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CHOICE BETWEEN RELIABLE AND UNRELIABLE OUTCOMES: MIXED PERCENTAGE-REINFORCEMENT IN CONCURRENT CHAINS

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Pigeons' choices between alternatives that provided different percentages of reinforcement in mixed schedules were studied using the concurrent-chains procedure. In Experiment 1, the alternatives were terminal-link schedules that were equal in delay and magnitude of reinforcement, but that provided different percentages of reinforcement, with one schedule providing reinforcement twice as reliably as the other. All pigeons preferred the more reliable schedule, and their level of preference was not systematically affected by variation in the absolute percentage values, or in the magnitude of reinforcement. In Experiment 2, preference for a schedule providing 100% reinforcement over one providing 33% reinforcement increased systematically with increases in the duration of the terminal links. In contrast, preference decreased systematically with increases in the duration of the initial links. Experiment 3 examined choice with equal percentages of reinforcement but unequal delays to reinforcement. Preference for the shorter delay to reinforcement was not systematically affected by variation in the absolute percentage of reinforcement. The overall pattern of results supported predictions based on an extension of the delay-reduction hypothesis to choice procedures involving mixed schedules of percentage reinforcement.

Key words: choice, percentage reinforcement, mixed schedules, risk sensitivity, reinforcement delay, reinforcement magnitude, concurrent-chains schedule, delay-reduction hypothesis, key peck, pigeons

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One problem that animals often face in their natural environments is that of choice between alternatives that entail different probabilities of obtaining reward. This choice can be studied experimentally using a variation of the concurrent-chains procedure (Autor, 1969) with differing percentages of reinforcement in the terminal links (Fantino, Dunn, & Meck, 1979; Kendall, 1974, 1985). Under this procedure, access to the terminal links is provided according to equal, independent schedules on the response keys during the initial links (i.e., choice phase), and access to an outcome is provided according to equal schedules for the two terminal links. However, each outcome may consist of either a reinforcement (food presentation) or a blackout, and the two terminal links differ with respect to the percentage of reinforcements (i.e., one terminal link provides reinforcement more reliably than the other).

Using this basic procedure, Kendall (1974) reported that pigeons sometimes preferred a schedule of reinforcement that provided food 50% of the time to one that provided food 100% of the time, a preference that would seem maladaptive inasmuch as it lowered the overall amount of food obtained. However, Kendall's procedure involved an unusual set of stimuli: Unlit keys served both as the initial-link stimuli during the choice phase and as the nonoperative terminal-link stimulus. Using a more traditional concurrent-chains procedure, in which illuminated keys served as the initial-link stimuli, Fantino et al. (1979) found that pigeons preferred the schedule providing the higher percentage of reinforcement. Furthermore, Fantino and his co-workers failed to find consistent preference for intermittent reinforcement even when they attempted to directly replicate Kendall's procedure.

Recently, however, Kendall (1985) has re-

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ported another replication of preference for unreliable reinforcement, this time with initial-link keys illuminated. He also demonstrated limiting conditions for the phenomenon. Preference for the unreliable alternative appears to depend on the use of short initial-link and long terminal-link schedules. Furthermore, this preference appears to develop reliably only in a "multiple" or "correlated" percentage-reinforcement procedure in which the food and no-food outcomes are signaled by terminal-link stimuli (Kendall, 1974, 1985).

In contrast to the inconsistent results found with multiple percentage-reinforcement procedures, preference for reliable reinforcement schedules has been the typical finding in "mixed" or "uncorrelated" procedures in which a single terminal-link stimulus precedes both food and no-food outcomes (Kendall, 1974, 1985; Schneider, 1968). Although considerable attention has been given to preference for percentage reinforcement with multiple schedules, little is known about the variables that affect the apparently consistent preference for reliable reinforcement in mixed procedures. For example, is a choice between 25% and 50% reinforcement comparable to a choice between 50% and 100% reinforcement? Is choice for different percentages of reinforcement on a concurrent-chains schedule affected by the duration of the initial or terminal links?

