bias in favor of the variable ratio schedule. Undermatching was most evident in time measures and the bias towards the ratio schedule was more pronounced in response measures. Rider (1981) also reports that the absolute rate of changeovers tended to decrease as the FI schedule was increased in duration. The pattern of changeovers also altered as the FI was increased. With a short FI the animals would stay throughout the interval before switching into the ratio schedule. As the FI was increased the animals would spend most of their time working on the ratio schedule and would switch only occasionally (and for short time durations) into the FI schedule.

Assessment

A comparison between the results obtained in these six studies is difficult. The only elements common to all the studies are the choice of subjects and the use of concurrent schedules of reinforcement. Poling's (1978) use of time-out from shock as a reinforcer, along with the procedures used for the arrangement of reinforcement contingencies make his study conceptually different from studies using positive reinforcement and continuously available concurrent schedules. Rider's (1981) study didn't employ <u>conc</u> VI VI schedules and therefore cannot be compared with the remaining studies. The use of fixed-interval schedules in concurrent paradigms has been shown to produce undermatching (e.g. LaBounty & Reynolds, 1973; Lobb & Davison, 1975; Nevin, 1971; White & Davison, 1973), and the inclusion of variable-ratio schedules has been shown to produce bias (e.g. Green, Rachlin & Hanson, 1983; Herrnstein & Loveland, 1975). Graft et al. (1977) used <u>conc</u> VI VI schedules, but studied a group of animals living in the experimental setting, and obtaining all their food from the concurrent schedules. The only restriction on the food supply was the animal's willingness to respond. This implies that the animals were in a relatively non-deprived state, and makes comparison of the obtained results to those obtained with deprived animals difficult (Fantino & Logan, 1979, p.225).

The three remaining studies (Baum, 1976; Norman & McSweeney, 1979; Shull & Pliskoff, 1967) are similar to each other along several dimensions. They each employ rats working under continuously available *conc* VI VI schedules for positive reinforcement, and they each employ a COD that ranges up to 25-33% of the richer of the two concurrently available alternatives. With respect to the two questions asked at the outset: (1) do rats show evidence of matching response and time ratios to reinforcement ratios, and (2) if rats show evidence of matching, how is this behavior affected by the inclusion of a changeover delay, all three of these studies found general support for both Herrnstein's (1961) formulation of the matching law, and Baum's (1974) generalization of the matching law. in this sense, the three pertinent studies agree with the large body of literature reviewed by Baum (1979) and Wearden and Burgess (1982). The data presented leads to the conclusion that rats match behavioral output to obtained reinforcement ratios in a manner similar to that reported in pigeon studies.

All three of these studies also all imply that there are systematic changes in changeover behavior in the various conditions of their respective procedures. In the one study that explicitly manipulated COD duration (Shull & Pliskoff,1967), it was found that matching provided a better description of observed performance as the duration of the COD was increased to 7.5 seconds. Increases beyond that had no further effect on matching behavior, but Shull and Pliskoff reported a decrease in changeover rates, and more extreme partitioning of behavior than would be predicted by the underlying reinforcement schedules, as the duration of the COD was increased beyond 7.5 seconds. They speculated that the COD was as important as the relative reinforcement rate in determining response partitioning, and that the two variables interacted to influence changeover behavior. Baum (1974) found a decrease in changeover behavior as the underlying schedules became more disparate. Norman and McSweeney (1978) felt future studies should investigate factors that result in differences between obtained and scheduled reinforcement rates.

Houston and McNamara (1981) addressed these issues in their optimality model. They suggested that if the ratio of the schedules is held constant and the COD is increased relative to the richer schedule an animal will spend an increasing proportion of its time responding to the richer schedule. They further suggested that if the ratio of the COD to the richer schedule is held constant, an animal will exhibit less switching behavior as the ratio of the two concurrent schedules is increased. Their review of the literature could not point to any existing empirical studies that covered the full range of their model's parameters; particularly lacking were studies that tested COD durations that were greater than 33% of the richer available schedule. A full test of the optimality model may provide useful insights into the mechanisms underlying foraging behavior.

