AN INVARIANT RELATION BETWEEN CHANGING OVER AND REINFORCEMENT

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Although concurrent schedules may arrange reinforcers irregularly, relatively large numbers of reinforcers are obtained when an animal changes from one schedule to the other. This paper proposes a quantitative relation that predicts the proportion of reinforcers obtained when an animal is working on a schedule and the proportion when the animal changes over to a schedule. Basically the relation states that the number of reinforcers obtained while an animal works on a schedule varies directly with the relative amount of time spent working on that schedule; and the number of reinforcers obtained when an animal changes to a schedule varies directly with the relative amount of time spent on the alternate schedule. An important aspect of this relation is that when relative reinforcement rates are less than .50, more reinforcers are obtained just after an animal changes to a schedule than at all other times when this schedule is engaged. Data obtained both from a stat-bird and a live pigeon were in close agreement with the quantitative predictions. The relation between changing over and reinforcement held across several procedural changes that included changes in relative reinforcement rate, changes from independent to interdependent scheduling procedures, and changes in the variable-interval reinforcement distributions. The results are discussed in terms of the effects of the local distribution of reinforcement on responding. The local reinforcement distribution can affect local response rates and affects the resulting matching relation. This arrangement has implications for explanations of choice.

Key words: concurrent schedules, changeover, reinforcer distribution, changeover delay, variable-interval schedule, matching, pigeons

Among the dominant issues for the experimental analysis of behavior are issues about the appropriate characterization of choice. The study of choice has produced precise quantitative relations, a diverse group of theoretical views, and an ever increasing number and broader scope of experiments (see Catania, 1966; de Villiers, 1977; for reviews). The study of choice has often involved use of concurrent schedules, which is due in part to the matching relation that is typically obtained. When two schedules are available concurrently with reinforcers produced under each, the relative number of responses emitted or the relative time spent on a schedule equals or matches the relative number of reinforcers produced on that schedule. Different variations on concurrent schedules have been used, but the great majority of experiments has used the specific ar-

rangement of concurrent variable-interval variable-interval schedules. Variable-interval (VI) schedules seem to have unique advantages as concurrent schedule pairs. VI schedules are time-based, which ensures reinforcer delivery in spite of large variations in performance. Only one response is required so reinforcement does not depend on the number of responses emitted as is the case with ratio schedules. Additionally, the delivery of reinforcers happens irregularly so that reinforcers occur more or less randomly in time for both operants. With the other time-based schedules, performance often changes periodically as a function of the temporal regularities imposed by the schedule. VI schedules reduce temporal regularities between behavior and reinforcement and between one reinforcer and the next.

Although both VI schedules of a concurrent pair arrange reinforcers irregularly, certain regularities emerge when animals make contact with the schedules. If, for example, the animal responds to Schedule A, Schedule B continues to operate and may arrange a reinforcer. As a

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result, this reinforcer is then delivered for the first response following a changeover from Schedule A to Schedule B. Experimenters have long recognized that a large enough proportion of reinforcers might be delivered this way to produce a pattern of behavior in which the animals simply alternate from schedule to schedule with each response (e.g., Herrnstein, 1961). Employing a changeover delay, which specifies an interval following a changeover during which responses are not reinforced, eliminates patterns of simple alternation from schedule to schedule. But, a part of the problem has remained: Some reinforcers still occur just after a changeover, but now at the end of the changeover requirement. The question is what proportion of reinforcers occur this way? Previous discussions suggest that the number is not trivial (Catania, 1966). Menlove's (1975) detailed analysis of concurrent performance demonstrated that by far the largest numbers of reinforcers occur just after a changeover delay, more than at any other time following a changeover. Real (Note 1) has suggested that the pattern of reinforcement may be a basic determiner of choice. The present paper is concerned with the numbers of reinforcers that occur following a changeover, quantitative regularities that exist in this regard, and implications of these regularities for performance.

