CHOICE AND TRANSFORMED INTERREINFORCEMENT INTERVALS

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Pigeons chose between two aperiodic, time-based schedules of reinforcement. The arithmetic mean interreinforcement interval of the first schedule was short, but the harmonic mean was long, whereas the arithmetic mean interreinforcement interval of the second schedule was long, but the harmonic mean was short. The pigeons preferred the schedule with the shorter harmonic mean in a concurrent-chains procedure when a terminal link ended after the first scheduled reinforcer had been gained on a terminal-link entry, but reversed their preferences, such that they preferred the schedule with the shorter arithmetic mean, when the terminal links ended after a fixed duration of exposure to the schedule. Moreover, the pigeons preferred the schedule with the shorter arithmetic mean in a two-key concurrent variable-interval variable-interval procedure, as well as in a concurrent variable-time variable-time, changeover-key procedure. The data suggest that an aggregate property of a schedule may not yield valid information about the responding that schedule will maintain as a choice alternative.

Key words: choice, concurrent chains, concurrent schedules, changeover-key procedure, harmonic rate of reinforcement, key peck, pigeons

Much empirical and theoretical work in the experimental analysis of behavior has been concerned with the specification of orderly relations between parameters of reinforcement and parameters of responding on concurrent schedules (Herrnstein, 1970). Of central importance in this work have been attempts to derive from response measures a functionally effective scale of sensitivity to reinforcers, that is, a scale that delineates how a subject may be expected to respond given alternative parameters of reinforcement, analogous to a functionally effective scale of stimulus sensitivity in psychophysical tasks (Stevens, 1957). There has been a certain empirical, pragmatic character to such undertakings, in that whatever measure of reinforcement that establishes the orderly relation, judged by goodness of fit criteria, may be taken as useful (particularly appropriate are linear

functions, since curve fitting is decidedly easier). Furthermore, formulations of the data according to any criteria that produce a good fit are not to be ruled out. The generality of such formulations would have to be determined empirically, but even if a particular formulation proves to be situation-specific, the appropriateness of that formulation for its context is not diminished. In practice, what this approach has amounted to is the assumption of an intervening variable of response strength that is tautologous with a composite index of reinforcer effectiveness, value. Indeed, Baum (1974b) and Rachlin (1971) have explicitly argued that the demonstration of such a tautology is the objective of the work, because the demonstration of a tautology is the appropriate form of scientific laws, theories, and explanations (see also Killeen, 1972). Thus, if subjects respond equivalently on each of two concurrently available schedules, then the measures of reinforcement value for each schedule must by definition be equal, and if subjects respond more on one schedule than another, the measure of reinforcement value for that schedule must be greater (Killeen, 1968b, p. 263). On the basis of such assumptions, the data from choice experiments

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should produce converging evidence regarding which measures of responding and reinforcement will yield the desired orderly relation. That is, choice experiments may be viewed as being concerned with elucidating the inherent structure of behavior as a function of reinforcement value, and presumably the same ordinal relations about directions of preference should obtain across procedures, though perhaps with some degree of error inherent in the measurement or in the translation from one setting to another.

Given that reinforcement value is to be estimated post hoc from responding that has already occurred within an experimental setting, what becomes important in assessing the adequacy of the approach described above are criteria of internal consistency, generality, and parsimony, rather than percentage of variance accounted for. That is, how general are the treatments that are intended to provide an account of the relations between responding and reinforcement? Is there one account that can accommodate the data from more experimental settings than others? To address these questions, I turn to a particular domain in the analysis of choice and reinforcement parameters, the assessment of reinforcement value using the concurrent-chains procedure, as a kind of case history that is concerned with these broader issues.

A convenient starting point is the work of Autor (1969) and Herrnstein (1964a), who systematically investigated choice between variable-interval (VI), variable-ratio (VR), and variable-time (VT) terminal links on concurrent-chain schedules. They found that the relative rate of responding on a given key during the concurrently available VI 60-s initial links was roughly proportional to the relative rate of terminal-link reinforcement it afforded, where that rate was calculated in the ordinary arithmetic sense. On the basis of such data, Herrnstein (1964a, p. 33) suggested that choice in concurrent chains was governed by relative rate of terminal-link reinforcement, much as relative rate of reinforcement appeared to

govern choice in simple concurrents (Herrnstein, 1961).

However, Herrnstein (1964b) subsequently found that VI terminal-link schedules were preferred over fixed-interval (FI) terminal-link schedules, and Fantino (1967) found that mixed-ratio terminal-link schedules were preferred over fixed-ratio terminal-link schedules in concurrent chains, even when the nominally scheduled (arithmetic) rates of terminal-link reinforcement were equivalent. Herrnstein (1964b) interpreted his results by suggesting that the pigeons' method of averaging the interreinforcement intervals (IRIs) in such cases was not linear, and that the pigeons' method of averaging tended to weight the shorter intervals of a schedule more than the longer ones. Similarly, Fantino (1967) noted that his pigeons' preferences could be well described by considering the relative geometric rates of reinforcement. Thus, it appeared that initial-link response distribution could not be generally well described in terms of its relation to terminal-link rate of reinforcement, where rate was understood in its straightforward arithmetic sense.