The present investigations extend the empirical study of choice in situations involving mixed percentage reinforcement. In addition, the present experiments sought to examine a possible extension of the delay-reduction model (Fantino, 1969, 1981) to choice between alternatives that entail percentage reinforcement. The delay-reduction hypothesis states that the strength of a stimulus as a conditioned reinforcer is a function of the reduction in time to reinforcement correlated with the onset of that stimulus. The hypothesis was first developed to describe choice between schedules that provide different delays to reward (Fantino, 1969). According to this hypothesis, preference for a terminal-link schedule in a concurrent-chains procedure depends upon the reduction in overall time to reward correlated with entry into that terminal link, relative to the reduction correlated with entry into the other terminal link. More formally,

$$\frac{R_l}{R_l + R_r} = \frac{(T - t_l)}{(T - t_l) + (T - t_r)}, \quad \text{when } t_l < T,\ t_r < T$$
$$= 1 \ (\text{when } t_l < T,\ t_r > T)$$
$$= 0 \ (\text{when } t_l > T,\ t_r < T)$$

where, R_l and R_r are the numbers of responses to the left and right initial-link stimuli, respectively, t_l is the left terminal-link interval, t_r is the right terminal-link interval, and T is the average time to reinforcement from the onset of the initial links (see Fantino, 1977). (A simple computational formula for T in a two-choice concurrent-chains procedure with equal initial-link variable-interval schedules (ILVI) is .5 (ILVI) + .5 (t_l) + .5 (t_r). Determination of T becomes more complex with unequal initial-link schedules—see Squires & Fantino, 1971.)

Although this delay-reduction equation contains only parameters for time to reinforcement, Navarick and Fantino (1976) suggested that the equation could be applied to choice for different magnitudes of reinforcement by transforming magnitude into a delay value. This transformation is based on the assumption that increases in the number of seconds per unit time that the organism has access to the reinforcer are functionally equivalent, whether they are produced by decreases in the delay to reinforcement or by increases in the magnitude of reinforcement. Navarick and Fantino suggested, for example, that a fixed-interval 5-s (FI 5) schedule with 4.5 of reinforcement might be roughly equivalent to an FI 1.7-s schedule with 1.5 s of reinforcement. More recently, Green and Snyderman (1980) and Snyderman (1983) have provided data that argue against simple functional equivalence of delay and magnitude parameters. In particular, increases in reward magnitude seem to be less effective than decreases in delay to reward. Nevertheless, the Navarick and Fantino extension of the delay-reduction equation provides a reasonably adequate qualitative description of choice between different reward magnitudes under various conditions. For example, with equal terminal-link durations but unequal reward magnitudes, the delay-reduction model predicts that preference for the larger reward will increase with increases in the duration of the terminal links. This prediction was supported both by the results of Navarick and Fantino's study and by the results of subsequent studies on rats' choices between different magnitudes of reinforcement (Ito, 1985; Ito & Asaki, 1982). The effect of varying the delay to different magnitudes of reinforcement parallels the results of studies that have varied the absolute durations of unequal delays to reinforcement (terminal links) while the ratio of delays was held constant (Williams & Fantino, 1978). In these studies, level of preference increased with increased terminal-link durations.

The extension of the delay-reduction model to choice between differing magnitudes of reinforcement, together with recent evidence that the model can also be applied to such phenomena as the behavior of observing (Case & Fantino, 1981), elicited responding (Fantino, 1982), three-alternative choice (Fantino & Dunn, 1983), and foraging (Fantino & Abarca, 1985), suggests that the model may have considerable generality. An extension to choice between differing percentages of reinforcement would further enhance this generality.

It is not immediately obvious, however, just how percentage reinforcement should be represented in the delay-reduction equation. Navarick and Fantino (1976) represented magnitude of reinforcement in this equation by first transforming the different magnitudes into unequal delay values (i.e., t_l and t_r), and then using these new values in the determination of T. Because percentage reinforcement, like both magnitude and delay, affects the duration of access to reinforcement per unit time, it might be appropriate also to transform percentage reinforcement values into delay values, and to use these transformed values as t_l and t_r, as well as in the determination of T. For example, with equal VI 90-s initial links and equal FI 15-s terminal links, 100% reinforcement on the left and 50% reinforcement on the right, the transformed delay values would be $t_l = 15/1 = 15$, $t_r = 15/.5 = 30$, and T would be calculated as $.5(90) + .5(15) + .5(30) = 67.5$. When these values are used in the delay-reduction equation, the predicted choice proportion for the left terminal link is .58.