To some degree the matter can be figured out logically. Consider the case where two VI schedules each arrange an equal number of reinforcers, 50 for Schedule A and 50 for Schedule B. If matching obtains, with relative response rate and time spent matching relative reinforcement rate, the animal will spend half the session working on each schedule. With time allocated this way, it follows that half of the 50 reinforcers delivered by Schedule A will be arranged while the animal works on Schedule A. The remaining 25 reinforcers delivered by Schedule A will be arranged while the animal works on Schedule B and, as a result, these reinforcers will be obtained just after the animal changes from Schedule B back to Schedule A. Similarly, half of the reinforcers for Schedule B would be arranged with Schedule B in effect and half with Schedule A in effect. Consider next a case where Schedule A delivers 90 reinforcers and Schedule B delivers 10 reinforcers. If the animal spends 90% of its time in Schedule A, 81 of the 90 reinforcers will be arranged while Schedule A is in effect, and

Fig. 1. Predicted numbers of reinforcers that are obtained different ways as relative reinforcement rate varies. The solid curve represents reinforcers obtained when an animal works on the schedule appropriate to that reinforcer. The dashed curve represents reinforcers arranged when the alternate schedule is in effect, reinforcers that are then obtained when the animal changes to the appropriate schedule. For each relative reinforcement rate value (e.g., .75) there is a corresponding value for the other schedule of the pair (e.g., .25) such that the combined total of all reinforcers for the schedule pairs equals 100.

nine reinforcers while Schedule B is in effect. In contrast only 1 of the 10 reinforcers arranged by Schedule B will be arranged while the animal works on Schedule B since so little time is spent on this schedule; nine of the reinforcers, the great majority, will be arranged while the alternate schedule is in effect.

Figure 1 expands these examples by showing the general relation we would expect for reinforcement both for delivery following a changeover and delivery while the schedule is engaged. Figure 1 shows how reinforcers obtained in different ways change with relative reinforcement rate. There are several important features of Figure 1. First, and somewhat obvious, the combined number of reinforcers delivered both ways increases directly as relative reinforcement rate increases. With relative reinforcement rate of .75 for example, 56 reinforcers are obtained one way and 19 the other way for a combined total of 75. Second, with relative reinforcement rates above .5, relatively more reinforcers are arranged while the animal engages the schedule appropriate to those reinforcers. When, however, relative reinforcement rates are below .5, relatively more rein-

forcers are delivered when the animal has just changed from the alternate schedule. An important point here is that the majority of reinforcers—often the great majority—are obtained just after an animal changes over to the schedule associated with fewer reinforcers; very few are delivered while the animal otherwise engages this schedule. Third, the greatest number of reinforcers arranged when the alternate schedule is in effect occurs when relative reinforcement rate is .50 and the number decreases as relative reinforcement rates deviate from .50.

Figure 1 represents an idealized case. How might different aspects of actual concurrent situations affect the relation depicted in Figure 1? The relation should not be affected by the composition of the schedules; there should be little effect whether the VI series was arithmetic, geometric, or the like. There should be little effect, if any, of procedural variations related to the use of changeover-key vs. two-key procedure or independent vs. interdependent scheduling procedures (de Villiers, 1977). Also, the absolute value of the VI schedules should not affect the relation of Figure 1 (unless schedule values were extremely small). Several factors could affect the relation of Figure 1. First, the rate of changing over from schedule to schedule could alter this relation. Once a reinforcer is arranged, the VI schedule stops until that reinforcer is collected. Reinforcers arranged by a schedule cannot be collected until the animal changes over to and then responds to a schedule. So the stopping of the tapes and the pattern of changing from schedule to schedule could have an effect. A second factor concerns the way an animal might distribute its time working on the two schedules. The relation of Figure 1 assumes matching between relative time spent to relative reinforcement rate. Obviously the relation would not hold as shown if relative reinforcement rate were .5 but the animal spent 90% of its time working on one of the schedules.