Killeen (1968b) further analyzed this problem and reported that averaging a transformation of the IRIs on a VI schedule would bring some measure of correspondence between the distribution of initial-link pecks and a measure of terminal-link reinforcement frequency. More specifically, he proposed the following quantitative treatment to account for the data:

$$V_L = \left[\frac{1}{N} \cdot \sum_{i=1}^N (y_i^r) \right]^{1/r} \quad (1)$$

Relative response rate is then proportional to relative value as given by the following equation (Baum, 1974a):

$$\frac{R_L}{R_L + R_R} = \frac{V_L}{V_L + V_R} \quad (2)$$

Thus, Killeen proposed that a given terminal-link IRI be raised to the power r , where $r = -1$, and that the reciprocal of the average of the transformed intervals (i.e.,

the harmonic mean) be taken as the appropriate measure of terminal-link reinforcement frequency (e.g., "value"). The relative rate of responding on a key during the initial links would then be proportional to the relative harmonic rate of terminal-link reinforcement on that key. This treatment was consistent in spirit with the earlier findings of Herrnstein (1964b) and Fantino (1967), which showed that proportionally greater weight had to be assigned to shorter intervals, and also with the earlier work of Chung (1965) and Chung and Herrnstein (1967), who had shown that choice in simple concurrents was proportional to delay of reinforcement. Note here that delay and immediacy are inversely related (by some measures, immediacy is the reciprocal of delay); indeed, Killeen (1968b) noted that it was a fine conceptual line that distinguished rate from delay, because the two parameters tended to covary:

It is not clear whether reinforcement in the presence of a stimulus confers upon that stimulus a reinforcing strength of its own, which mediates behavior in the first link, or whether reinforcement acts directly on responses in the first link with an effectiveness inversely proportional to its delay. That question may be settled by an experiment employing more than one reinforcement in the terminal links. If first-link behavior is maintained by the change in key-light color, relative harmonic rate of reinforcement should predict preference. If, on the other hand, reinforcement in the terminal link acts directly on first-link behavior, preference should match the relative immediacy of reinforcement on a key, where immediacy is measured from the last response in the first link to each reinforcement separately, and then summed. (p. 269)

Subsequent data from comparisons employing multiple terminal-link reinforcers have tended to be consistent with the relative immediacy interpretation. For example, Fantino and Herrnstein (1968) presented

pigeons with a choice between a large number of reinforcers in one terminal link and a small number in the other, where all were made available according to identical VI schedules. According to reasoning based on Killeen's (1968b) analysis, if preference is a function of relative rate of reinforcement, transformed or not, the pigeons should be indifferent. Alternatively, if preference is a function of the summed relative immediacies of reinforcement, the pigeons should prefer the terminal link with the larger number of reinforcers. Fantino and Herrnstein (1968) found that indeed the pigeons did prefer the larger number of reinforcers, and that there was a correspondence between relative rate of initial-link responding and the summed relative immediacies of terminal-link reinforcers, exactly the possibility suggested by Killeen earlier. Similarly, Davison (1968; see also Hursh & Fantino, 1973) presented pigeons with a choice between one terminal link, in which reinforcers were made available according to two consecutive FI 30-s schedules, and another terminal link, in which reinforcers were made available according to two consecutive FI schedules that also summed to 60 s—for example, FI 10-s and FI 50-s. He reasoned that if preference was a function of a relative rate of reinforcement, the pigeons should be indifferent; alternatively, if preference was a function of relative immediacy of reinforcement, the pigeons should prefer the terminal link with the shorter first FI schedule. Davison found that the pigeons indeed preferred the terminal link with the shorter first FI schedule, again supporting a relative immediacy over a relative rate interpretation. In further investigations of the relation between initial-link responding and temporal parameters of terminal-link reinforcement, Duncan and Fantino (1970) found that in cases of choice between two fixed-ratio (FR) schedules or between two FIs, preference for the richer schedule increased as the absolute size of the schedules increased, despite a constant relative rate of reinforcement (see also a review by Rider, 1983a, p. 265). They proposed that, in order to achieve some corre-

spondence between initial-link response distribution and a measure of terminal-link reinforcement frequency, the size of the transformation parameter may depend upon the size of the shortest IRI in the terminal link (see their Figure 8, p. 83). With short terminal-link IRIs (e.g., less than 10 s), as on VI schedules, ($r = -1$) tended to be appropriate. As terminal-link IRIs became longer, as in FI 20-s or FI 30-s, a transformation parameter of ($r = -3, -4, -5$) tended to be more appropriate.

The general finding that emerged from this entire body of research, then, was that the temporal characteristics of terminal-link reinforcement were the critical factor, and that the exact way to generate a correspondence between initial-link responding and terminal-link reinforcement was a function of certain procedural features of the experiment, such as the absolute duration of the terminal-link IRI. Moreover, the results of certain other experiments, such as Killeen's (1968a) and Neuringer's (1969) findings of indifference between response-dependent and response-independent terminal-link reinforcers, and Schneider's (1972) finding of indifference between chain and tandem terminal-link VI schedules, have been used to argue in favor of the primacy of terminal-link IRIs in the determination of value and, hence, preference.

