A LOCAL MODEL OF CONCURRENT PERFORMANCE

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Concurrent procedures may be conceptualized as consisting of two pairs of schedules with only one pair operating at a time. One schedule of each pair arranges reinforcers for staying in the current alternative, and the other schedule arranges reinforcers for switching to the other alternative. These pairs alternate operation as the animal switches between choices. This analysis of the contingencies suggests that variables operating within an alternative produce behavior that conforms to the generalized matching law. Rats were exposed to one pair of stay and switch schedules in each condition, and the probabilities of reinforcement varied across conditions. Both run length and visit duration were power functions of the ratio of the probabilities of reinforcement for staying and switching. The local model, a model of performance on concurrent procedures, was derived from this power function. Performance on concurrent schedules was synthesized from the performances on the separate pairs. Both the generalized matching law and the local model fitted the synthesized concurrent performances. These results are consistent with the view that the contingencies in the alternative, the probability of stay and switch reinforcement, are responsible for performance consistent with the generalized matching law. These results are compatible with momentary maximizing and molar maximizing accounts of concurrent performance. Models of concurrent performance that posit comparisons among the alternatives are not easily applied to these results.

Key words: concurrent schedules, probability of reinforcement, local models, stay schedules, switch schedules, lever press, rats

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Herrnstein's 1961 paper, showing that responses maintained by concurrent variable-interval (VI) VI schedules were apportioned as reinforcers were apportioned, occasioned experimental and theoretical work aimed at understanding this relationship. Currently, there are several theories that account for Herrnstein's result, which is now called matching. A significant advance was Baum's (1974) proposal of the generalized matching law,

$$\left(\frac{B_1}{B_2}\right) = b\left(\frac{R_1}{R_2}\right)^a, \qquad (1)$$

where B_n is the number of responses or amount of time allocated to each alternative and R_n is the number of reinforcers obtained at each alternative. The constant, a, is interpreted as behavioral sensitivity to reinforcer allocation, and b is a bias towards one alternative. This equation states that the behavior ratio, either responses or time at the alternatives, is a power function of the obtained reinforcer ratio.

One approach to understanding performance on concurrent schedules is to consider behavior and reinforcement contingencies separately for each alternative. MacDonall (1988, 1998), following the lead of Houston and McNamara (1981), showed that concurrent VI VI schedules could be analyzed as consisting of two pairs of schedules. One schedule of each pair arranges reinforcers for staying at one alternative, and the other schedule of the pair arranges reinforcers for switching to the other alternative. Only one pair of schedules operates at a time; switching between alternatives exchanges the pair of schedules operating. In the typical concurrent VI VI procedure, the value of the stay schedule in one pair equals the value of the switch schedule in the other pair. Thus, concurrent VI VI schedules consist of symmetric pairs of stay and switch schedules. Commonly, only one VI timer is used to schedule reinforcers at each alternative; thus, each timer functions alternately to arrange reinforcers according to the stay and switch schedule.

This analysis of concurrent choice procedures as consisting of two pairs of stay and switch schedules might clarify the different performances commonly seen in behavior maintained by concurrent VI VI and concurrent variable-ratio (VR) VR schedules. On concurrent VI VI schedules, the allocation of responses and time varies as a continuous function of the ratio of the VI schedules (de Villiers, 1977), whereas, on concurrent VR VR schedules, responses and time are allocated almost exclusively to the alternative with the higher scheduled reinforcer rate (Herrnstein & Loveland, 1975). This difference might be a result of the different arrangements and operations of the stay and switch schedules. In concurrent VI VI schedules, the schedules usually operate constantly except when a reinforcer is arranged. According to the present conception, this procedure results in the stay VI at one alternative equaling the switch VI at the other alternative. Responding at an alternative results in the likelihood of reinforcement for switching becoming greater than the likelihood of reinforcement for staying. If staying and switching were sensitive to these differential likelihoods of reinforcement, switching would occur at those times and matching would result (cf. Hinson & Staddon, 1983; Shimp, 1966). When the schedule is changed so that the VI schedule correlated with each alternative operates only during responding at that alternative, which makes the switch schedules extinction, behavior is allocated almost exclusively at the alternative with the higher scheduled rate of reinforcement (Findley, 1958). In Findley's study, although the switch schedule was extinction, switching was occasionally reinforced when a stay reinforcer followed the first stay response after a switch. The time it took to switch allowed the stay schedule to operate, arranging reinforcers that were obtained following the next switch back to that alternative. While at the alternative with a higher scheduled rate of reinforcement, the likelihood of reinforcement for staying was always greater than the likelihood of reinforcement for switching. The opposite held while at the less favorable alternative. These differential likelihoods of reinforcement could have resulted in nearly exclusive preference for the alternative with the higher scheduled rate of reinforcement.

In the typical concurrent VR VR procedure (Herrnstein & Loveland, 1975), the ratio schedules associated with each alternative operate only when at that alternative, which makes the switch schedules extinction. As in concurrent VI VI, stay reinforcers could follow a switch. Similar to the VI case, stay responses could arrange for the next stay response to be reinforced, but then if a switch occurred, the first stay response after the next switch back to that alternative would be reinforced. This produced differential patterns of likelihoods of reinforcement for staying and switching that were similar to those seen in Findley's (1958) experiment. Behavior was allocated exclusively at the alternative with the higher scheduled probability of reinforcement (Herrnstein & Loveland, 1975). However, graded matching was produced when the procedure was changed so that both the stay and switch VR schedules operated when responding occurred at either alternative; reinforcers earned at an alternative were held until it was switched to, and the stay schedule at one alternative equaled the switch schedule at the other alternative (MacDonall, 1988). Under these conditions, high frequencies of switching occurred, and matching resulted. Thus, the difference in behavior allocation between concurrent VI VI versus concurrent VR VR schedules might not be the result of the type of schedule (interval versus ratio). Instead, it might be the result of how those schedules usually operate and the relationship of the stay schedule in one alternative to the switch schedule in the other alternative. When the relationships among the stay and switch schedules and how they operate are analogous, behavior allocations are similar (Findley, 1958; MacDonall, 1988).

MacDonall (1998) showed, in a concurrent VI VI procedure, that run length and visit duration were power functions of the ratio of the rates of reinforcement for staying and switching. Run length was the number of responses during a visit to an alternative, and visit duration was the duration of visits to an alternative. He also showed, in a concurrent VR VR procedure, that run lengths and visit durations were power functions of the ratio of the probabilities of reinforcement.

The function relating run length, visit duration, and the ratio of the probabilities of reinforcement may be the basis for a model

of concurrent performance. The power function relating run length to the ratio of the probabilities of reinforcement at Alternative 1 can be expressed as

$$\left(\frac{B_1}{C_2}\right) = l_1\left(\frac{Pt_1}{Pw_2}\right)^{k_1}, \qquad (2)$$

where B_1 is the number of responses at Alternative 1, C_2 is the number of changeovers to the other alternative, Pt_1 is the probability that responding at Alternative 1 arranged a reinforcer for staying at Alternative 1, and Pw_2 is the probability that responding at Alternative 1 arranged a reinforcer for switching to the other alternative. The parameters k_1 and l_1 are constants representing, respectively, behavioral sensitivity to differences in the probabilities of reinforcement for staying at the present alternative and for switching to the other alternative, and bias to emit stay responses or to stay at the current alternative.

The probability that a response at Alternative 1 arranged a reinforcer for staying is the number of reinforcers obtained for staying at Alternative 1 (Rt_1) divided by the number of responses at Alternative 1 (B_1). The probability that a response at Alternative 1 arranged a reinforcer for switching to Alternative 2 is the number of reinforcers obtained for switching to Alternative 2 (Rw_2) divided by the number of responses at Alternative 1 (B_1). Substituting for the obtained probability of reinforcement for staying (Rt_1/B_1) and the obtained probability of reinforcement for switching (Rw_2/B_1) and simplifying yields

$$\left(\frac{B_1}{C_2}\right) = l_1\left(\frac{Rt_1}{Rw_2}\right)^{k_1}. \qquad (3)$$

Expressing this equation in logarithmic form produces

$$\log\left(\frac{B_1}{C_2}\right) = k_1\log\left(\frac{Rt_1}{Rw_2}\right) + \log l_1, \qquad (4)$$

which plots as a straight line and can be fitted using least squares linear regression.