Figure 1 predicts outcomes under concurrent schedules. The main point of the experiments was to see if the predicted relations hold under experimental conditions. The experiment has two parts. In the first, concurrent performance was simulated by relay circuitry to create a "stat-bird." A number of parameters of concurrent schedules were varied and the "behavior" of the stat-bird was assessed to test the predictions of Figure 1. In the second part,

the predictions were compared with the behavior of a live pigeon.

METHOD: STAT-BIRD

Procedure: Stat-Bird

A stat-bird circuit was arranged to simulate performance under a variety of concurrent schedules. This circuit consisted simply of two timers that alternated. The timers were functionally the equivalent of an organism spending time in the presence of each schedule and alternating from schedule to schedule. Concurrent schedules were arranged in the usual way with VI tape drives arranging "reinforcers." Delivery and recording of "reinforcers" depended on the tapes, on the operation of the two timers (the stat-bird's behavior), and on a changeover delay. The changeover delay was a 2-sec interval during which "reinforcers" could not be delivered; this delay period began each time one of the two timers started (i.e., the equivalent of a changeover from one schedule to the other). Sessions lasted until the stat-bird received fifty "reinforcers." Ten sessions were conducted in each condition except that 20 sessions were studied in the condition with relative rate of reinforcement equal to .90. The stat-bird procedure is similar to concurrent situations but simpler in three ways. First, the timers arranged only two interchangeover times (one for each schedule), whereas the interchangeover times of animals vary from changeover to changeover. Second, interchangeover times generally were selected so that "relative time spent" would match relative reinforcement; often there are slight deviations from perfect matching in experiments. Third, no "response" was required; a reinforcer was delivered if the appropriate timer operated. Since the stat-bird situation was simplified, some of the variations in the conditions involved changes in interchangeover times and deviations from matching to assess the importance of these factors.

When a hole was reached in the VI tape the event was recorded as a "reinforcer" and categorized according to prevailing conditions. A "reinforcer" was recorded as being arranged while the appropriate schedule was in effect if the timer appropriate to that schedule operated and if the changeover delay did not (e.g., Timer A operated when Schedule A arranged a "reinforcer"). In these cases the tape

drive continued to operate. If, however, a hole was reached while the alternate timer operated, the event was recorded as a "reinforcer" arranged while the stat-bird engaged the alternate schedule (e.g., Schedule A arranged a "reinforcer" when Timer B operated). Similarly, when the appropriate timer operated but the changeover delay was in effect, the "reinforcer" was categorized as one occurring given the alternate conditions (e.g., Schedule A arranged a "reinforcer," Timer A operated, but the changeover delay was in effect). In either case, the tape drive stopped until the "reinforcer" was "collected." Four classes of events were thus recorded, two for each schedule: "reinforcers" arranged when the appropriate timer (and, no changeover delay) operated and "reinforcers" arranged when the alternate schedule or the changeover delay was in effect.

Table 1 shows the schedules used and important aspects of the procedure for the different conditions. The different conditions may be considered in five groups. (1) The first eight used a one-tape procedure (Stubbs & Pliskoff, 1969), whereas the last seven used a two-tape procedure. Under the one-tape procedure, a single tape arranged all "reinforcers" and these were distributed to the two schedules by a stepping switch. Under the two-tape procedure, two separate and independent tapes operated, each one associated with a schedule of the concurrent pair. (2) Relative reinforcement rate was varied (Conditions 1 to 3) from .05 to .75 to .90. (3) Different distributions of intervals comprising the VI schedule were used. The distributions were arithmetic, geometric, Catania and Reynolds, and Fleshler and Hoffman series (see Catania & Reynolds, 1968, for details of the construction of these series). (4) The settings on the timers, the equivalent of interchangeover times, were varied across "sessions." In most cases, the times were picked because they are similar to the interchangeover times of pigeons under similar conditions (Stubbs, Pliskoff, & Reid, 1977). In some instances, both with the one-tape procedure (Conditions 3 to 5) and the two-tape procedure (Conditions 9 to 11), interchangeover times were varied to see if different interchangeover times would influence the distribution of reinforcers. (5) In the last four conditions, "relative reinforcement rate" was held constant at .50 while the settings on the timers were varied. The purpose was to see if the relation of

Table 1

Different conditions for stat-bird. VI distribution: distribution of intervals comprising variable-interval schedule; ICT: interchangeover time; C & R: Catania and Reynolds (see Catania & Reynolds, 1968); F & H: Fleshler and Hoffman (see Catania & Reynolds, 1968).