The foregoing is a cursory review of nearly 15 years of research dealing with the "averaging problem" (cf. Fantino & Navarick, 1974, p. 158). As Rider (1983a, pp. 264-265) has recently noted, however, Fantino and Navarick found that (a) aperiodic and periodic schedules to which pigeons were indifferent are not necessarily equally preferred to a third schedule in a separate test of choice, and (b) aperiodic and periodic schedules that are equally preferred to a third schedule do not necessarily generate indifference in a separate test of choice. These findings imply at least that current models of choice attempting to achieve a fit to the data by transforming terminal-link IRIs were of very limited adequacy, even if a regression line did account for an agreeably

high percentage of the variance. Indeed the findings may even imply that the entire matter of reducing choice to unidimensional control by obtained terminal-link IRIs is essentially futile and doomed to failure. However, efforts at both the conceptual and empirical level continue on the relation between initial-link responding and temporal parameters of terminal-link reinforcement. For example, Baum (1973) has argued:

an organism can be viewed as collecting time samples of the significant events in its environment (e.g., reinforcers and punishers), which it integrates and utilizes to control its behavioral output. The exact nature of this integrating or averaging process has been the subject of some recent research. (p. 148)

Baum then cites four concurrent-chains articles in support of his argument, two of which are by Killeen (1968b) and Duncan and Fantino (1970). However, the empirical generality of the transformed interreinforcement-interval effect, even when restricted to choice between two aperiodic time-based schedules, is somewhat unclear. For example, the Squires and Fantino (1971) equation, which is extraordinarily successful in describing choice in concurrent chains with VI initial- and terminal-link schedules, employs arithmetic means; use of the harmonic means of the VIs would greatly reduce its accuracy. Baum (1974a) claimed to have found matching in chained concurrent schedules, but neither the initial- nor the terminal-link schedules were viewed in terms of their harmonic means. Indeed, although the matching law does concern simple concurrents, rather than concurrent chains, it is predicated upon arithmetic means; it does not employ harmonic means (cf. Baum, 1979). More recently, Shull, Spear, and Bryson (1981; see also McDiarmaid & Rilling, 1965) have found support for an analysis involving summed immediacies of reinforcers, whereas Moore (1979, 1982) has not. Similarly, Rider (1983a) has found that the harmonic mean delay model did not

provide a compellingly accurate estimate of preference in the case of choice between mixed and fixed delays of reinforcement (see also studies cited in the introduction of his article).

In addition, in a more recent study, Rider (1983b) reported that although rats preferred mixed-ratio schedules to a fixed-ratio schedule when the schedules were presented as terminal links in concurrent chains, rats preferred the fixed-ratio over the mixed-ratio schedule when choice was assessed with a simple concurrent procedure. The critical issue here is not so much the adequacy of any particular averaging model, but rather the more fundamental question of why there should be complete reversal of preference with only a change in choice procedure. Presumably, if one is to accept responding as tautologous with the value of the schedule, then there is a problem with the internal consistency of the account outlined in the beginning of the present introduction. The value of a schedule should presumably not change when the procedure used to measure its value changes. The two procedures should provide converging, rather than conflicting, evidence concerning what the correct scale of reinforcement value is.

The present research examined further the generality of an analysis of choice processes that appeals to molar rather than to molecular events, and to the harmonic averaging process. Pigeons were presented with an opportunity to choose between two aperiodic schedules of reinforcement. For the first schedule, the arithmetic mean IRI was short, but the harmonic mean was long, whereas for the second schedule, the arithmetic mean IRI was long but the harmonic mean was short (cf. Killeen, 1968b). The schedules were presented for choice (a) as terminal links in concurrent chains under three terminal-link scheduling procedures, (b) in a 2-key, simple concurrent procedure, and (c) in a changeover-key procedure with response-independent reinforcers. Of particular concern was the pattern of preference that emerged from this array of comparisons. Was the schedule with the shorter

harmonic mean preferred uniformly, suggesting that the harmonic mean was indeed the important characteristic of an aperiodic schedule to which pigeons responded? Or, alternatively, if the schedule with the shorter harmonic mean was not preferred uniformly, what are the implications of the results for current theoretical analyses of the reinforcement process?

METHOD

Subjects

Five adult male pigeons (R-3, R-4, R-16, R-19, R-20) of mixed breeds and various experimental histories, maintained at approximately 80% of their free-feeding weights, served as subjects.

Apparatus

A two-key version of a standard experimental chamber for pigeons was employed. Conventional electromechanical apparatus, with motor-driven VI tape programmers, was located in a room adjacent to the chambers, and was used to control events within the chambers and to record the data.

Procedure

Three sets of choice comparisons (concurrent chains, concurrent VI VI, concurrent VT VT) were conducted. Primary reinforcers (3-s access to mixed grain) in all comparisons were arranged by two aperiodic schedules, as in Killeen (1968b). The IRIs on one schedule were 4, 36, 50, 3, 25, 15, 124, 394, 6, 9, 75 and 217 s, and on the other, 56, 60, 18, 37, 66, 48, 7, 31, 42, 13, 25, and 76 s. The arithmetic mean of the IRIs on the first schedule is approximately 80 s, and on the second schedule, 40 s. The harmonic mean of the IRIs on the first schedule is approximately 12 s, and on the second schedule, 25 s (see Equation 1). Henceforth, each schedule will be referred to in terms of its *arithmetic* mean IRI, as either VI 40-s or VI 80-s. Sessions in all comparisons were terminated after the pigeon had received 48 reinforcers, as in Killeen

(1968b). Starting points of the tapes on the VI programmers were varied randomly on a session-by-session basis. The left-hand column of Table 1 presents the details and sequence of the schedules to which the pigeons were exposed. Further procedural details of each comparison are listed in other columns of Table 1.