One potentially troublesome aspect of this method, which we will refer to as "Extension A," is that T no longer represents the mean time to reinforcement from the onset of the initial links. In the above example, the mean *interoutcome* interval is $.5(90) + .5(15) + .5(15) = 60$ s. Because reinforcement is available for 100% of the outcomes on one side and 50% of the outcomes on the other side, the mean scheduled *interreinforcement* interval is therefore $60/[(.5 + 1.0).5] = 80$ s. Furthermore, in a mixed percentage-reinforcement procedure, the delay to reinforcement correlated with entry into a terminal link is not simply the reciprocal of the rate of reinforcement in the presence of the terminal-link stimulus. Rather, the delay correlated with entry into a terminal link (say the left) is $p_l(t_l) + (1 - p_l)(t_l + T)$, where p_l is the probability of reinforcement on the left. That is, upon entry into the left terminal link, reinforcement will occur after t_l s with probability p_l. In addition, with probability $1 - p_l$, the delay to reinforcement is increased to t_l s plus the average interreinforcement interval (T).

Therefore, the mean reduction in delay signaled by the onset of the left terminal-link stimulus is $T - \{p_l(t_l) + [(1 - p_l)(t_l + T)]\}$. This simplifies to $Tp_l - t_l$. Accordingly, the following extension of the delay-reduction equation could be applied to concurrent-chains procedures that involve mixed percentage reinforcement:

$$\frac{R_l}{R_l + R_r} = \frac{Tp_l - t_l}{(Tp_l - t_l) + (Tp_r - t_r)}.$$

With this equation, which we will refer to as "Extension B," the predicted choice proportion for the left terminal link in the above example becomes $[80(1.0) - 15]/[80(1.0) - 15] + [80(.5) - 15] = .72$, a more extreme preference than the .58 level predicted by Extension A.

The present experiments assess the general applicability of these extensions of the delay-reduction model to choice with mixed percentage reinforcement. The procedures parallel those that have demonstrated orderly relations in the study of choice between unequal delays to reinforcement (Fantino, 1969, 1977, 1981). With the exception of Experiment 3, the procedures involved choice between two unequal percentages of reinforcement. The ratio of these two percentages was held constant within each experiment. In Experiment 1, the absolute percentage values and the magnitude of reinforcement were varied. In Experiment 2, the durations of the initial and terminal links of the concurrent chains were varied. In Experiment 3, the percentage values were equal and the durations of the terminal links were unequal on the two alternatives; the absolute percentage values were varied.

GENERAL METHOD

Subjects

Ten adult White Carneaux pigeons were maintained at approximately 80% of their free-feeding weights by food obtained during and after experimental sessions. All the pigeons had previously served in an autoshaping experiment. They were housed individually with water and grit continuously available. Four pigeons served in Experiment 1, 4 in Experiment 2, and 2 in Experiment 3.

Apparatus

Cylindrical operant-conditioning chambers, 36 cm in height and 33 cm in diameter, were used for 6 of the subjects (R1–R6), and 35.5-cm cubical chambers were used for the remaining subjects (S1, S2, S3, and S6). Each chamber contained three horizontally aligned translucent response keys, but only the two side keys were used. A force of approximately 0.15 N was required to operate each of the keys. Stimulus projectors mounted behind the keys were used to transilluminate them with light of various colors. A solenoid-operated grain hopper was located below the center key, and a lamp within the hopper was illuminated during grain presentations. General chamber illumination was provided by a houselight mounted above the center key, and white noise was continuously present. Experimental contingencies and data recording were controlled by a PDP-8E® computer (with Systol® software) located in an adjacent room.

Procedure

Preliminary training. For each experiment, preliminary training consisted of a few sessions of the autoshaping procedure to reestablish reliable pecking at each stimulus on each key, followed by a few sessions of exposure to concurrent variable-interval (VI) schedules.