Schedule	Procedure	VI Distribution	Rel. Rein. Rate	ICT (sec)
VI 100-sec	one tape	C & R	.90	45 + 5 sec
VI 100-sec	one tape	C & R	.50	15 + 15 sec
VI 100-sec	one tape	C & R	.75	30 + 10 sec
VI 100-sec	one tape	C & R	.75	60 + 20 sec
VI 100-sec	one tape	C & R	.75	15 + 5 sec
VI 100-sec	one tape	Arithmetic	.75	30 + 10 sec
VI 100-sec	one tape	Geometric	.75	30 + 10 sec
VI 100-sec	one tape	F & H	.75	30 + 10 sec
VI 60-sec	two tapes	C & R	.75	30 + 10 sec
VI 180-sec	two tapes	C & R	.75	15 + 5 sec
VI 60-sec	two tapes	C & R	.75	150 + 50 sec
VI 180-sec	two tapes	C & R	.50	15 + 15 sec
VI 90-sec	two tapes	C & R	.50	24 + 12 sec
VI 90-sec	two tapes	C & R	.50	30 + 10 sec
VI 90-sec	two tapes	C & R	.50	45 + 5 sec

Figure 1 would be affected by changes in "relative time spent" that deviated from matching.

METHOD: PIGEON

Subject

One adult male White Carneaux pigeon, maintained at 80% of its free-feeding weight, served. This pigeon had prior experience with several experiments.

Apparatus

The experimental chamber was a standard homemade ice-box pigeon chamber. The chamber had three response keys, but only the left and center keys were used. The chamber was housed in a room in which white noise was always present. Sessions were arranged by relay circuitry located in an adjacent room.

Procedure

Sessions, generally conducted six days a week, lasted until the pigeon obtained 60 reinforcers. A changeover-key procedure was used for the experiment. The left-key (main-key)

color was either red or green and these colors were each associated with different VI schedules. Responses to this key were reinforced intermittently with responses in the presence of green being reinforced according to one schedule and responses in the presence of red according to a separate schedule. The center-key (changeover key) color was yellow, and responses to this key alternated the stimulus and schedule on the main key.

Each schedule of a concurrent pair was arranged by a separate tape drive. Each schedule operated whether the stimulus on the main key was the one associated with that schedule or the one associated with the alternate schedule. When a tape assigned a reinforcer, that tape stopped until the reinforcer was obtained. Reinforcers consisted of 4-sec access to mixed grain, during which the keylights were off and both tape drives stopped. A changeover-delay procedure was used. Each response to the changeover key started a 2-sec delay period during which main-key responses could not produce food.

The following concurrent schedules were used: VI 60-sec VI 180-sec (93 sessions); VI 90-sec VI 90-sec (50 sessions); VI 180-sec VI 60-sec (60 sessions); and VI 50-sec VI 450-sec (37 sessions). The first schedule of each pair was associated with red, the second with green. The schedules were arranged by the method described by Catania and Reynolds (1968). Each schedule contained 20 intervals except the VI 450-sec schedule which, due to its length, contained only 10. Each condition except the first was in effect until performance appeared stable, as judged visually, for at least seven sessions (the first condition examined long-term stability of behavior).

RESULTS

Stat-Bird. Figure 2 shows data when relative reinforcement rate was varied. Figure 2 is similar in form to Figure 1 but shows the fit of the obtained data to the predicted values. The data represent means of all 10 sessions for each condition except with relative "reinforcement" rate of .90; here, data were averaged over 20 sessions since so few "reinforcers" were delivered on the leaner schedule of this pair.