Concurrent-chains comparisons. In the concurrent-chains comparisons, the pigeon was presented with two concurrently available response keys, each illuminated by a stimulus correlated with the initial link of a chain. Occasionally, a response produced a terminal-link stimulus and accompanying VI schedule, whereby further responding produced food. At the conclusion of the terminal link, the initial links were reinstated for the next period of choice and the cycle began anew (Killeen, 1968b).

The initial-link schedules were independent VI 60-s schedules. The initial-link stimulus on each key was a cross. One of the aforementioned VI schedules arranged food reinforcers in the left terminal link, and the other arranged food reinforcers in the right terminal link. The terminal-link stimulus on the left key was a vertical line, and on the right key, a horizontal line. All pigeons were first exposed to the standard terminal-link scheduling procedure, in which the initial links were reinstated after a single terminal-link reinforcer. This procedure was identical to that employed by Killeen (1968b). Following exposure to this procedure, each pigeon was exposed to concurrent chains with a modified terminal-link scheduling procedure, in which the initial links were reinstated after a fixed duration of time in each terminal link. In one procedure, the VI 40-s schedule was in effect for 40 s (VI 40/40), and the VI 80-s schedule was in effect for 80 s (VI 80/80). In a second procedure, the VI 40-s schedule was in effect for 80 s (VI 40/80), and the VI 80-s schedule was in effect for 160 s (VI 80/160). Reinforcers that were scheduled but not collected during a terminal link were canceled at the conclusion of the terminal link. In these procedures, timing for terminal-link duration continued

during the 3-s reinforcement cycle, but timing for the IRI of the correlated VI schedule did not. Stability for Pigeons R-3, R-4, and R-16 was assessed by means of a formal criterion that required performance in at least 15 daily sessions. Following the 15th session or any session thereafter, if the criterion had not been satisfied, the choice proportions from the last nine sessions were considered in three blocks of three sessions each. When the means of the three blocks differed by no more than 0.05 and showed neither monotonically increasing nor decreasing trends, behavior was considered stable and the next condition was instituted. Stability for Pigeons R-19 and R-20 on a given determination was assessed by visual inspection. An initial determination and a reversal were conducted to demonstrate experimental control on the modified procedures.

Concurrent VI VI comparisons. In the concurrent VI VI comparisons, reinforcers on the left key were arranged directly by one of the aforementioned schedules, and on the right key, by the other schedule (Herrnstein, 1961). The stimulus on the left key (S1) was a vertical line, and on the right key (S2) was a horizontal line. A standard changeover delay of 2 s (2-s COD) prevented reinforcement of the switching response. An initial determination and a reversal were conducted to demonstrate experimental control. Stability was assessed by visual inspection.

Concurrent VT VT comparisons. In the concurrent VT VT comparisons, response-independent reinforcers were arranged concurrently by each of the aforementioned schedules. Each schedule was correlated with a different exteroceptive stimulus, and only one or the other schedule/stimulus pair was in effect at a given time. Reinforcers were delivered by a given schedule only when it was in effect. The schedule and stimulus could be changed by a response on the only key that was illuminated and operative in the chamber, the changeover key. A 2-s COD was in effect after every peck on the changeover key (Brownstein & Pliskoff, 1968). For R-20, the changeover key was always white, and the stimuli were white

Table 1

Details of the schedules to which the pigeons were exposed. Included for the concurrent-chains comparisons are the terminal-link schedules, expressed in terms of their arithmetic mean IRI and accompanied by the number of reinforcers per entry (1*) or duration of entry (initial-link schedules were always VI 60-s); responses per min during initial and terminal links on left and right keys; the relative reinforcement rate on the left key, and the number of sessions in that determination. Included for the concurrent VI VI and the concurrent VT VT comparisons are time and response measures (collected after the 2-s COD had elapsed), relative reinforcement for S1, and the number of sessions in that determination. The order in which the comparisons were conducted is also presented. Data are means from the last three sessions of each comparison.

<i>Conc chains Terminal-link Schedule</i>	<i>Left Initial</i>	<i>Responses per minute</i>		<i>Right Terminal</i>	<i>Rel. Reinf. on Left</i>	<i>Sessions</i>	<i>Order</i>
R-3							
L VI 80/1*	23	33	10	43	.51	32	A
R VI 40/1*							
L VI 80/80	8	27	12	58	.53	19	B
R VI 40/40							
Died before further conditions could be completed.							
R-4							
L VI 80/1*	46	70	17	56	.49	17	A
R VI 40/1*							
L VI 40/1*	11	63	27	32	.50	25	B
R VI 80/1*							
L VI 40/80	32	71	23	26	.48	16	C
R VI 80/160							
L VI 80/160	16	36	34	70	.46	15	D
R VI 40/80							
L VI 40/40	58	101	19	42	.46	15	E
R VI 80/80							
L VI 80/80	12	28	16	77	.50	35	F
R VI 40/40							
R-16							
L VI 80/1*	11	15	4	54	.49	15	C
R VI 40/1*							
L VI 80/160	4	10	7	59	.46	15	D
R VI 40/80							
L VI 40/80	26	62	10	7	.46	35	E
R VI 80/160							
<i>Conc Schedules</i>	<i>Total Time</i>	<i>Total Resp.</i>	<i>Resp./ Min.</i>	<i>Change- overs</i>	<i>Rel. Reinf. on S1</i>	<i>Sessions</i>	<i>Order</i>
S1: VI 80	2.3	86	32	30	.30	7	A
S2: VI 40	13.6	533	39				
S1: VI 40	8.9	475	53	106	.68	12	B
S2: VI 80	4.1	162	40				
S1: VT 40	12.3			518	.65	15	E
S2: VT 80	2.5						
S1: VT 80	6.7			408	.40	21	F
S2: VT 40	10.6						