In a concurrent procedure, run lengths at Alternative 1 are a power function of the number of reinforcers obtained for staying at Alternative 1 divided by the number of reinforcers for switching to Alternative 2. There is a corresponding power function for run length and reinforcers at Alternative 2. A model of concurrent performance based on the ratio of these power functions is,

$$\frac{\left(\dfrac{B_1}{C_2}\right)}{\left(\dfrac{B_2}{C_1}\right)} = \frac{l_1\left(\dfrac{Rt_1}{Rw_2}\right)^{k_1}}{l_2\left(\dfrac{Rt_2}{Rw_1}\right)^{k_2}} = \frac{l_1}{l_2}\left(\frac{Rt_1}{Rw_2}\right)^{k_1}\left(\frac{Rw_1}{Rt_2}\right)^{k_2}. \qquad (5)$$

Run length at Alternative 1 is the total responses at Alternative 1, B_1, divided by the total switches to Alternative 2, C_2. The ratio of reinforcers earned at Alternative 1 is the number reinforcers earned for staying at Alternative 1, Rt_1, divided by the number of reinforcers earned for switching to Alternative 2, Rw_2. Similarly, run length at Alternative 2 is the total responses at Alternative 2, B_2, divided by the total switches to Alternative 1, C_1. The ratio of reinforcers earned at Alternative 2 is the number reinforcers earned for staying at Alternative 2, Rt_2, divided by the number of reinforcers earned for switching to Alternative 1, Rw_1. This model, called the local model, suggests that concurrent performance consists of two independent performances, one at each alternative. These performances are joined by the changeover response, but the variables that control behavior at one alternative are independent of the variables that control behavior at the other alternative. Because previous results indicate that k_1 and k_2 are stable across sessions and conditions (MacDonall, 1998), assume $k_1 = k_2$ and substitute k'. Letting $b = l_1/l_2$, and rearranging, produces

$$\frac{\left(\dfrac{B_1}{C_2}\right)}{\left(\dfrac{B_2}{C_1}\right)} = b\left(\frac{Rt_1 \cdot Rw_1}{Rt_2 \cdot Rw_2}\right)^{k'}. \qquad (6)$$

This equation says the ratio of run lengths is a power function of the ratio of the product of the number of reinforcers obtained at each alternative. Expressing this equation in logarithmic form, which plots as a straight line and allows fits by least squares linear regression, yields

$$\log\left[\left(\frac{B_1}{C_2}\right)\Big/\left(\frac{B_2}{C_1}\right)\right] = k' \log\left(\frac{Rt_1 \cdot Rw_1}{Rt_2 \cdot Rw_2}\right) + \log b. \qquad (7)$$

MacDonall (1998) noted that the generalized matching law (Equation 1) might be rewritten by viewing behavior on a per-visit basis. Dividing the numerator and denominator of the left side of Equation 1 by the number of changes out of their respective alternatives produces

$$\left(\frac{B_1}{C_2}\right)\bigg/\left(\frac{B_2}{C_1}\right) = b\left(\frac{R_1}{R_2}\right)^a, \qquad (8)$$

where the symbols are as in previous equations. Because the numbers of changes out of each alternative are necessarily within one of each other, and the number of changeovers is large, say greater than 100, the value of the response ratio is essentially unchanged. This equation says the ratio of run lengths at each alternative is a power function of the ratio of obtained reinforcers at each alternative. Because the number of reinforcers obtained at each alternative is the sum of the number of stay and switch reinforcers obtained at that alternative, this equation could be expressed as

$$\left(\frac{B_1}{C_2}\right)\bigg/\left(\frac{B_2}{C_1}\right) = b\left[\frac{(Rt_1 + Rw_1)}{(Rt_2 + Rw_2)}\right]^a. \qquad (9)$$

Just as behavior can be viewed on a per-visit basis, reinforcers can be viewed on a per-visit basis. The reinforcers per visit for staying at an alternative are the number of reinforcers for staying (Rt_1) divided by the number of visits, C_2, that is, the number of switches to Alternative 2, producing Rt_1/C_2 and Rt_2/C_1. The reinforcers per visit for switching to that alternative are the number of reinforcers for switching, Rw_1, divided by the number of switches to that alternative, C_1, producing Rw_1/C_1 and Rw_2/C_2. Substituting the per-visit number of reinforcers into the above equation yields

$$\left(\frac{B_1}{C_2}\right)\bigg/\left(\frac{B_2}{C_1}\right) = b\left\{\frac{\left[\left(\frac{Rt_1}{C_2}\right) + \left(\frac{Rw_1}{C_1}\right)\right]}{\left[\left(\frac{Rt_2}{C_1}\right) + \left(\frac{Rw_2}{C_2}\right)\right]}\right\}^a. \qquad (10)$$

Again, because the numbers of changeovers out of each alternative are within one of each other, and the number of changeovers is large, the value of the reinforcer ratio is unchanged. Expressing this equation in logarithmic form, which plots as a straight line and allows fits by least squares linear regression, produces

$$\log\left(\frac{B_1}{C_2}\right)\bigg/\left(\frac{B_2}{C_1}\right)$$
$$= a\log\left\{\frac{\left[\left(\frac{Rt_1}{C_2}\right) + \left(\frac{Rw_1}{C_1}\right)\right]}{\left[\left(\frac{Rt_2}{C_1}\right) + \left(\frac{Rw_2}{C_2}\right)\right]}\right\} + \log b. \qquad (11)$$

This equation states that the log of the ratio of run lengths is proportional to the log of the ratio of the sum of the stay and switch reinforcers obtained on each visit plus a constant.

The previous analysis focused on run length and probabilities of reinforcement. Parallel arguments, which substitute visit duration for run length or reinforcement rates for probabilities of reinforcement, produce corresponding conclusions.

Recognizing that stay and switch schedules operate at each alternative of a concurrent schedule suggests methods to manipulate those contingencies, allowing an experimental investigation of these independent variables. The results of two experiments support the present view, that performances at the alternatives are independent of each other, by showing that performance consistent with generalized matching (Equation 11) could be synthesized from simpler elements (MacDonall, 1998). MacDonall exposed rats to the pair of schedules at one alternative of a concurrent procedure and varied the parameters of the stay and switch schedules. The resulting run lengths, visit durations, and stay and switch reinforcers were well fitted by Equation 11.

The purpose of the present experiment was to begin to assess the adequacy of the local model (Equation 7) as a general model of concurrent performance. Aspects of procedures used in prior experiments (MacDonall, 1998) did not accurately reproduce typical contingencies in concurrent schedules when concurrent performance was synthesized from the independent performances. For example, in Experiment 1 of the earlier

study, the analysis synthesized a one-lever procedure; switching was reinforced immediately after a press of the changeover lever, rather than waiting until the first press of the main lever for reinforcement (or waiting until the first press of the main lever after changeover delay elapsed; Findley, 1958). In addition, switching required two changeover-lever responses and allowed main-lever responses to intervene. In Experiment 2 of the earlier study, the stay and switch schedules did not always operate simultaneously, unless a reinforcer was arranged, as occurs in concurrent VI VI schedules. In the present experiment, rats were exposed to one pair of stay and switch schedules in which the contingencies were equivalent to those at one alternative of a two-lever concurrent VR VR programmed to operate like a concurrent VI VI, and the schedule parameters varied. For two reasons, VR rather than VI schedules were used. First, between responses on concurrent VR VR schedules, the probability of stay and switch reinforcement is constant, whereas between responses on concurrent VI VI schedules, the probability of stay and switch reinforcement changes with each clock tick. Second, the prior analyses showed that performance on concurrent VI VI schedules is equivalent to performance on concurrent VR VR schedules provided that the stay schedule at each alternative equals the switch schedule at the other alternative. The results support three conclusions. First, run length and visit duration were power functions of the ratio of the obtained probabilities of reinforcement (Equation 4). Second, Equation 7 was supported for both run lengths and visit durations, using obtained probabilities of reinforcement. Third, Equation 11 was supported for both run lengths and visit durations, using obtained reinforcers per visit. That is, performance on concurrent schedules was synthesized and matching produced by combining results from independent but symmetric pairs of stay and switch schedules.