Figure 2 indicates a close correspondence between predictions and the obtained data. The data points lay close to the curved lines

in all cases. The unfilled symbols adjacent to smooth-curved prediction lines represent a slightly modified set of predictions. The modifications take into account the interchangeover times, an effect of the changeover delay, and the way in which the "reinforcers" were categorized. When, for example, relative reinforcement rate was .75, interchangeover times were 30 sec and 10 sec. The prediction is that 75% of the "reinforcers" delivered by the one schedule, or (as Figure 1 shows) 56 of 75 "reinforcers," should occur with appropriate conditions in effect; 25% or 19 of the 75 "reinforcers" should occur with alternate conditions in effect. But a 2-sec changeover delay was used, so "reinforcers" could be delivered only during the last 28 sec of a 30-sec period. "Reinforcers" were recorded as "appropriate" only for this 28-sec period; "reinforcers" were recorded as "alternate" if they occurred either during the 10-sec interchangeover time or during the 2-sec changeover delay beginning the 30-sec period. The resulting predictions taking changeover delay into account are that 52 of the 75 "reinforcers" would occur with appropriate conditions in effect and 22 with alternate conditions in effects. The difference between these predictions and those of Figure 1 is slight but systematic. These modified predictions provide a closer fit to the obtained data. The absolute difference between predicted and obtained data was calculated. The mean absolute difference between predicted and obtained data—between filled and unfilled symbols—is 1.4%, which shows a close fit of obtained data to predicted. The averaged data might have obscured daily differences, so for each "session" the absolute difference between predicted and obtained data was calculated. The average of all these daily absolute differences was 2.1%; a difference of 2% or less was observed in nearly two-thirds of the comparisons. So, the daily data indicate close agreement with predictions.

Figure 3 shows stat-bird data across a variety of conditions when relative "reinforcement" rate was held constant at .75. The different manipulations included (a) use of different arrangements for the composition of the VI schedules, (b) the use of one-tape or two-tape procedures, and (c) changes in the interchangeover time. The points are means of obtained data; the horizontal lines are predictions like those of Figure 2 that take into account the

Fig. 2. "Reinforcers" obtained different ways when relative reinforcement rate was varied for the stat-bird. Filled circles represent reinforcers delivered when the appropriate schedule was in effect, and filled triangles represent reinforcers arranged when alternate conditions were in effect (and then obtained when the appropriate schedule operated). The curved lines represent the predictions of Figure 1; the unfilled symbols represent the modified predictions that take the changeover delay into account.

changeover delay. Basically Figure 3 shows that there is a close agreement between predictions and obtained data across the various changes. The average absolute deviation between predicted and obtained "reinforcers" was 2.2%.

The data involving different interchange-over times deserve some comment. The stat-bird circuit arranged one set of interchange-over times similar to the average times of actual birds, but pigeons do not change over with such regularity. So, it was important to

assess performance with a range of different interchangeover times to see if systematic deviations would result as a function of variation of interchangeover times. Figure 3 shows roughly similar performance across conditions and generally a close correspondence between predictions and obtained data. Only when the interchangeover times become extreme (150 and 50 sec) did deviations from predictions become relatively extreme. (Doug Lea has calculated that the deviations from predictions will begin to grow large when interchangeover times

Fig. 3. "Reinforcers" obtained different ways by the stat-bird under a variety of conditions. On the left, the distribution of reinforcers was varied; CP refers to the constant probability distribution of Flesher and Hoffman. On the right, the interchangeover times were varied; for these conditions the distribution of reinforcers was arranged after the manner of Catania and Reynolds. The upper panels show reinforcers for the schedule delivering 75% of the reinforcers; the bottom panels are for the schedule delivering 25%.

exceed the average value of the VI schedule.)