Table 1—continued

<i>Conc chains</i> <i>Terminal-link</i> <i>Schedule</i>	<i>Left</i> <i>Initial</i>	<i>Responses per minute</i> <i>Left</i> <i>Terminal</i>		<i>Right</i> <i>Initial</i>	<i>Right</i> <i>Terminal</i>	<i>Rel. Reinf.</i> <i>on Left</i>	<i>Sessions</i>	<i>Order</i>
R-19								
L VI 80/1*	70	81	39	67	.49	22	C	
R VI 40/1*								
L VI 80/80	23	74	50	74	.52	21	D	
R VI 40/40								
L VI 40/40	51	93	32	68	.47	20	E	
R VI 80/80								
<i>Conc</i> <i>Schedules</i>	<i>Total</i> <i>Time</i>	<i>Total</i> <i>Resp.</i>	<i>Resp./</i> <i>Min.</i>	<i>Change-</i> <i>overs</i>	<i>Rel. Reinf.</i> <i>on S1</i>	<i>Sessions</i>	<i>Order</i>	
S1: VI 80	3.9	384	98	152	.30	7	A	
S2: VI 40	8.6	616	72					
S1: VI 40	6.8	578	85	144	.73	9	B	
S2: VI 80	3.3	297	90					
S1: VT 80	5.8			309	.40	22	F	
S2: VT 40	12.4							
S1: VT 40	25.9			189	.65	18	G	
S2: VT 80	3.4							
<i>Conc chains</i> <i>Terminal-link</i> <i>Schedule</i>	<i>Left</i> <i>Initial</i>	<i>Responses per minute</i> <i>Left</i> <i>Terminal</i>		<i>Right</i> <i>Initial</i>	<i>Right</i> <i>Terminal</i>	<i>Rel. Reinf.</i> <i>on Left</i>	<i>Sessions</i>	<i>Order</i>
R-20								
L VI 40/1*	22	61	83	56	.50	12	C	
R VI 80/1*								
L VI 40/80	23	70	22	66	.44	20	D	
R VI 80/160								
L VI 40/160	5	58	47	88	.47	12	E	
R VI 40/80								
L VI 40/80	26	67	21	85	.43	61	F	
R VI 80/160								
<i>Conc</i> <i>Schedules</i>	<i>Total</i> <i>Time</i>	<i>Total</i> <i>Resp.</i>	<i>Resp./</i> <i>Min.</i>	<i>Change-</i> <i>overs</i>	<i>Rel. Reinf.</i> <i>on S1</i>	<i>Sessions</i>	<i>Order</i>	
S1: VI 80	7.2	262	36	289	.33	5	A	
S2: VI 40	16.5	857	52					
S1: VI 40	13.5	616	46	225	.63	9	B	
S2: VI 80	7.5	344	46					
S1: VT 80	8.0			190	.33	8	G	
S2: VT 40	14.5							
S1: VT 40	14.0			316	.65	10	H	
S2: VT 80	4.6							

(S1) and amber (S2) houselights. For R-16 and R-19, the two exteroceptive stimuli were a horizontal line (S1) and a vertical line (S2) and were located on the key itself. An initial determination and a reversal were conducted to demonstrate experimental control. In the reversal for R-19, the schedules were nonindependent (Stubbs & Pliskoff, 1969). In all other determinations for all other pigeons, the schedules were independent. Stability was assessed by visual inspection.

RESULTS

The results of the choice comparisons are presented in Table 1 and Figures 1 and 2. With regard to the concurrent-chains comparisons, all pigeons preferred the VI 80-s schedule over the VI 40-s schedule in the standard procedure with a single reinforcer per entry (VI 40/1* vs. VI 80/1*), a finding which replicated Killeen's (1968b) results. However, under the modified terminal-link

Fig. 1. The choice proportions for the concurrent-chains comparisons are shown for all pigeons. The data are taken from Table 1, and if more than one determination is involved, are averages of the entries. The standard procedure (S) involved a single reinforcer per terminal-link entry (VI 40/1* vs. VI 80/1*). One modified procedure (M1) involved a fixed duration of entry that was equal to the arithmetic mean IRI in that terminal link (VI 40/40 vs. VI 80/80). The second modified procedure (M2) involved a fixed duration of entry that was twice the arithmetic mean IRI in that terminal link (VI 40/80 vs. VI 80/160). All schedule values and durations are in seconds, and the choice proportions are expressed in terms of the VI 40-s terminal-link schedule. The dotted line at .50 represents indifference. Hence, bars below the line indicate preference for the VI 80-s terminal link; bars above the line indicate preference for the VI 40-s terminal link.

Fig. 2. The choice proportions for the concurrent VI 40 VI 80 and concurrent VT 40 VT 80 comparisons are shown. The data are taken from Table 1 and are averages of the initial and reversal determinations. Schedule values are in seconds, and the preference measures for response distribution and time allocation are presented separately. The dotted line at .50 represents indifference. Hence, bars above the line indicate preference for the VI/VT 40-s schedule.

scheduling procedures, all pigeons preferred the VI 40-s schedule, although R-20's preference for VI 40/80 over VI 80/160 did not emerge until the second and third determinations.