METHOD

Subjects

The subjects were 4 male albino Sprague-Dawley rats obtained from Hilltop Animal Labs, Inc. When they were approximately 130 days old, they were maintained at 80% of their then-determined free-feeding weights and the present experiment began. The rats were housed individually in a temperature-controlled colony room on a 14:10 hr light/dark cycle with free access to water. Because Rat 381 became ill during Condition 20, it was removed from the experiment. Their behavior was magazine trained, shaped to lever pressing, and exposed to schedules up to FR 10 by students in introductory psychology laboratory sections.

Apparatus

Four operant conditioning chambers were each located in a sound- and light-controlled enclosure. Each was 20 cm wide and 20 cm high, three were 20 cm long, and one was 30 cm long. The food cup, 5 cm square, was centered horizontally on one 20-cm wide wall 1 cm above the floor. The centers of two response levers, 5 cm long and 1 cm high (Gerbrands G6312), were located 5.5 cm from the center line of the food cup 5 cm above the floor. A minimum force of approximately 0.3 N operated each lever. A Gerbrands feeder, located behind the food cup, dispensed 45-mg rodent pellets (Noyes Formula A/1). A houselight, mounted on the ceiling of the enclosure, operated during sessions. A speaker, located on the ceiling of the chamber, presented white noise. In an adjacent room, an IBM-compatible computer with MED Associates Inc. hardware and MED-PC® software recorded responses and controlled contingencies.

Procedure

Responses on the left (stay) lever incremented the stay and switch VR counters. When the stay counter arranged a reinforcer, it was delivered immediately. When the switch counter arranged a reinforcer, it was delivered for the first press on the right (switch) lever. Additional presses on the stay lever before the switch reinforcer was obtained continued to increment the stay counter and deliver a stay reinforcer if arranged. The next value for the switch ratio was not incremented until the switch reinforcer was obtained. Presses on the switch lever obtained the switch reinforcer only if arranged; they did not increment either counter. The contingencies resembled those at the left alternative of

a two-lever VI-like concurrent VR VR procedure.

The Appendix lists, for each rat, the sequence of conditions and the number of sessions that each condition was in effect. The experiment consisted of three phases. In the first phase (14 or 16 conditions), the rats were exposed to all possible combinations of VR 10, VR 20, VR 40, and VR 80 as the stay and switch schedules. In the second phase, various other stay and switch VR schedules were used. The third phase consisted of combinations of stay and switch VR schedules that produced an overall scheduled probability of reinforcement equal to .05. The overall scheduled probability of reinforcement was the sum of the scheduled probability of reinforcement for staying plus the scheduled probability of reinforcement for switching. The scheduled probability of reinforcement was the reciprocal of the VR schedule value (1/VR stay, or 1/VR switch).

When the ratio of probabilities of reinforcement (probability of reinforcement for staying divided by the probability of reinforcement for switching) was extreme, for example, 9 or 0.11, then during each session one schedule was expected to deliver 10 reinforcers and the other delivered 90 reinforcers. If the VR schedule consisted of more than 10 ratios, then depending on which ratios were selected, the obtained number of reinforcers could vary widely from the scheduled number. To try to keep the number of scheduled and obtained reinforcers the same, each VR schedule contained only 10 ratios. The 10 ratios were exponentially distributed and obtained by the method of Fleshler and Hoffman (1962), in which responses were treated as seconds and ratios were rounded to the nearest whole number. Values from the set were randomly selected without replacement, each day beginning at a different location on the list. There was no changeover delay (COD; Herrnstein, 1961). Conditions remained in effect for at least 10 sessions and until visual inspection showed there were no apparent upward or downward trends in mean run lengths or mean visit durations for five consecutive sessions. The houselight and white noise were on only during sessions. Typically, sessions were conducted 7 days per week and ended after 100 reinforcers or at least 1 hr had elapsed.

Initial training. Because the rats had been exposed to FR schedules in introductory psychology laboratories, stay and switch schedules began at VR 10 and, except for Rat 381, increased over the next 15 to 20 sessions to the VR schedules used in the first condition. Because the first condition for Rat 381 was VR 10 for staying and VR 10 for switching, the experiment began at this point. Pressing the switch lever was not shaped. This response emerged when the stay and switch schedules were VR 10.

RESULTS

All calculations were based on the sums of the last five sessions of data. The Appendix presents these sums for number of stay responses, switch responses (first press of the switch lever after the stay lever was pressed), extra switch responses before the stay lever was next pressed, number of reinforcers for staying and switching, and time in the session.

Figure 1 shows, for all conditions in the experiment, that mean run length and mean visit duration increased as the ratio of the probabilities of reinforcement increased. Mean run length was the number of presses on the stay lever divided by the number of switches. Mean visit duration was the session time divided by the number of switches. In some conditions with low frequencies of reinforcement (e.g., Rat 383, VR 21.33 for staying and VR 320 for switching), responding was not maintained for the entire session: At the beginning of each session, stay and switch responding was reliable, but the rats stopped responding before 100 reinforcers were obtained. In those conditions, pauses exceeded 5 min, which produced unusually long session durations. Because the sequential visit durations were recorded, the mean visit duration, before responding stopped, was calculated. If the session ended with a long (>5 min) visit duration, the last visit duration was deducted from the session duration and then mean visit duration was calculated. For those sessions, mean visit duration was the session duration minus the last visit duration divided by the adjusted number of switches. In several sessions as many as the last three visit durations were unusually long, and these were deducted from the session duration. The number of switches was adjusted according to the
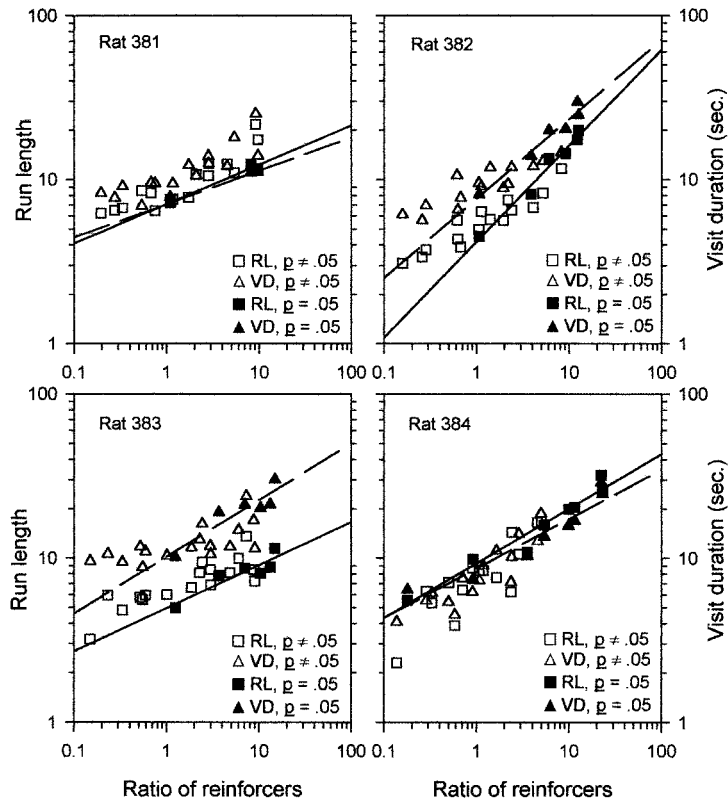
Fig. 1. On log-log coordinates, mean run length and mean visit duration as a function of the ratio of the number of reinforcers obtained for staying to the number of reinforcers obtained for switching. The missing data points were conditions in which run lengths could not be determined: Rat 384 stopped pressing the switch lever when VR 10 was the stay schedule and VR 80 was the switch schedule; Rat 383 stopped pressing both levers when VR 80 was the stay schedule and VR 80 was the switch schedule; the condition in which VR 10 was the stay schedule and VR 10 was the switch schedule was accidentally omitted. Because Rat 382 stopped responding under VR 80 stay and VR 40 switch, his schedule was changed to VR 70 stay and VR 40 switch. During Phases 1 and 2 the overall scheduled probabilities of reinforcement varied. Open symbols represent results from these conditions. Phase 3 maintained a constant overall scheduled probability of reinforcement equal to .05; the results from these conditions are filled symbols. The results from the VR 40 for staying and VR 40 for switching, which were part of Phase 1, are depicted with a filled symbol because the scheduled overall probability of reinforcement was .05. Solid lines represent the best fitting line for run length, and dashed lines represent the best fitting line for visit duration. Occasionally a cluster of data points obscures a data point.

number of visits that were excluded. Conditions with these adjustments to session duration, which comprised 11 of the 88 conditions in the experiment, are noted in the Appendix.