Concurrent-chains schedule. The basic concurrent-chains procedure used in the present experiments is depicted in Figure 1. During the initial link of the chain, the left key was illuminated with one color and the right key with a different color (shown as A and B). Access to the terminal links was made available on two equal, independent VI schedules; the particular VI values are specified later. Entry into one of the terminal links produced the terminal-link color (shown as C or D) on the key on which a peck had produced the transition, caused the other key to become dark and inoperative, and halted the VI timer for the other key (saving its value for the beginning of the next cycle). In a terminal link, responding on the lighted key produced an outcome (either a food presentation or a blackout of the same duration) according to a fixed-interval (FI) schedule (Experiments 1 and 2) or a VI schedule (Experiment 3). The percentage of food presentations in a given

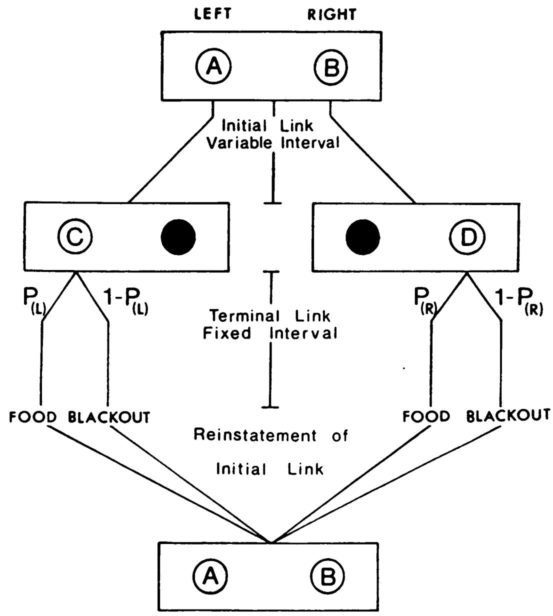

Fig. 1. General sequence of events in the percentage-reinforcement concurrent-chains procedure. A and B represent colored lights on two concurrently available keys during the initial links, C represents the terminal-link stimulus on the left, and D represents the terminal-link stimulus on the right. Initial-link VI schedules were always equal for the two sides, but were varied across experimental conditions. The specific terminal-link FI schedules varied but were always equal for the two sides in Experiments 1 and 2. In Experiment 3, unequal VI schedules were in effect during terminal links. Outcomes ended in either food or blackout according to probability values that varied across experimental conditions.

terminal link was determined by a random-probability subroutine with the constraint that the programmed percentage occur within each block of 12 outcomes in that terminal link. During blackouts the houselight was turned off. During both outcomes the keys were darkened and inoperative. Following an outcome, the initial-link stimuli were reinstated and another cycle began.

The values of the initial- and terminal-link schedules, the outcome durations, and the percentage of reinforcement correlated with each key were varied as described in the individual experiments. The VI schedules were composed of 20 intervals derived from the constant-probability progression suggested by Fleshler and Hoffman (1962).

Assessment of preference. During each session the number of responses made on each initial-link stimulus was recorded, as was the time between the first response following a changeover to either side key and the first response on the alternative key. Preference for a particular outcome was measured by calculating choice proportions for responses during the initial links (i.e., the number of responses on one initial-link stimulus divided by the sum of the responses on both initial-link stimuli). Each condition was in effect for a maximum of 30 sessions or until these choice proportions satisfied the following stability criterion: After 15 sessions (and each session thereafter until stability was reached), the choice proportions for the 9 preceding sessions were divided into blocks of 3 sessions. Preference was considered stable when the block means (M) did not differ by more than $\pm.05$, and showed neither an upward trend ($M_1 < M_2 < M_3$) nor a downward trend ($M_1 > M_2 > M_3$). All values reported are means from these 9-day periods. Experiments 1 and 2 contained a replication of the first one or two conditions run for each bird. The values obtained during these replications are reported in the figures and tables but are not included in the statistical evaluation of the results because the remaining conditions were not replicated. Sessions contained approximately 60 outcomes and were conducted 6 days a week.

EXPERIMENT 1

Kendall (1974, 1985) and Schneider (1968) have demonstrated preference for 100% over 50% reinforcement in concurrent-chains procedures with mixed percentage reinforcement. Experiment 1 investigates the generality of this preference for the more reliable alternative across variations in the absolute percentage and magnitude of reinforcement.