Whereas relative time matched relative reinforcement rate in the previous figures, Figure 4 provides information when there were deviations from matching: when relative "reinforcement" rate was held constant but relative time spent varied. The basic relation of Figure 1 assumed matching but predictions can be made even with deviations. If, for example, two schedules each arrange 50 reinforcers but an animal spends 60% of the time on Schedule A, 30 of the reinforcers delivered by Schedule A will be arranged while that schedule is engaged and 20 while the alternate schedule is in effect; 20 reinforcers will be arranged by Schedule B while it is engaged and 30 while the alternate schedule is in effect. Figure 4 shows predictions and obtained data when relative time spent varied. The straight lines are the basic predictions and the unfilled symbols are modified predictions that take the 2-sec changeover delay into account. There is close

agreement between predictions and obtained results. The results indicate that matching is not necessary and that in fact predictions can account for performance that deviates substantially from matching.

Pigeon Data. Table 2 and Figure 5 show data for the pigeon that are similar to those in experiments on choice. Table 2 shows the number of responses, the time spent, and the reinforcers associated with the two schedules of a concurrent pair, as well as the number of changeover responses. Figure 5 shows relative response rate and relative time as functions of change in relative reinforcement. Relative measures were calculated in the usual way by dividing the responses in one schedule by the total number of responses, dividing the time spent in one schedule by total time, and by dividing reinforcers delivered by the one schedule by the total number of reinforcers. Figure 5 shows a close approximation to matching for the time data and a tendency towards under-

Fig. 4. "Reinforcers" obtained different ways when relative time spent varied under conditions of equal relative reinforcement by two concurrent schedules. Filled circles represent reinforcers delivered when the appropriate schedule was in effect, and filled triangles represent reinforcers arranged when alternate conditions were in effect. Straight lines represent predictions like those of Figure 1; the unfilled symbols represent modified predictions that take the changeover delay into account.

matching for the response data (Baum, 1974). Neither response nor time data indicated a bias to either schedule (Baum, 1974).

Figure 6 shows the numbers of reinforcers arranged when the different stimulus-schedule pairs were in effect. Figure 6 provides data similar to those in Figure 2 for the stat-bird. Fig-

ure 6 gives both predicted and obtained data; the predictions take the 2-sec changeover delay into account. The obtained data are very similar to the predicted values. Predictions about reinforcers were calculated for each of the last seven sessions of a condition. Predictions for each day were based on the average interchangeover times for that session; then the difference between predicted and obtained reinforcers was calculated. The average absolute difference between predicted and obtained data was calculated by averaging each day's difference across the last seven sessions of the four experimental conditions. The average absolute difference was 2.3% with three-fourths of the scores being 3% or less. So the data for the live pigeon compare favorably to those of the stat-pigeon.

DISCUSSION

The results, both for the pigeon and for the stat-bird, confirmed a relation between changing over and the distribution of reinforcers. Relatively large and predictable numbers of reinforcers were delivered following a changeover from one schedule to the other. The relationship held in spite of a variety of changes, including changes in relative reinforcement rate, changes in interchangeover time, and deviations from matching. It appears that the relation is invariant in that it holds across a wide variety of changes that well exceed the behavior that animals normally exhibit under concurrent schedules. As such, the invariant relation is an integral part of experiments using concurrent schedules. The questions naturally arise, what effects do the local changes in reinforcement have on behavior, and how might this invariant feature affect our view of choice?

Figure 7 is instructive, illustrating some of the effects the reinforcement distribution might have on behavior. Figure 7 is based on the data of Silberberg and Fantino (1970) and was drawn from data given in their summary table. Figure 7 shows local response rates both during and after the changeover delay. Each point represents average performance of six pigeons, but the data are representative for the individual birds. There are three main features of this figure. First, response rates were higher during the changeover delay than afterwards. This finding held for individual birds

Table 2

Means of the last seven sessions for responses, time spent (minutes), and reinforcers associated with red and green. Means for changeover responses (COs) are also given. Coefficient of variation measures averaged .07, with all measures except two below .10.