Because the plots in Figure 1 are roughly linear on log-log coordinates, run length and visit duration are approximated by power functions of the ratio of the reinforcers. The overall scheduled probability of reinforcement, the sum of the scheduled probabilities of reinforcement for staying and switching, varied among conditions. For example, when VR 10 was the stay schedule and VR 10 was

the switch schedule, the overall scheduled probability of reinforcement was .2 (.1 plus .1); when VR 80 was the stay schedule and VR 80 was the switch schedule, the overall scheduled probability of reinforcement was .025 (.0125 plus .0125). An overall probability of reinforcement of .05 was most common. Because the overall probability of reinforcement may affect run length or visit duration, data from conditions with an overall scheduled probability of reinforcement of .05 are indicated. Because holding the overall scheduled probability of reinforcement constant appeared to reduce variability, only data from

Table 1

Fits of Equation 4 to mean run length or mean visit duration as a function of the ratio of the number of reinforcers obtained for staying and switching when the overall scheduled probability of reinforcement was .05.

Rat	k_1	SE	log l_1	SE	df	r^2
Run lengths						
381	0.24	0.04	0.85	0.03	1	.97
382	0.58	0.05	0.62	0.04	4	.97
383	0.26	0.06	0.69	0.05	4	.83
384	0.33	0.03	0.97	0.03	6	.95
Visit durations						
381	0.20	0.01	0.85	0.01	1	1.00
382	0.48	0.05	0.89	0.04	4	.96
383	0.35	0.08	1.01	0.07	4	.84
384	0.30	0.04	0.94	0.04	6	.89

conditions with an overall probability of reinforcement of .05 were fitted by Equation 4. Table 1 presents fits of Equation 4 to run length and visit duration. Fits to run length

are good to excellent, r^2 is greater than .83, and the standard errors are small. Slopes (k_1) range from 0.24 to 0.58, and the y intercepts (log l_1) range from 0.62 to 0.97. Fits to visit duration are also good to excellent, r^2 is greater than .84, and the standard errors are small. The slopes (k_1) range from 0.20 to 0.48, and the y intercepts (log l_1) range from 0.85 to 1.01.

The data from symmetric pairs of conditions in Phase 1 were used to synthesize concurrent performance. Because data were not available for some conditions, the data from the corresponding paired condition could not be used in the synthesis. This resulted in 10 rather than 12 conditions for Rats 382 and 384. Figure 2 shows, for conditions used to synthesize concurrent performance, that mean run length and mean visit duration increased with the ratio of the number of reinforcers for staying to the number of rein-
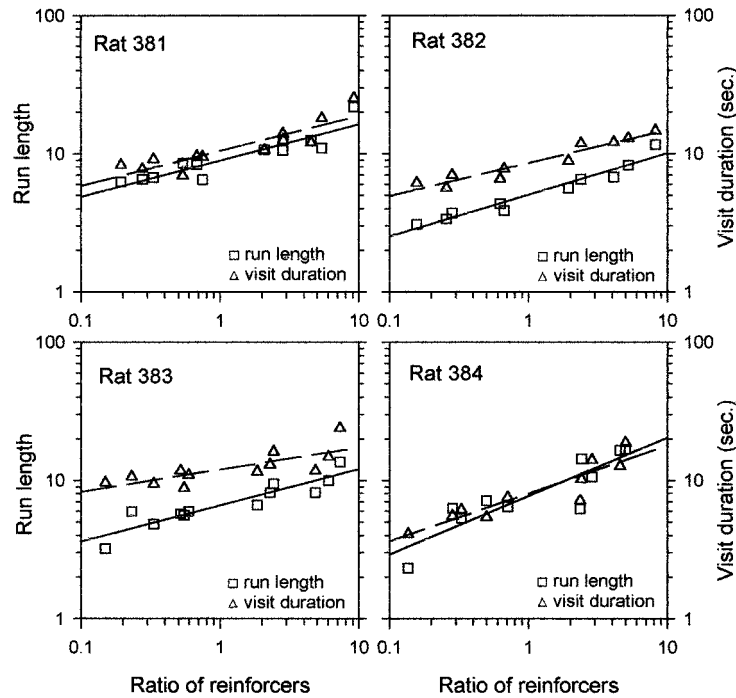
Fig. 2. On log-log coordinates, mean run length and mean visit duration as a function of the ratio of reinforcers obtained for staying to reinforcers obtained for switching. The data used in this figure were from the symmetric pairs of stay and switch schedules, from Phase 1, that were used to synthesize concurrent performance in Figures 3 and 4. For some rats and some pairs, data from only one of the symmetric pairs was available: Rat 384, VR 10 stay and VR 80 switch, stopped switching so run lengths could not be determined, and data from the symmetric condition, VR 80 stay VR 10 switch, were omitted; Rat 382, VR 70 stay and VR 40 switch and VR 40 stay and VR 80 switch, do not form symmetric pairs, so data from both conditions were omitted. Solid lines represent the best fitting line for run length, and dashed lines represent the best fitting line for visit duration.

Table 2

Fits of Equation 4 to mean run length or mean visit duration as a function of the ratio of the number of reinforcers obtained for staying and switching from pairs of conditions in Phase 1 that were used to synthesize concurrent performance.

Rat	k_1	SE	$\log l_1$	SE	df	r^2
Run lengths						
381	0.26	0.04	0.95	0.02	10	.83
382	0.30	0.03	0.70	0.01	8	.94
383	0.26	0.04	0.82	0.02	10	.84
384	0.38	0.09	0.89	0.04	8	.66
Visit durations						
381	0.25	0.04	1.02	0.02	10	.78
382	0.24	0.02	0.93	0.01	8	.92
383	0.16	0.04	1.08	0.02	10	.60
384	0.38	0.07	0.88	0.03	8	.76

forcers for switching. Because the relations are roughly linear on log-log coordinates, run length and visit duration are approximated by power functions of the ratio of reinforcers. Table 2 presents fits of Equation 4 to these data. Fits to run lengths are fair to good, r^2 ranges from .66 to .94, and the standard errors are small. The slopes (k_1) range from 0.26 to 0.38, and the y intercepts ($\log l_1$) range from 0.70 to 0.95. The fits to visit duration are fair to good, r^2 ranges from .60 to .92. Slopes (k_1), which are less than for run length, range from 0.16 to 0.38. The y intercepts ($\log l_1$) range from 0.88 to 1.08. Variations in the overall probability of reinforcement appeared to increase variability in run length and visit duration (Figure 1). The values of r^2 were higher in seven of eight com-

parisons when the overall probability of reinforcement was held constant (Table 1) than when it varied (Table 2).