Appendix C: Sample Stability Calculation

A subject's performance was considered stable when the overall response rates on both schedules fell within the previous range for five consecutive days. Overall response rates are calculated as the number of responses on an alternative divided by the total session length, and are given as responses per minute. A sample calculation is reproduced below (this data is from Subject #1 on the <u>conc</u> VI 1-min VI 2-min schedule, the 1-minute values are listed first).

Day		Overall Response Rate		
		Right	Left	
1	Low —>	19.30	68.87	<— High
2		44.72	39.68	
3		65.73	20.24	
4		71.12	14.23	<— Low
5		64.80	23.91	
6		62.36	20.48	
7	High —>	71.92	17.80	
8		60.07	20.22	
9		59.15	19.24	
10		58.35	19.54	
11		56.72	23.62	
12		56.05	17.79	

The final stability data for this subject are as follows:

Total Responses		Time in Seconds		Reinforcers	
Right	Left	Right	Left	Right	Left
3600	1212	2856	740	51	14
3548	1154	2850	749	44	14
3499	1172	2752	846	48	18
3403	1417	2676	924	45	15
3353	1064	2914	675	52	14

Appendix D: Stability Data From All Subjects

For each subject the counts represent the daily totals of responses made on, seconds spent on, and total reinforcers received from, the alternate schedule and the constant 1-minute schedule respectively.

SUBJECT #1

Alternate Schedule	Responses Alternate/ 1-minute		Seconds Alternate/ 1-minute		Reinforcers Alternate/ 1-minute	
60	1355	923	2471	1123	43	21
60	1119	1048	2316	1282	40	28
60	1440	1276	2281	1318	41	27
60	1439	1228	2391	1208	42	24
60	1476	1080	2529	1071	50	27
15	1755	4	1311	9	81	0
15	1776	3	1324	3	81	0
15	1776	0	1323	0	81	0
15	1852	0	1338	0	81	0
15	1822	0	1344	0	81	0
30	3429	230	2567	203	78	3
30	4616	42	2580	49	81	0
30	4473	34	2500	78	80	1
30	4163	154	2543	165	77	4
30	4255	415	2488	326	76	5
120	1212	3600	740	2856	14	51
120	1154	3548	749	2850	14	44
120	1172	3499	846	2752	18	48
120	1417	3403	924	2676	15	45
120	1064	3353	675	2914	14	52
60	2837	1819	2167	1427	42	33
60	2688	2097	1851	1747	40	40
60	2400	1967	2024	1570	44	32
60	2725	2118	2005	1593	42	34
60	2677	2273	1921	1623	44	37

SUBJECT #2

Alternate Schedule	Responses Alternate/ 1-minute		Seconds Alternate/ 1-minute		Reinforcers Alternate/ 1-minute	
60	1029	1351	1538	2055	29	41
60	1010	1405	1596	2001	35	36
60	1127	1336	1651	1948	32	35
60	963	1391	1290	2308	26	44
60	1270	1426	1710	1882	37	39
15	887	1	1697	1	81	0
15	658	0	1653	0	81	0
15	1186	18	1649	26	81	0
15	809	0	1662	0	81	0
15	1039	6	1518	11	81	0
30	1171	668	1943	1025	58	23
30	1407	885	1866	931	58	23
30	1506	545	1945	822	61	20
30	1472	905	1808	886	59	22
30	1709	671	2163	809	62	19
120	1423	2110	1321	2275	22	46
120	1061	1975	1117	2482	17	45
120	1214	2301	1186	2414	18	45
120	1241	1671	1549	2051	23	37
120	1352	2052	1359	2241	20	43
60	917	1082	1606	1994	38	38
60	1063	1127	1677	1892	37	42
60	895	1389	1271	2327	32	44
60	865	1189	1623	1975	36	41
60	975	1073	1616	1980	36	40

SUBJECT #3

Alternate Schedule	Responses Alternate/ 1-minute		Seconds Alternate/ 1-minute		Reinforcers Alternate/ 1-minute	
60	2999	2630	1784	1816	38	41
60	2408	2256	1710	1889	39	39
60	2718	2283	1829	1771	39	40
60	2205	3001	1503	2096	34	43
60	2319	2589	1657	1925	38	43
15	2161	0	1467	0	81	0
15	2128	0	1451	0	81	0
15	2100	1	1373	2	81	0
15	2219	0	1413	0	81	0
15	2161	0	1347	0	81	0
30	2768	1160	1757	766	60	21
30	3087	1105	1689	744	59	22
30	2873	1220	1733	874	57	24
30	3263	1097	1832	738	60	21
30	3811	1095	1929	633	63	18
120	1790	3730	1103	2497	22	47
120	2291	3126	1373	2227	22	47
120	1871	3076	1329	2270	21	46
120	1557	3074	1169	2430	22	49
120	1733	3838	1139	2458	21	47
60	2217	1544	1690	1649	39	42
60	2005	1599	1681	1636	42	39
60	2657	1630	1893	1608	42	39
60	2379	1702	1820	1779	41	39
60	2524	1429	1595	2001	44	37