Schedules	Responses		Time (Min)		Reinforcers		COs
	Red	Green	Red	Green	Red	Green	
Concurrent VI 60-sec	2443	1214	61.5	21.9	45	15	300
Concurrent VI 180-sec	2136	2078	39.8	42.6	30	30	427
Concurrent VI 90-sec	1088	2204	19.1	64.8	14	46	248
Concurrent VI 50-sec	2178	187	76.2	7.4	55	5	93
Concurrent VI 450-sec

Fig. 5. Relative response rate and relative time spent as a function of changes in relative reinforcement rate. Data are means of the last seven sessions.

and has also been observed by Pliskoff (1971), by Menlove (1975), and by Pliskoff, Cicerone, and Nelson (1978). The detailed recordings of Menlove indicate that the high average rate during the changeover delay results from an increasing response rate following a changeover which reaches a maximum near the end of the changeover delay and then declines. The changes in response rate follow changes in local reinforcement probability and are similar to those observed under simple VI schedules (Catania & Reynolds, 1968).

A second feature of the data is that response rates during the changeover delay were higher under the schedule with the less dense reinforcement rate than the schedule with the higher reinforcement rate. Rates were higher in 15 of 17 comparisons (one bird was not exposed to one condition). However, once the changeover delay had elapsed, rates tended to be higher in the schedule with the higher reinforcement rate; this effect was not consistently observed for individual birds. It might at first seem odd that the schedule with the lower reinforcement rate would generate the higher response rate during the changeover delay. However, a consideration of the local distribution of reinforcers clarifies the matter. Consider, for example, the case where 10 reinforcers are delivered by one schedule and 90 by the other. When only 10 reinforcers are delivered, the animal spends little time in contact with the schedule and as a result almost all reinforcers occur just after the changeover

delay has terminated (Figure 1 predicts that 9 of the 10 reinforcers are delivered this way). Additionally, since so little time is spent in this component, each bout of responding lasts only slightly longer than the changeover delay which further ensures that the few remaining reinforcers occur close in time to the end of the delay. In contrast, many of the reinforcers in the other schedule occur at times beyond the changeover delay; relatively few of the reinforcers delivered in this schedule occur just after the changeover delay.

Third, Figure 7 suggests that findings of higher response rates during the changeover delay depend on the value of the changeover delay. The results indicate that rates during the changeover delay declined when the value was increased to 3.5 sec. Pliskoff (1971) used a more complete range and observed an inverted U-shaped function relating response rates and changeover delay, with highest changeover-delay rates when the changeover-delay value was 1 sec. There are probably several reasons for these results: with very short delays, the animal might not be able to respond on the main key before the changeover delay elapsed; with very long delays, the fixed-interval-like aspect of the delay might produce more pausing at the beginning of the interval.

The present results bear on the matching relation. Recent reviews indicate that a typical outcome of concurrent schedules is undermatching rather than matching (Baum, 1974, 1979; de Villiers, 1977; Myers & Myers, 1977).

Fig. 6. Reinforcers obtained different ways when relative reinforcement rate was varied. The unfilled symbols are means of obtained data for the last seven sessions. Circles represent reinforcers delivered when the appropriate schedule was in effect and triangles represent reinforcers arranged when the alternate conditions were in effect.

The local distribution of reinforcers with its resulting effects on responding probably contributes to undermatching in several ways. First, Figure 7 indicates that rates were higher in the leaner schedule during the changeover delay. This higher local rate inflates the number of responses assigned to the schedule when relative response rates are calculated, with the effect of increasing relative response number for that schedule and hence undermatching. Second, as relative reinforcement rates change and the animals engage the schedules for different times, response rates during the change-

over delay contribute unequally to the two schedules in such a way as to produce undermatching. If, for purposes of discussion, performance can be conceptualized simply into a high-rate component during the changeover delay and a low-rate component after, consider the case where relative reinforcement rate is .75 with a 2-sec changeover delay; the average interchangeover times might be 10 sec and 30 sec (Stubbs & Pliskoff, 1969). The high rate of responding during the 2-sec changeover delay comprises 20% of the 10-sec interchangeover time but only 7% of the other. Thus the rela-

Fig. 7. Data from Silberberg and Fantino (1970) showing local response rates during and after changeover delays. The data are averaged across six pigeons. Data are shown for different changeover delay values for both members of a concurrent pair, one schedule having a higher relative reinforcement rate. The schedules were Concurrent VI 135-sec VI 270-sec for two pigeons, Concurrent VI 113-sec VI 450-sec for two, and Concurrent VI 101-sec VI 810-sec for two.

tive contribution of the high-rate component is greater for the schedule in which the animal spends less time.