If concurrent performance is based on the behavior and contingencies at each alternative, then data from pairs of conditions in the present experiment can be used to synthesize concurrent performance according to the local model (Equation 7) and the generalized matching law (Equation 11). Conditions from Phase 1 were grouped into symmetric pairs to synthesize traditional concurrent procedures. The pair of schedules VR x for staying and VR y for switching and the pair of schedules VR y for staying and VR x for switching form a symmetric pair of schedules, synthesizing concurrent VR x VR y. Figure 3 shows the results of the synthesis according to the local model. The log ratio of run lengths and visit durations increased as the log ratio of the products of reinforcers for staying and switching increased. Because the plots of the log values are roughly linear, the ratios of run lengths and of visit durations are approximated by power functions of the ratio of the products of the reinforcers. Run lengths and visit durations are used, and not total responses or time, because the number of switches differs among members of each pair. The numerators of each ratio were the values from the first of the two conditions that comprised the relevant ratio. However, when two pairs of conditions produced approximately the same ratio of products of reinforcers (according to Equation 7), the value from the first condition in the second pair comprised
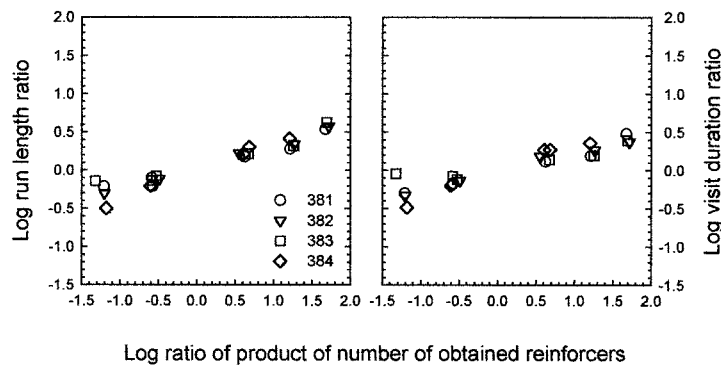

Fig. 3. Log ratio of mean run lengths and mean visit durations as a function of the log ratio of the product of the number of reinforcers obtained for staying and switching (see Equation 7). These are the same pairs of conditions as in Figures 2 and 4.

Table 3

Fits of Equation 7 to mean run length or mean visit duration as a function of the obtained number of stay and switch reinforcers. To facilitate comparisons of the results of these fits to the fits of Equations 4 and 11, k_1 from Table 2 and $a/2$ from Table 4 are reproduced in this table.

Rat	k'	SE	log b	SE	df	r^2	k_1	$a/2$
Run lengths								
381	0.26	0.03	0.03	0.03	4	.95	0.26	0.24
382	0.29	0.02	0.04	0.02	3	.99	0.30	0.28
383	0.25	0.04	0.09	0.04	4	.91	0.26	0.24
384	0.38	0.02	−0.01	0.02	3	.99	0.38	0.36
Visit durations								
381	0.25	0.02	−0.02	0.03	4	.96	0.25	0.24
382	0.24	0.02	−0.01	0.02	3	.98	0.24	0.23
383	0.15	0.03	0.05	0.04	4	.84	0.16	0.15
384	0.37	0.03	−0.01	0.03	3	.98	0.38	0.34

the denominator of the ratio. This method was used to produce a greater range in the ratio of the products of reinforcers. For example, VR 40 VR 20 and VR 80 VR 40 both produced ratios of products of about 0.25; placing the first condition for the VR 80 VR 40 pair in the denominator produced a ratio of products of about 4.0. Table 3 presents the fits of Equation 7 to these data, which are good to excellent; r^2 exceeds .84 for each rat, and the standard errors are small. Slopes (k') range from 0.15 to 0.38, and the y intercepts (log b) are close to zero. Each rat's slope for run length was greater than the slope for visit duration. To facilitate comparison of k' with k_1, Table 3 also presents the slopes for run length and visit duration from Table 2. For each rat, the slope (k_1) is within 0.66 standard errors of the corresponding slope (k').

Concurrent performance also may be synthesized according to Equation 11 using the data from pairs of conditions in Phase 1 (the same pairs used in Figure 3 and Table 3). MacDonall (1998) showed that performance on a one-lever concurrent procedure could be synthesized by fitting Equation 11 to run lengths and visit durations. The conditions from Phase 1 were grouped into symmetric pairs, as in Figure 3. The number of stay reinforcers per visit (Rt_1/C_2 or Rt_2/C_1) is the number of reinforcers for staying at one alternative divided by the number of switches to the other alternative. The number of switch reinforcers per visit (Rw_1/C_1 or Rw_2/C_2) is the number of reinforcers for switching to an alternative divided by the number of switches to that alternative. Because the analysis is based on per-visit behavior and the number of visits varied in different conditions, calculations used per-visit responses and reinforcers and not the absolute numbers of these variables. Figure 4 shows that the log ratio of run lengths and the log ratio of visit durations increased, roughly linearly, as the log synthesized reinforcer ratio increased. Table 4 presents the fits of Equation 11 to these data, which are good to excellent; r^2 is greater than .84, and standard errors are small. Undermatching was consistently found ($a < 1.0$). Slopes (a) ranged from 0.48 to 0.72 for run lengths and from 0.30 to 0.69 for visit durations. For each rat, the slope for ratios of run lengths was greater than the slope for ratios of visit durations. There was no systematic bias. To facilitate comparisons of $a/2$ and k', Table 3 also presents $a/2$. In all comparisons, $a/2$ is within 1 standard error of the estimate of k'.
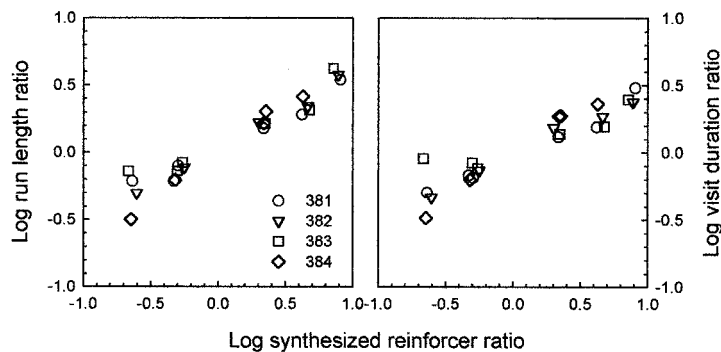

Fig. 4. Log ratio of mean run lengths and mean visit durations as a function of the log synthesized reinforcer ratio. These are the same pairs of conditions as in Figures 2 and 3.

Table 4

Fits of Equation 11 to mean run length or mean visit duration as a function of the per-visit number of reinforcers obtained for staying and switching.

Rat	a	SE	$\log b$	SE	df	r^2
Run lengths						
381	0.49	0.05	0.03	0.03	4	.96
382	0.56	0.04	0.03	0.02	3	.99
383	0.48	0.08	0.08	0.04	4	.91
384	0.72	0.04	−0.00	0.02	3	.99
Visit durations						
381	0.47	0.04	−0.02	0.02	4	.97
382	0.47	0.03	−0.02	0.02	3	.98
383	0.30	0.07	0.05	0.04	4	.84
384	0.69	0.05	−0.00	0.02	3	.98

Momentary maximizing proposes that the response (stay or switch) that is most likely to be reinforced at the moment of responding is the response that occurs (Shimp, 1966). Because VR schedules were used, the run length predicted by momentary maximizing can be determined for each condition. The probability of reinforcement for staying was approximately constant and was estimated by the obtained probability of stay reinforcement, the number of stay reinforcers divided by the number of responses. The probability of reinforcement for switching began as the obtained probability of reinforcement for switching, Pw, the number of switch reinforcers divided by the number of stay responses, increased as stay responses occurred, and returned to the initial value when a switch response occurred. The probability of reinforcement for switching was approximated by $[1 - (1 - Pw)^N]$, where N is the number of stay responses since the last switch response (MacDonall, 1998). Using these two estimates of the probability of reinforcement for staying and switching, run lengths were predicted. The predicted run length for each condition was the shortest run length (N) whose probability of reinforcement for switching was greater than the probability of reinforcement for staying. Figure 5 shows, for each rat, that the obtained run lengths were roughly linearly related to the run lengths predicted by momentary maximizing. The diagonal lines represent the predictions by momentary maximizing. For each rat the obtained run length was displaced upwards from the diagonal by an approximately constant amount.