With regard to the other choice comparisons, Figure 2 shows that all pigeons preferred the VI 40-s schedule in both the concurrent VI VI and concurrent VT VT procedures. The preferences in the concurrent VI VI procedure seemed to develop in fewer sessions than the preferences in the concurrent VT VT procedure, but preference in terms of time allocation was slightly greater under concurrent VT VT than under concurrent VI VI. The absolute response rates generated by the schedules did not seem to vary systematically with preferences between choice procedures. Killeen (1968b) noted that the (preferred) VI 80-s terminal-link schedule generated a faster rate of responding for one pigeon, a slower rate for another, and about the same rate for a third, when compared to the (nonpreferred) VI 40-s terminal-link schedule. In the present concurrent-chains comparisons, the (nonpreferred) VI 40-s schedule generated faster rates of responding in 4 of 6 determinations in the replication of Killeen's (1968b) findings and in 10 of 12 determinations involv-

ing modified terminal-link scheduling procedures, when it was the preferred schedule. It generated a faster rate of responding in 3 of 7 concurrent VI VI determinations, however. Moreover, the absolute rate of responding generated by a given schedule was faster when the schedule appeared as a terminal link in concurrent chains than when it was in the concurrent VI VI procedure (see also Wilton & Gay, 1969).

DISCUSSION

The pigeons in the present experiment preferred the schedule with the shorter harmonic mean IRI (i.e., VI 80-s) in the standard concurrent-chains choice procedure, in which the terminal link ended after the first scheduled reinforcer was obtained, but preferred the schedule with the shorter arithmetic mean IRI (i.e., VI 40-s) in modified concurrent-chains procedures, in a concurrent VI VI procedure, and in a concurrent VT VT procedure. Thus, the pigeons did not uniformly prefer the same schedule across all choice procedures. Rather, their preferences varied as a function of the procedure employed. Given these results, two questions follow: (a) How might one account for the present results? and (b) How do the present results relate to current theories of choice and reinforcement processes?

First, let us address the concurrent-chains results. In an effort to gain an understanding of the variables that might be operating in the terminal links of the present concurrent-chains procedure, a computer program was written that calculated in several ways the value of a given VI schedule as a function of the temporal parameters of reinforcement. The value of a VI schedule as typically reported is a simple function of the average space (duration) between holes punched on the scheduling tape—that is, the arithmetic mean IRI. Killeen (1968b) suggested that the harmonic mean IRI was a better measure of the value of the schedule, but all such ways of computing value apply only to the standard method terminal-link scheduling procedure, in which a terminal link ends

after the first scheduled reinforcer is obtained. The present program calculated value in the modified procedure by starting at all possible (integral) starting points of the tape, then calculating both the arithmetic and harmonic mean delay to the first reinforcer only, and then including any other reinforcers that might be gained during that fixed duration. For those cases when the IRI was longer than the fixed duration, meaning that a reinforcer would not be scheduled during that terminal-link exposure, the program simply assumed a reinforcer at the conclusion of the fixed duration; the program also assumed a minimum delay of 1 s to the first reinforcer after schedule onset. This way of computing value is simply one possible logical extension of Killeen's (1968b) approach. The program was applied to the present tapes, IRIs of which have been specified in the procedure section, and also to tapes of the same arithmetic mean IRI generated according to the Fleshler and Hoffman (1962) progression for fixed duration equal to and twice the arithmetic mean IRI of the schedule. For the VI 40-s tape derived from the Fleshler and Hoffman equation, the IRIs were 25, 31, 9, 2, 64, 18, 14, 139, 49, 39, 5, and 84 s. The harmonic mean of these IRIs is approximately 11 s. For the VI 80-s tape derived from the Fleshler and Hoffman equation, the IRIs were 126, 49, 28, 19, 63, 168, 3, 11, 38, 79, 99, and 278 s. The harmonic mean of these IRIs is approximately 19 s. Table 2 gives the results of the calculations.

As shown in Table 2, ordinal differences between the VI 40-s and VI 80-s Fleshler and Hoffman (1962) schedules that prevailed under the standard scheduling procedure are preserved under the modified procedures. However, note that under the standard procedure, Killeen's (1968b) VI 40-s and VI 80-s schedules have harmonic mean IRIs of 25 and 12 s, respectively (thereby supporting the conclusion that preference is better described in terms of the shorter harmonic mean IRI), whereas under the modified procedure (terminal-link duration equal to arithmetic mean IRI), the harmonic mean delay to the first reinforcer for

Table 2

Mean delays to reinforcement associated with Killeen's (1968b) schedules and with comparable constant-probability schedules derived from the Fleshler and Hoffman (1962) equation. The VI 40/1* designation means the standard procedure, in which the terminal links concluded after the first scheduled reinforcer was obtained on that entry. The VI 40/40 and VI 80/80 designations mean the modified procedure, in which terminal links concluded after a fixed duration of 40 or 80 s exposure to a given schedule, irrespective of the number of reinforcers obtained on that entry. The arithmetic and harmonic mean delays based on the first reinforcer after schedule onset, and on all reinforcers after schedule onset, are listed separately. All schedule values and mean delays are in seconds.