The local distribution of reinforcers thus leads to an expectation of undermatching, but since the direct effects of this distribution are on responses, the implication is that undermatching should result for responses but not for time spent, a pattern of results consistent with two recent reviews (Baum, 1979; de Villiers, 1977). Several points need brief mention in this context. First, several authors have raised the issue of whether responses or time spent provide a better measure of choice (de Villiers, 1977); the present account suggests that time measures may be preferable due to local changes in responding which might contaminate relative responding as a measure of choice. Second, the changes in performance have been discussed in the context of a changeover-delay procedure. Other changeover requirements have been used, although far less often; these include a blackout (Silberberg & Fantino, 1970; Todorov, 1971), a fixed-ratio requirement (Pliskoff et al., 1978; Stubbs & Pliskoff, 1969), and a distance requirement (Baum, 1981). These procedures may avoid

some of the problems associated with changeover delays, but since an invariant relation between changing over and reinforcement remains, this relation will also affect performance in these situations. For once the blackout is completed, the ratio requirement met, or the distance traversed, the probability of reinforcement is high for the first response to a schedule. For the leaner schedule of a pair, the first response is the one most often reinforced; successive responses are reinforced only rarely. This arrangement could produce a tendency toward responding only once and then changing from the leaner schedule, a pattern of responding that would lead to overmatching as Pliskoff et al. (1978), Pliskoff and Fetterman (1981), and Baum (1981) have observed. Third, the present account has focused on the contributions of local reinforcement distribution to undermatching. Baum (1979) has noted that different degrees of undermatching result with different procedures and has discussed several factors that may be important. So reinforcement distribution is probably only one of several factors.

The invariant relation between changeovers and reinforcers could provide an alternate explanation of concurrent performance. The basic notion is that the choice is between staying on a schedule producing reinforcers irregularly, or changing to the alternate schedule and producing a reinforcer that is more likely to occur but after a short delay. The situation can be viewed as similar in some ways to a choice between VI and fixed-interval (FI) reinforcement. The situation is dynamic since the probability of reinforcement following a changeover increases in time. The data are consistent with this view of concurrent schedules. For example, changeover rates vary in appropriate ways as relative reinforcement rates change. And, as relative reinforcement rates approach .50, the total changeover rate increases (e.g., Stubbs & Pliskoff, 1969) as does the number of reinforcers following a changeover (Figure 1). Finally, there are orderly quantifiable relations between changeover behavior on the one hand and changes in the changeover requirement and the relative distribution of reinforcers on the other (Stubbs, Pliskoff, & Reid, 1977). The matching relation might be the outcome of specific patterns of changing over, which are a function of the changing probabilities of reinforcement for

staying on a schedule or changing to the alternate schedule.

The details of this explanation could be worked out and experiments done. (For example an animal would have a choice in a series of trials of working on a short FI schedule that is reinforced only on intermittent trials or working on a VI schedule for the trial). The available quantitative data on changeover behavior could be integrated to form a quantitative statement. We are hesitant, however, to go forth with the task since there are already explanations of concurrent performance that deal with matching, maximizing, optimization, economic equalizing, molar matching, molecular maximizing, and melioration, with quantitative accounts for each. Explanations are outstripping procedures for studying choice. Most of the explanations derive from concurrent VI VI schedules and closely related procedures, but in these situations the complex and often overlapping sets of contingencies afford an animal different possibilities at the same time. An animal might emit sequences of responses to two keys, equalize local reinforcement rates, match, and do so in some optimal way. Given this state of affairs, what is needed is not another explanation but different procedures for studying choice.

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