An important difference between the two proposed extensions of the delay-reduction hypothesis emerges when one considers what should happen if the schedules are changed from 100% versus 50% to 50% versus 25% reinforcement. According to Extension A, this change is equivalent to doubling both terminal-link values, which increases the difference between the two schedules in terms of the delay reduction they signal. Thus, halving the percentage-reinforcement schedules on both keys should increase preference for the more reliable side, in the same way that doubling the delay values has been shown to increase preference for the shorter delay (Williams & Fantino, 1978). For the example used in the introduction (i.e., equal VI 90-s initial links and equal FI 15-s terminal links), changing from 100% versus 50% to 50% versus 25% reinforcement increases the predicted choice proportions for the more reliable side from .58 to .67, according to Extension A.

According to Extension B, however, the predicted choice proportion is the same whether the schedules are 100% versus 50% or 50% versus 25%. The change to 50% versus 25% results in proportional changes in T and in both the left and right p values; the net result is no change in the difference between the two schedules in terms of the reduction in delay they signal. Thus, with Extension B, the predicted choice proportion for the more reliable side is .72 for the 100% versus 50% case and for the 50% versus 25% case.

In an analogous way, the two extensions also make qualitatively different predictions about the effect of varying reinforcer magnitudes that are equal on both sides. According to Extension A, increasing the magnitude of reinforcement on both sides should be equivalent to decreasing the delay (terminal links) on both, and should make preferences less extreme. In contrast, Extension B requires that an increase in magnitude of reinforcement on both alternatives influences the density of reinforcement over *both* the initial and terminal links of the chain, and therefore predicts no change in preference as reinforcer magnitudes are varied equally on the two sides.

Hence, the present experiment provides a test of these two ways of extending the delay-reduction hypothesis to choice between unequal percentages of reinforcement. The percentage of reinforcement correlated with one key was always twice that correlated with the other key, and reinforcer duration was always equal for the two keys. However, the different conditions of this experiment varied with respect either to the absolute percentages of reinforcement provided by the two chains (i.e., 50% and 100%, or 25% and 50%), or to the absolute reinforcer duration (i.e., 4.5 s, 3 s, or 1.5 s on both keys). It was of interest to assess, first, whether preference for the side providing more reliable reinforcement would be found consistently, and second, whether variation in the absolute percentage of reinforcement or in absolute reinforcer magnitude would have any systematic effect on preference.

In addition to the previously described predictions of either an inverse relationship between the magnitude or percentage of reinforcement and preference for more reliable schedules (Extension A) or no effect of these variables (Extension B), a third prediction can be derived from an entirely different theoretical perspective. A prediction of greater aversion to unreliable alternatives with larger reward magnitudes has been discussed in terms of Amsel's (1962) frustration theory (Spear & Pavlik, 1966), and is based on the idea that nonrewarded experiences should be more aversive in the context of large rewards than in the context of small rewards. From this perspective, one might expect preference for reliable schedules to become more extreme as reward magnitude increases.

There is some empirical support for this prediction. For example, Leventhal, Morrell, Morgan, and Perkins (1959) gave rats a choice between a reliable (100%) small reward and an unreliable (50%) large reward in an E maze. They found that the rats consistently preferred the alley that led to the unreliable large reward when the absolute reward magnitudes were small (e.g., 0.25 g vs. 0.5 g of food), but not when the absolute reward magnitudes were large (e.g., 1.0 g vs. 2.0 g). In a similar procedure but with equal reinforcer amounts, Spear and Pavlik (1966) found that preference for 100% reward over 50% reward in a T maze was more extreme in rats tested with 12-pellet rewards than in rats tested with 1-pellet rewards. More recently, studies of risk-sensitive foraging in white-crowned sparrows (e.g., Caraco, 1983) and common shrews (Barnard & Brown, 1985) have shown that preference for constant over variable feeding stations depends upon the conditions of food availability. Consistent with survivorship models of risk-sensitive foraging (e.g., Stephens, 1981), the animals were generally risk-averse during conditions that provided high levels of food availability (positive energy budgets). However, choice of the variable feeding stations increased when the overall level of food availability was insufficient and the animals were at risk of starvation (negative energy budget). Thus, one common finding in all of these studies may be an increased preference for reliable outcomes with increases in the absolute magnitude of food reward.