The effect is clearly seen for Rats 381, 382, and 384. The data for Rat 383 are more difficult to interpret. The results are consistent with the other rats, except for the five rightmost points. These five data points are from conditions in which responding was not well maintained throughout the session, which may have affected run length.

Figure 6 presents the percentage of the maximum number of reinforcers obtained as a function of the ratio of the scheduled probabilities of reinforcement (stay/switch). The maximum possible number of reinforcers was a function of the number of stay responses, which incremented the stay and switch VR schedules; switch responses collected switch reinforcers arranged by stay responding. Thus, the maximum number of reinforcers was the sum of the number of stay responses divided by the stay VR plus the number of stay responses divided by the switch VR. As the ratio of the scheduled probability of reinforcement increased, the percentage of possible reinforcers that were obtained also increased. When the scheduled ratio was large (the stay VR was small and the switch VR was large), usually almost all the possible reinforcers were obtained. When the scheduled probabilities were equal, from 84% to 98% of the maximum reinforcers were obtained. When the ratio was small, as few as 76% of the possible reinforcers were obtained. In 10 conditions, slightly more than the maximum number of reinforcers were obtained, up to 101.3%, which probably resulted from the start of each session not resuming at the point in the ratio when the prior session ended or from sampling error.

DISCUSSION

The results of the present experiment support the view that concurrent performance consists of two independent performances, one at each alternative. Varying the stay and switch VR schedules systematically changed run lengths and visit durations (Figures 1 and 2). When performances from appropriate conditions, consisting of symmetric pairs of schedules, were combined according to Equations 7 and 11, concurrent performances were synthesized (Figures 3 and 4), even though these data were not obtained from al-
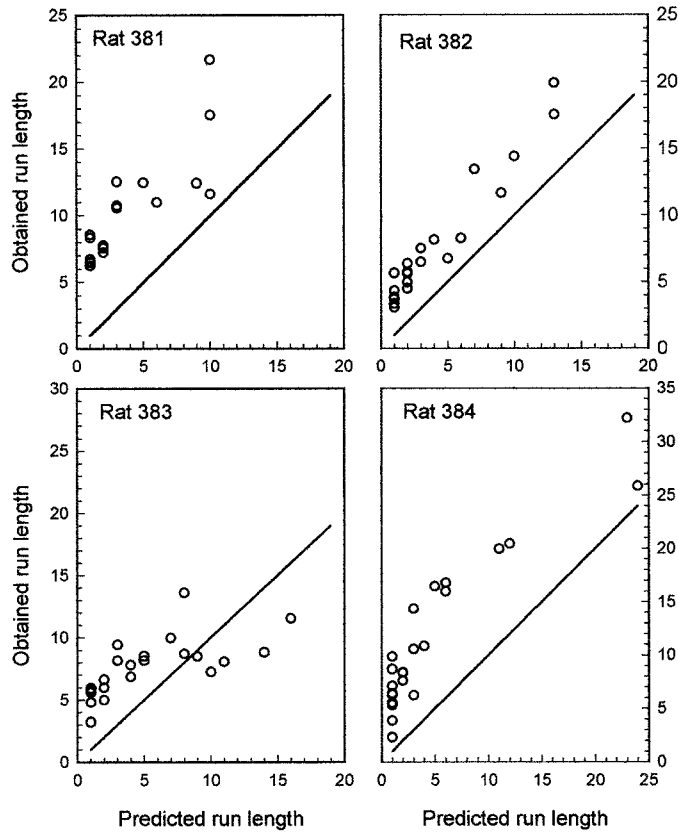
Fig. 5.   The obtained mean run length plotted against the run length predicted by momentary maximizing. The diagonal line represents perfect conformance to momentary maximizing.
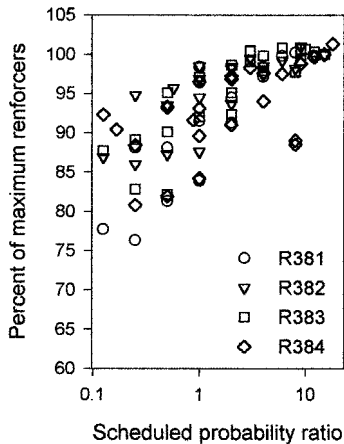
Fig. 6.   Percentage of the maximum possible reinforcers actually obtained as a function of the ratio of the scheduled probabilities of reinforcement (stay/switch). The scheduled probability of reinforcement was the reciprocal of the schedule value.

ternative choices in a concurrent procedure but rather from successive conditions.

Synthesizing concurrent procedures from the present procedures reproduced contingencies typically found in concurrent scheduling; the resulting synthesized concurrent performance was similar to performances obtained on concurrent schedules. The synthesis according to the generalized matching law resulted in excellent fits and no biases. MacDonall (1998) synthesized VI-like concurrent VR VR, as in the present experiment, and concurrent VI VI performance according to the generalized matching law and obtained large biases. Two unusual features of MacDonall's procedure, which were not present in the current procedures, probably contributed to the biases. First, the synthetic concurrent procedure, from MacDonall's Experiment 1, required rats to make two presses on the changeover lever to change the stimuli and associated schedules, which resembles FR

2 for switching. Marcucella and Margolius (1978) and Pliskoff and Fetterman (1981) used concurrent VI procedures with main and switching keys and pigeons as subjects, and also required completing an FR changeover requirement to change the stimuli and associated schedules. To prevent responding during the FR changeover requirement, Marcucella and Margolius (1978) and Pliskoff and Fetterman (1981) stopped illuminating the main key until the FR was completed. MacDonall used rats and did not prevent main-lever responses during the FR 2 changeover requirement. He found that rats pressed the main lever after the first and before the second press of the switch lever. It was unclear how these responses affected synthesized concurrent performance. The current synthesis required one switch response, moving from one lever to the other, to change alternatives, as in a two-lever concurrent procedure. Second, in MacDonall's Experiment 2, performance on concurrent VI VI schedules was synthesized. In this synthesized procedure, presses on the changeover lever started the stay timer, but the switch timer did not start until the rat pressed the main lever. Typically, on a one-lever concurrent VI VI procedure, pressing the changeover lever starts both the stay and switch timers simultaneously. In the present synthesis, presses on the main lever always incremented the stay and switch VR schedules unless a switch reinforcer was arranged. The contingencies in the present experiment when combined produced a typical two-lever concurrent schedule. The results of the present synthesis were consistent with the generalized matching law with no biases, supporting MacDonall's (1998) suggestion that the biases in the previous syntheses were due to the unusual contingencies.

Run Length and Visit Duration

Run length and visit duration were well described by Equation 4, that is, as power functions of the ratio of reinforcers for staying and switching (Figures 1 and 2, Tables 1 and 2). Also, the good fit of the data to Equation 7 (the combined data from symmetric pairs of schedules; Figure 3 and Table 3) further supports the utility of Equation 4, as does the close correspondence between k_1 from Equation 4 and k' from Equation 7 (Table 3). It is unlikely that such correspondence would oc-

cur unless power functions described the run length and visit durations.

Local Model

In a concurrent procedure, which is the fundamental relationship, Equation 4 or Equation 7? That is, in a concurrent procedure does behavior conform to Equation 4 and consequently produce behavior conforming to Equation 7? Because Equation 7 is derived from Equation 4, and Equation 4 cannot be derived from Equation 7, Equation 4 is the more fundamental. That is, probabilities of reinforcement for staying and switching affect run length and visit duration directly rather than as by-products of concurrent performance. The results of the present experiment, which were not obtained in a concurrent procedure and were well fitted by Equation 4, provide empirical support for the primacy of Equation 4.