Schedule	Mean delay to first reinforcer only		Mean delay to all reinforcers	
	Arithmetic	Harmonic	Arithmetic	Harmonic
Killeen (1968b)				
VI 40/1*	40	25		
VI 80/1*	80	12		
VI 40/40	23	7	24	9
VI 80/80	51	15	53	18
VI 40/80	25	9	40	13
VI 80/160	89	16	91	27
Fleshler & Hoffman (1962)				
VI 40/1*	40	11		
VI 80/1*	80	19		
VI 40/40	25	8	25	10
VI 80/80	50	14	50	17
VI 40/80	34	9	42	14
VI 80/160	69	14	85	25

the VI 40-s schedule is approximately 7 s, and for the VI 80-s schedule, approximately 15 s. These measures are not appreciably altered when the terminal-link duration was twice the IRI. Thus, the modified procedure reversed which schedule offered the shorter harmonic mean delay to the first reinforcer. Interestingly, for both the standard and modified procedures, the pigeons can be said to prefer the schedule with the shorter harmonic mean delay to the first reinforcer. Hence, the results of the three sets of concurrent-chains comparisons can actually be accommodated under the same general principle: Pigeons prefer the terminal link with the more immediate reinforcer, even though some aggregate measure of reinforcement may not be consistent with this local feature of the schedule. Indeed, control by local features over aggregate when they have been placed in opposition has been shown in certain other cases as well (Moore, 1979, 1982). Although the role of reinforcers after the first is not altogether clear, they appear in most

cases to have little, if any, influence (but see Shull et al., 1981). Even according to Killeen's (1968b) account, they are not given much weight.

The process by which the harmonic mean delay to the first reinforcer reversed under the modified procedure with Killeen's (1968b) schedules but not with constant-probability schedules may be understood as a function of both the shape of the distribution of the IRIs and of the inherent nature of the fixed-duration scheduling procedure. The Fleshler and Hoffman (1962) progression arranges an approximately homogeneous density of reinforcement across time, hence the designation of a "constant-probability" schedule (see also Catania & Reynolds, 1968; Millenson, 1963; Segal, 1964). The shape of the distribution approximates that of the exponential decay function. In contrast, the IRIs in Killeen's tapes are not exponentially distributed; indeed, the departure from the exponential distribution is what gives them the properties reflected in the contrasting

arithmetic and harmonic mean IRIs. The fixed-duration scheduling procedure is a kind of sampling without replacement technique. The sampling without replacement technique preserved the ordinal differences between constant probability as shown in Table 2 and by the results of Autor (1969), who actually used the modified procedure and reported data consistent with the standard procedure. However, the modified procedure exerts a profound effect on schedules in which reinforcer density is not homogeneous. Consider Killeen's VI 80-s schedule. Under the standard procedure, the short IRIs of this schedule would be the first and only IRIs, and would then exert the strong controlling influence shown in Killeen's (1968b) original experiment and in the present replication. However, under the modified procedure, these short IRIs were frequently bracketed between the beginning and end of the terminal link, such that they did not appear first but later, perhaps in the middle or toward the end of the fixed-duration terminal link. Given that these short IRIs were occasionally so temporally remote from terminal-link onset, they could not exert as disproportionate a controlling influence as when they occur earlier (e.g., as under the standard procedure).

With regard to the concurrent VI VI and concurrent VT VT data, it appears that "there are already explanations . . . that deal with matching, maximizing, optimization, economic equalizing, molar matching, molecular maximizing, and melioration, with quantitative accounts for each" (Dreyfus, Dorman, Fetterman, & Stubbs, 1982, p. 338). The present few comparisons are not intended to provide any new basis for yet another account of choice. Suffice it to note that Dreyfus et al. examined performance under several concurrent schedules, where the IRIs were taken from a distribution that provided a constant probability of reinforcement over time (Catania & Reynolds, 1968; Fleshler & Hoffman, 1962), as well as from arithmetic and geometric progressions. They found that one distribution did not produce performance that was appreciably different

from another—that is, the nature of the distribution of the IRIs did not matter appreciably, and pigeons preferred the schedule with the higher arithmetic rate of reinforcement. So far as is presently known, the effects of such distributions have not been systematically examined by arranging such schedules as terminal links of concurrent chains, although Davison (1972) did examine preference for mixed-interval schedules as a function of the number of component intervals, and found no effect of the number of component intervals per se.

In any event, a computer simulation resembling that of Dreyfus et al. (1982) was conducted in connection with the present data (S. Hale and J. Myerson, personal communication, 1983). Obtained local response rates and obtained interchangeover times (ICTs) from the present comparisons were applied to the IRIs of Killeen's (1968b) schedules in one VI 40-s versus VI 80-s comparison, and to the intervals from the aforementioned Fleshler and Hoffman (1962) schedules in a second VI 40-s versus VI 80-s comparison. The simulation yielded a profile of reinforcers in relation to changeovers. Note that the actual data of the present experiment were not recorded in such a way as to permit the derivation of this profile. For both the Killeen and Fleshler and Hoffman schedules, the simulation indicated that all of the reinforcers on the VI 80-s schedule were earned right after a changeover. Between 65% and 70% of the reinforcers on the VI 40-s schedule were earned within 3 s of a changeover. Thus, the simulation showed that to a rough approximation, the same relation between reinforcement and changing over prevailed for both distributions.