METHOD

During all conditions of this experiment, the percentage reinforcement produced in the left terminal link was twice that produced in the right terminal link, and the reinforcer duration was equal for the two terminal links. VI 90-s schedules were in effect on both keys during the initial links, and FI 15-s schedules were in effect during both terminal links. In the first set of conditions, the absolute percentages of reinforcement were varied, and in a subsequent pair of conditions the absolute reinforcer duration was varied. The sequence of conditions and number of sessions per condition for each bird are presented in Table 1. Bird S3 stopped pecking one of the keys (even under corrective conditions) part way through the experiment and consequently was not tested under the last two conditions.

Varying Absolute Percentage Reinforcement

During the lean percent (LP) condition, the percentage of reinforcement correlated with the less reliable key was 25% (i.e., for each outcome on that key, reinforcement occurred with a probability of .25 and blackout with a probability of .75), and the percentage of reinforcement on the more reliable key was 50%. The duration of each outcome (reinforcement or blackout) was 3 s on both keys. The rich percent (RP) condition was identical to the

Table 1

Results of each condition in Experiment 1 in order of presentation. "C.P." and "Time" refer to choice proportions and time allocation during initial links on the key correlated with the higher percentage-reinforcement schedule. Response rates are in terms of responses per second.

Bird	Condition	Scheduled percent reinf. left/right	Seconds of reinf. left/right	C.P.	Time	Obtained percent reinf. left/right	Initial-link responses	Terminal-link responses left/right	Sessions
R5	RP	50/100	3/3	.84	.86	.50/1.00	.64	2.03/2.13	28
	LP	25/50	3/3	.78	.86	.26/.50	.59	1.49/1.50	16
	RP	50/100	3/3	.70	.75	.52/1.00	.54	1.34/1.42	24
	LM	50/100	1.5/1.5	.76	.75	.50/1.00	.40	.84/2.00	22
	RM	50/100	4.5/4.5	.76	.75	.53/1.00	.50	1.32/2.02	15
R6	RP	50/100	3/3	.52	.68	.51/1.00	.86	1.80/1.99	21
	LP	25/50	3/3	.62	.75	.24/.51	.84	1.57/1.61	19
	RP	50/100	3/3	.66	.76	.50/1.00	.85	1.64/1.96	19
	LP	25/50	3/3	.63	.71	.25/.49	.81	2.05/3.29	25
	LM	25/50	1.5/1.5	.63	.73	.26/.50	.88	2.04/3.94	16
	RM	25/50	4.5/4.5	.65	.70	.26/.50	.83	2.32/2.62	26
S3	LP	25/50	3/3	.70	.60	.24/.47	.57	1.05/1.18	30
	RP	50/100	3/3	.86	.82	.48/1.00	.75	1.09/1.58	24
	LP	25/50	3/3	.86	.77	.26/.50	.60	1.36/2.00	30
S6	LP	25/50	3/3	.95	.89	.15/.49	.20	.95/1.17	25
	RP	50/100	3/3	.94	.93	.50/1.00	.37	.95/1.15	22
	LP	25/50	3/3	.97	.91	.21/.49	.18	.73/1.22	15
	RP	50/100	3/3	.95	.91	.54/1.00	.34	1.37/2.07	29
	LM	50/100	1.5/1.5	.96	.94	.37/1.00	.21	.56/.84	22
	RM	50/100	4.5/4.5	.96	.95	.54/1.00	.73	.67/1.74	17

LP condition except that the less reliable key provided 50% reinforcement and the more reliable key provided 100% reinforcement.

Varying Reinforcer Duration

During both conditions of this phase, the percentages of reinforcement provided by the two keys were set at 50% and 100% for Birds R5 and S6, and at 25% and 50% for Bird R6. In the lean magnitude (LM) condition, the reinforcer duration (and the blackout duration) was 1.5 s for both terminal links, whereas in the rich magnitude (RM) condition each reinforcer or blackout lasted for 4.5 s. The last condition of the first phase represents an intermediate magnitude (IM) condition (i.e., 3.0-s outcome durations).