The present data suggest that performance on concurrent schedules is comprised of independent performances at the alternatives, and that concurrent performance can be synthesized from these independent performances in accord with Equations 7 and 11. Table 4 shows that the generalized matching law fitted concurrent performance synthesized from run lengths, visit durations, and the obtained numbers of stay and switch reinforcers per visit. Equation 7 (the local model) and the generalized matching law are related. In concurrent schedules, the scheduled probability of reinforcement for staying at each alternative equals the scheduled probability of reinforcement for switching to that alternative. Assuming reasonably frequent switching, the obtained probability of reinforcement for staying at each alternative approximately equals the obtained probability of reinforcement for switching to that alternative ($Pt_1 \cong Pw_1$ and $Pt_2 \cong Pw_2$). Substituting the probabilities of reinforcement for numbers of reinforcers in Equation 7 yields

$$\frac{(B_1/C_2)}{(B_2/C_1)} \cong b\left[\frac{(Pt_1 \cdot Pt_1)}{(Pt_2 \cdot Pt_2)}\right]^k = b\left(\frac{Pt_1}{Pt_2}\right)^{2k}. \quad (12)$$

From Equation 11, substituting the feedback functions and factoring produces

$$\frac{(B_1/C_2)}{(B_2/C_1)} \cong b\left(\frac{Pt_1}{Pt_2}\right)^a. \quad (13)$$

Thus, $a/2$ from Equation 11 (the generalized matching law) approximately equals k' from Equation 7 (the local model), which was found (Table 4). This relationship among the obtained probabilities of reinforcement for staying and switching at each alternative and the expected equalities explains how both models account for concurrent performance. However, because Equation 11, like Equation 7, is derived from Equation 4, and Equation 4 cannot be derived from Equation 11, Equation 4 may be the more fundamental.

Implications of the Local Model

The meaning of parameter k_1 in Equation 4 is similar to a in Equation 1. Specifically, k_1 is the sensitivity of behavior to differences in the probability of reinforcement for staying and switching. The results in Figures 1 and 2 and Tables 1 and 2 support this interpretation.

The parameter l_1 has a new meaning. It is the bias to emit stay responses or to stay at the current alternative, and is affected by variables other than the ratio of the probabilities of stay and switch reinforcement. In general, those variables that produce bias in Equation 1, that is, make b not equal to 1, will alter l_1. The local model uses the ratio of l_1 and l_2 at the two alternatives to produce b, the bias parameter. As long as the conditions, other than reinforcer allocation, are equivalent, $l_1 = l_2$, and there is no bias. When $l_1 \neq l_2$, then there is a bias towards the alternative with the large l_n. For example, when the reinforcers correlated with the two alternatives are unequal in value, bias towards the higher valued alternative is observed (Miller, 1976). According to the local model, this bias could result from the different effects that the values of the reinforcers have on the bias to stay or switch at the two alternatives. Suppose that Alternative 1 is correlated with the more valued reinforcer. Then at Alternative 1, the more valued reinforcer would be delivered for stay responses, and the less valued reinforcer would be delivered for switch responses, which would produce relatively larger values for l_1. Conversely, at Alternative 2, the less valued reinforcer would be delivered for stay responses, and the more valued reinforcer would be delivered for switch responses, which would produce a relatively smaller value for l_2. Because l_1 would be greater than l_2, the ratio of these

parameters, as in Equation 7, would be greater than 1, indicating a bias towards Alternative 1.

The present view, that performance on concurrent procedures is a result of combining independent performances that are described by Equation 4, helps to resolve an issue regarding the concurrent performance that conforms to the generalized matching law (Equation 1). The issue, in terms of the generalized matching law, is whether behavioral sensitivity is normally perfect; that is, whether $a = 1$ (Baum, 1979; Myers & Myers, 1977). In terms of Equation 7, this translates to whether behavioral sensitivity $k' = 0.5$. If we assume that $k' = 0.5$, then k_1, from Equation 4, must also equal 0.5. Because Equation 7 was derived from Equation 4, and Equation 4 cannot be derived from Equation 7, there needs to be a reason to assume $k_1 = 0.5$. Because there is no apparent reason to assume this, k_1 does not necessarily equal 0.5. Consequently, k' does not necessarily equal 0.5, nor does a necessarily equal 1. This implies that behavioral sensitivity is empirically determined for each behavior and its contingencies. Additional research will determine the variables, including a COD, that alter behavioral sensitivity (Shull & Pliskoff, 1967).

The local model promotes a new conception of concurrent choice, one that regards the consequences of staying and switching as the determining variables. It treats any delayed effect of stay reinforcers on switching as minimal. At the local level of analysis, the choice is not between staying at two concurrent alternatives but rather between staying and switching, which is due to the probabilities of reinforcement for staying and switching.

Theories of Concurrent Performance

The generalized matching law fitted the synthesized concurrent performances. If the variables that produced matching under the synthesized treatment are the same variables that operate under typical concurrent scheduling, then explanations of matching cannot posit comparisons among the alternatives. For example, matching as a fundamental principle of behavior (Herrnstein, 1970) and melioration (Vaughan, 1981) both posit comparisons among the alternatives as fundamental for matching to occur. Matching posits

comparisons of the distribution of reinforcers and behavior; behavior allocation adjusts to correspond to reinforcer allocation. Melioration posits a comparison of the local rates of reinforcement at the alternatives; behavior switches to the alternative with the higher local rate. A different approach, the contingency-discrimination model (Davison & Jenkins, 1985), also posits comparisons among the alternatives. Behavior allocation among the alternatives matches perceived reinforcer allocation among the alternatives. Because concurrent performance could be synthesized from independent performances according to Equation 11 (Figure 4 and Table 4), comparisons between alternatives are not necessary for matching to occur. Thus, explanations may need to look elsewhere.

Either molar maximizing (Green, Rachlin, & Hanson, 1983; Houston & McNamara, 1981; Rachlin, 1978) or molecular maximizing (Shimp, 1966), which do not posit comparisons between the alternatives, may explain concurrent performance. The finding that per-visit behavior is a function of the probabilities of reinforcement is compatible with a momentary maximizing perspective. The results in Figure 5 also support this view. Previous research on concurrent VR VR procedures, programmed with the stay VR at each alternative equaling the switch VR at the other alternative, demonstrated that the obtained run lengths were longer than predicted, although they followed the function predicted by momentary maximizing (MacDonall, 1988, 1998). One possible reason for this deviation is that the switch response is not equivalent to the stay response. It is more effortful to switch (i.e., move and press the other lever) than it is to stay (i.e., stay and press the current lever) (MacDonall, 1998). A simple model considers the switch response as equivalent to x stay responses. From this, momentary maximizing predicts that run length equals the number of stay responses that are equivalent to the effort of the switch response plus the run length that makes switching more likely to be reinforced than staying. In this model, the obtained run length is a linear function of the momentary maximizing prediction, the slope equals one, and the y intercept represents the switch response measured in units of the stay response. The patterns of mean run lengths for

Rats 381, 382, and 384 are consistent with this view. The pattern for Rat 383 is less clear; if the five rightmost points are discounted because responding in those conditions was poorly maintained, then Rat 383's data are consistent with a momentary maximizing interpretation.

The most frequent objections to momentary maximizing cite empirical work that shows that sequential behavior under concurrent VI VI schedules does not conform to momentary maximizing predictions (Heyman, 1979; Nevin, 1969, 1979; Silberberg, Hamilton, Ziriax, & Casey, 1978). As pointed out by Hinson and Staddon (1983), the analysis by Heyman is not necessarily applicable to predictions from a momentary maximizing perspective. Heyman found that the conditional probability of changing alternatives did not change as a function of the number of sequential responses (run length) at an alternative. He used concurrent VI VI schedules, in which the probability of reinforcement increases as a function of time at an alternative, which according to momentary maximizing should affect visit duration. Although, mean run length and mean visit duration are certainly correlated, it is unclear how closely they track each other on a visit-by-visit basis. Because Heyman used run length and not visit duration in his analyses, his finding is not definitive with respect to momentary maximizing. Nevin (1969) exposed pigeons to a discrete-trials concurrent VI VI procedure and failed to find the predicted response sequences. Because Nevin's results contrasted with those of Shimp (1966), Silberberg et al. (1978) replicated both Shimp's and Nevin's procedures and replicated both results, depending on how the results were analyzed. Nevin (1979) then reanalyzed his data and again failed to find the predicted response sequences. All investigators noted the high variability in the data. There may be too much variability to readily see the predicted response sequences at the level of individual sequences. Assuming that changes in response sequences result in changes in mean run length, the present investigation found evidence consistent with a momentary maximizing perspective when a more molar variable, mean run length, was analyzed (Figure 5). Using VR schedules, which explicitly relate response sequences to changes in the probabil-

ity of reinforcement, may have made it easier to obtain results consistent with the predictions of momentary maximizing.