SUBJECT #4

Alternate Schedule	Responses Alternate/ 1-minute		Seconds Alternate/ 1-minute		Reinforcers Alternate/ 1-minute	
60	1167	1287	2212	1380	38	26
60	1193	1115	2388	1210	43	25
60	1350	1083	2430	1164	43	24
60	1223	1051	2394	1203	43	23
60	1111	1275	2170	1420	42	33
15	1136	30	1467	75	80	1
15	1064	42	1413	50	80	1
15	964	37	1448	91	79	2
15	1098	47	1425	63	80	1
15	1135	129	1434	154	77	4
30	2219	659	1981	567	65	16
30	2748	760	1991	616	63	18
30	2037	713	1812	640	60	21
30	2434	769	2010	623	66	15
30	2147	710	1968	622	63	18
120	2126	2291	1665	1931	24	39
120	1296	2944	1295	2296	19	44
120	1388	2829	1429	2163	22	40
120	1402	3056	1455	2138	20	42
120	1275	3276	1331	2268	22	46
60	2147	2246	1737	1860	39	40
60	2352	2286	1738	1829	42	39
60	2168	2021	1933	1620	44	37
60	2079	2341	1773	1827	40	40
60	2085	1841	1905	1537	46	35

SUBJECT #5

Alternate Schedule	Responses Alternate/ 1-minute		Seconds Alternate/ 1-minute		Reinforcers Alternate/ 1-minute	
60	581	744	1505	2088	27	42
60	696	711	1662	1935	31	37
60	642	747	1765	1828	32	34
60	469	719	1523	2064	26	38
60	510	681	1645	1953	28	35
15	684	3	1435	11	81	0
15	690	1	1382	2	81	0
15	708	4	1356	25	80	1
15	655	2	1409	5	81	0
15	704	2	1321	8	81	0
30	1864	267	2197	397	69	12
30	1448	447	2206	789	65	14
30	1275	355	2063	749	63	18
30	1503	281	2085	565	67	14
30	1641	359	2148	546	68	13
120	626	1586	898	2696	14	49
120	531	1170	1180	2418	19	41
120	579	1486	929	2670	15	48
120	418	1669	791	2781	17	52
120	505	1517	807	2792	15	52
60	1081	885	2077	1520	42	34
60	1400	855	2398	1197	47	30
60	1162	822	2222	1369	46	31
60	1246	825	2256	1344	45	34
60	1282	951	2285	1315	46	31

SUBJECT #6

Alternate Schedule	Responses Alternate/ 1-minute		Seconds Alternate/ 1-minute		Reinforcers Alternate/ 1-minute	
60	1052	44	3494	106	52	0
60	958	54	3455	142	54	1
60	874	84	3415	169	51	0
60	1114	113	3351	231	53	1
60	1156	16	3544	53	55	0
15	1165	0	1438	0	81	0
15	1209	2	1423	10	81	0
15	1169	0	1397	0	81	0
15	923	9	1551	44	81	0
15	1126	0	1405	0	81	0
30	2056	0	2564	0	81	0
30	1866	0	2619	0	81	0
30	2039	2	2651	2	81	0
30	1517	149	2560	150	79	2
30	1856	1	2584	3	81	0
120	833	2753	1240	2360	19	46
120	871	2186	1632	1967	21	36
120	1452	2283	1603	1996	23	40
120	918	2504	1187	2411	18	45
120	987	2546	1038	2559	16	50
60	1269	1482	1982	1612	41	34
60	1026	1653	1824	1775	36	35
60	1303	1637	1881	1719	41	34
60	938	1882	1675	1920	32	37
60	938	2101	1530	2066	31	43