How do the present data relate to current theories of choice and reinforcement processes? The present data are consistent, at least in spirit, with an analysis that emphasizes immediacy of reinforcement (e.g., Killeen, 1968b). The notion of immediacy, upon which the harmonic averaging process is based, does indeed assign greater weight to short delays to reinforcement, and that is what the current data suggest needs to be

done. Similarly, the current data are also consistent with conceptualizing certain aspects of organism-environment interactions in terms of a feedback relation (Baum, 1973). The present data show the importance of such an interactive analytical approach, and stress the dependence between the effect of reinforcers and the IRIs according to which these reinforcers are actually obtained.

However, a molar feedback approach also emphasizes *overall rate* of reinforcement (Baum, 1973, p. 149). If this notion of rate is to have an explanatory force—for example, as a molar principle that differs from other (molecular) principles—then it suggests, indeed it *requires*, “transcending the momentary” (Baum, 1973, p. 147). Yet, the present data show that it is necessary to consider the momentary, that is, the initial delay to reinforcement encountered by the organism, to understand correctly how behavior is determined by a given distribution of reinforcing events. Thus, “rate of reinforcement” does not appear to characterize the “value” of a choice alternative such as a VI schedule, if by rate one means the molar characteristics of a schedule considered in isolation, quite apart from the way the first reinforcer on the schedule is actually encountered. Accordingly, the present data clarify *what* one should take into account, rather than *how* one should take it into account. What should be taken into account is presumably the delay from terminal-link onset to the subsequent reinforcer in order to understand choice in the present concurrent-chains comparisons, rather than simply the number of reinforcers per unit of time. How one should take this variable into account may well be in terms that emphasize the importance of short delays to reinforcement. In any case, one should not allow the intervals between successive reinforcers per se to enter into the transformational process, and then presume that the product of this process represents some basic measure of reinforcement “value” to which the pigeons responded (for further comments regarding the molar approach, see Moore, 1983).

The present results complement those of Rider (1983b) in suggesting that what is preferred under one choice procedure need not necessarily be preferred under another. Such results are challenging for the assumptions of the molar approach outlined in the introduction of this paper, according to which choice responding may safely be taken as indicating the value of the available alternatives. Although perhaps a scale of value could be derived from experimental research, it appears that such a scale will have to be predicated upon far more than simply obtained IRIs. No doubt temporal factors are important, but others must be as well—hence such findings as the intransitivity effect (Navarick & Fantino, 1974) and the present asymmetry of results within and across procedures. In any case, there appear to be many factors whose experimental importance remains to be determined.

A final implication of the present data concerns the practice of estimating post hoc a transformation parameter that will yield a proportionality between initial-link responding and terminal-link reinforcement. The practice is widespread, but it appears to be methodologically as well as epistemologically suspect. At issue is why one would have expected to find such a parameter. Such an expectation would be appropriate if the distribution of initial-link responding were a function of terminal-link reinforcement parameters only, and were independent of initial-link schedule parameters. However, Fantino (1969) has shown that the degree of preference for a VI 30-s terminal link over a VI 90-s terminal link in concurrent chains does indeed vary with the size of the initial links: Preference may be great with one set of equal initial links (e.g., VI 40-s), intermediate with another set (e.g., VI 120-s), and tend toward indifference with a third set (e.g., VI 600-s). Thus, even if some transformation parameter were discovered for a set of terminal-link IRIs that did yield a proportionality between initial-link responding and terminal-link reinforcement, that parameter would have to vary with the size of the initial links. Perhaps all these points are

moot, because there seems to be no transformation parameter that will work in more than a few instances (Fantino & Navarick, 1974). In any case, it seems conceptually awkward to argue first that the correct way to describe the pigeon's behavior is in terms of transformed terminal-link IRIs, then to argue second that one transformation is more appropriate than another for a given set of those IRIs, and then third to change the transformation parameter when the initial links are made longer or shorter, even though terminal-link IRIs have remained the same. The point applies to the present experiment, and also to Killeen's (1968b), in the following way. If shorter initial links had been used, regardless of whether the standard or modified procedure was in effect during the terminal links, preferences would have been greater, and an r more negative than ($r = -1$) would have been required to fit the data. In contrast, if longer initial links had been used, preferences would have been less pronounced, and an r less negative than ($r = -1$) would have been required to fit the data. However, recall that the rationale for transforming terminal-link IRIs has nothing to do with the size of the initial links, but rather with specifying the psychologically correct measure of reinforcer frequency, as in tapping into some subjective scale of reinforcement that is supposed to be analogous to the subjective scales uncovered in psychophysics (Killeen, 1968b, p. 268). Yet, in the present case, the parameters of the reinforcement schedule (i.e., the IRIs themselves) would not have been altered at all. Rather, only the parameters of some other aspects of the procedure, the initial links, would have been altered. Again, there seem to be problems with the internal consistency and generality of the molar approach.

The practice of transforming IRIs might be valid if it is viewed as expressing in an ordinal way the potency of specified reinforcement parameters, *provided* one then combines this factor with such other factors as initial-link parameters in the final expression of the independent variable. Thus, although it may well be that a given set of data does

support a "matching" relation between the the distribution of responding and certain temporal parameters of reinforcement, the evidence suggests such a relation is at best a fortuitous by-product of the schedules employed, rather than a fundamental law elucidating either the inherent structure of behavior or the way that organisms express their sensitivity to reinforcing events distributed over time.

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