Taken together, the present results encourage the view that performance on concurrent schedules consists of independent performances at each alternative. Each performance is a power function of the local contingencies, that is, the ratio of stay and switch probabilities of reinforcement at each alternative (Equation 4). Both the generalized matching law (Equation 11) and the local model (Equation 7) can be derived from Equation 4 and both described performances on synthesized concurrent procedures.

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APPENDIX

The sequence of conditions, number of sessions in each condition, five-session sums of the number of stay responses, first switch response, extra switch responses, reinforcers from the stay and switch schedules, and the session duration for each rat.

| Rat | Se-quence | Ses-sions | VR schedule | | Responses | | | Reinforcers | | Time (s) |
			Stay	Switch	Stay	First switch	Extra switch	Stay	Switch	
381										
Phase 1	1	24	10	10	3,017	388	16	321	185	4,745.6
	2	14	20	20	5,520	727	22	272	233	6,852.5
	3	14	40	40	10,432	1,443	16	263	240	10,435.8
	4	19	80	80	20,335	2,692	106	261	239	21,016.9
	5	15	10	80	4,639	214	1	460	50	5,382.2
	6	10	20	40	7,113	568	3	373	131	7,129.1
	7	10	40	20	7,631	917	24	204	300	8,785.7
	8	17	80	10	5,778	926	26	82	423	7,672.6
	9	16	40	10	5,255	782	21	125	376	7,115.6
	10	10	20	10	4,124	638	10	215	288	6,045.8
	11	12	80	20	9,084	1,395	36	108	392	10,818.1
	12	17	10	20	3,718	352	3	376	133	4,897.7
	13	11	80	40	14,356	1,680	17	176	326	11,626.1
	14	14	10	40	4,151	378	4	425	79	6,821.0
	15	13	40	80	13,828	1,289	8	340	163	13,677.1
	16	10	20	80	8,156	655	1	410	91	7,884.2
Phase 2	17	31	18	144	8,049	459	2	457	47	6,402.5
Phase 3	18	13	23.33	140	10,117	815	2	450	55	8,974.9
	19	18	21.67	260	10,037	865	3	454	47	9,631.0
382										
Phase 1	1	22	80	80	20,303	3,182	34	264	236	28,876.0
	2	13	40	40	10,366	2,299	4	259	243	18,623.3
	3	20	20	20	5,303	1,067	13	257	244	10,152.0
	4	22	10	10	2,878	503	3	294	210	5,929.2
	5	11	10	20	3,608	555	4	357	150	6,590.0
	6	17	10	40	4,130	500	0	422	81	6,456.4
	7	23	10	80	4,580	393	0	451	55	5,747.5
	8	17	20	10	3,834	988	8	201	301	7,650.6
	9	10	20	40	6,856	1,220	3	333	172	10,804.0
	10	16	20	80	8,201	1,215	28	406	99	14,636.3
	11	15	40	10	4,651	1,247	20	110	390	8,686.9
	12	13	40	20	7,161	1,650	12	193	309	10,804.4
	13	17	40	80	13,582	1,808	12	343	158	16,989.0
	14	20	80	10	5,125	1,665	30	68	433	10,190.3
	15	26	80	20	8,435	2,501	68	102	398	14,094.3
	16	17	70	40	11,846	2,091	94	169	276	22,664.9[a]
Phase 3[b]	17	13	26.67	80	10,068	1,235	15	398	103	17,101.9
	18	16	22.22	200	10,016	696	19	456	50	14,096.2
	19	15	23.33	140	10,219	760	30	435	72	15,122.1
	20	17	21.67	260	10,090	576	13	466	38	17,064.0
	21	17	21.33	320	10,110	508	12	468	37	12,505.5
383										
Phase 1	1	32	10	80	4,594	338	15	444	61	8,071.2
	2	20	20	40	7,009	743	6	354	146	11,994.9
	3	11	40	20	7,411	1,292	144	171	330	15,148.1
	4	11	80	10	5,079	1,580	134	65	436	15,141.9
	5	23	40	40	10,320	2,074	73	278	223	20,947.7
	6	14	20	20	5,478	915	67	253	251	9,445.0
	7	13	80	20	9,001	1,518	158	94	407	16,097.7
	8	14	80	40	13,039	2,337	92	165	300	20,585.6[a]

APPENDIX

(*Continued*)

Rat	Se-quence	Ses-sions	VR schedule		Responses			Reinforcers		Time (s)
			Stay	Switch	Stay	First switch	Extra switch	Stay	Switch	
	9	12	40	80	13,277	2,001	192	319	172	23,300.2[a]
	10	11	40	10	4,830	1,004	67	125	375	9,488.1
	11	10	20	80	8,084	991	17	418	86	11,632.1
	12	9	20	10	4,079	687	18	188	316	7,514.0
	13	13	10	40	4,133	414	4	434	72	6,133.0
	14	14	10	20	3,627	445	19	349	153	5,781.9
Phase 2	15	11	21.33	64	8,072	949	26	374	126	11,216.0
	16	18	17.78	160	8,063	1,111	9	450	50	12,743.2
	17	12	21.33	64	7,987	1,163	21	376	125	12,260.2
Phase 3	18	22	21.67	260	9,967	1,235	12	456	44	24,881.6
	19	10	20.22	200	8,761	1,031	8	431	49	19,698.3[a]
	20	14	22.22	200	7,672	870	10	357	27	30,280.8[a]
	21	14	23.33	140	9,728	1,119	13	429	61	24,269.6[a]
	22	13	26.67	80	5,511	703	43	217	59	34,853.0[a]
	23	28	21.33	320	4,477	388	6	208	14	11,672.3[a]
384										
Phase 1	1	18	80	10	4,815	2,080	37	60	440	8,486.2
	2	13	40	20	7,193	1,849	6	185	318	8,335.1
	3	16	20	40	6,993	1,123	1	358	152	8,018.5
	4	28	10	80	8,164	5	0	812	5	11,192.3
	5	13	20	80	8,209	498	1	411	90	6,325.9
	6	14	40	80	13,767	959	33	353	147	9,767.8
	7	7	40	40	10,784	1,091	93	240	262	8,076.9
	8	10	10	40	4,330	258	0	424	85	4,816.9
	9	11	80	80	20,722	2,383	63	238	262	14,812.7
	10	18	80	40	13,669	1,922	3	159	319	24,445.7[a]
	11	16	10	20	3,706	350	1	375	131	4,909.2
	12	10	20	20	5,603	667	18	272	230	5,978.7
	13	11	80	20	9,087	1,443	35	111	391	7,971.9
	14	17	10	10	3,000	394	6	314	191	4,373.7
	15	12	20	10	4,103	639	3	209	295	4,818.8
	16	11	40	10	4,959	928	15	124	377	5,686.7
Phase 2	17	20	20	160	15,272	24	1	756	4	11,345.1
	18	21	33	29	8,490	1,015	35	261	243	7,436.3
Phase 3	19	31	22.22	200	10,120	507	3	454	46	7,969.3
	20	25	21.67	260	10,062	492	4	461	40	8,263.6
	21	17	26.67	80	10,236	943	11	392	111	9,658.9
	22	18	23.33	140	10,320	646	2	424	79	8,718.7
	23	20	21.33	320	10,115	391	1	485	21	9,647.9
	24	32	21.11	380	8,729	271	6	423	19	7,826.8[a]
	25	45	140	23.33	11,084	2,002	100	76	425	12,822.6

Note. For Rat 383, Condition 19, the stay VR was mistakenly set at 20.22; these data are omitted from the Phase 3 analyses.

[a] Conditions in which data were adjusted due to long pauses that developed at the end of the session. See text for details.

[b] There was no Phase 2 for Rat 382.