Results

All analyses were based on the mean data from the last nine sessions of each condition. Figure 2 shows the choice proportions (relative rates of responding) of each bird under the various conditions, measured in terms of preference for the side with higher percentage reinforcement. The left panel of Figure 2 shows the choice proportions obtained during Phase 1 in the LP (25 vs. 50) and RP (50 vs. 100) conditions, in order of exposure for each bird. The right panel shows the choice proportions as a function of reinforcer duration. The 1.5 s and 4.5 s points are from Phase 2; the 3.0 s data point is from the last condition of Phase 1. As can be seen from the figure, the choice proportions of all birds were above .5 in each condition, indicating a consistent preference for the more reliable schedule. The choice proportions were not systematically affected by either the absolute percentage reinforcement or the absolute reinforcer duration. Also, t tests for paired observations failed to reveal any significant differences between the choice proportions obtained in Conditions LP and RP [$t(3) = 0.5, p > .5$] or between those obtained in Conditions LM and RM [$t(2) = 1.0, p > .1$].

Table 1 shows the absolute response rates in the initial and terminal links as well as the time-allocation measures for the initial links. These data also reveal no systematic effect of absolute percentage reinforcement or of rein-

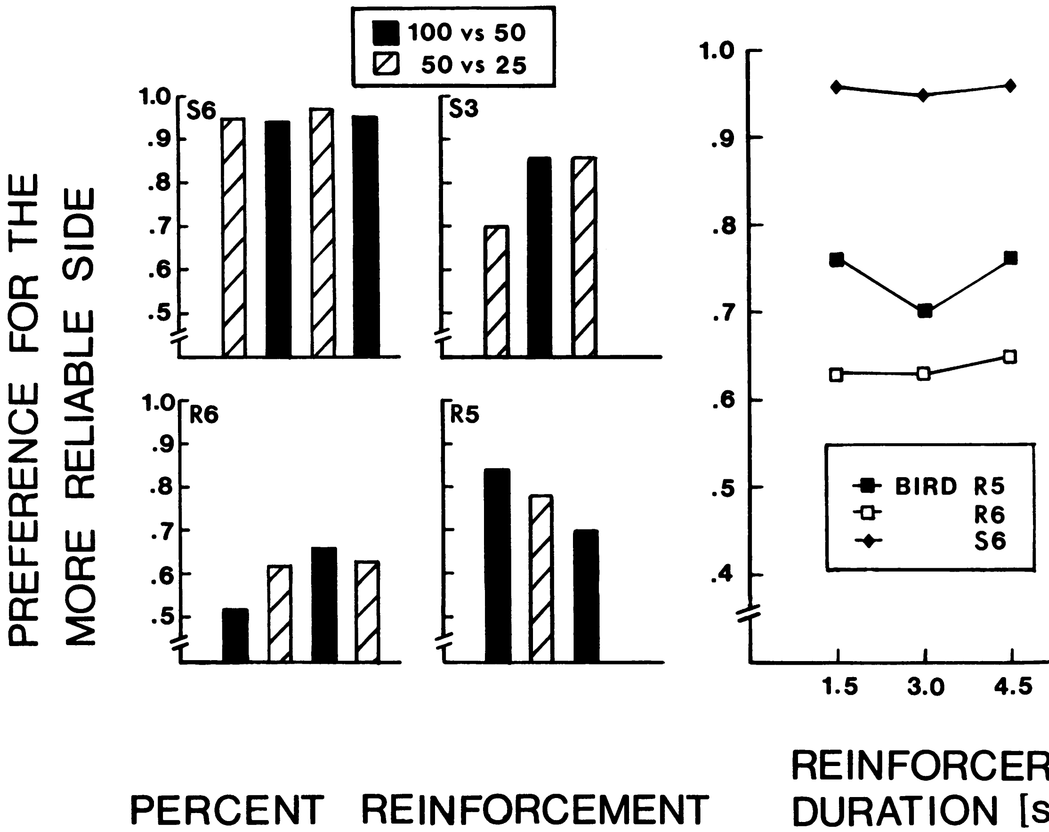

Fig. 2. Preference for the side providing more reliable reinforcement as a function of the absolute percentage of reinforcement (left panel) or the absolute magnitude of reinforcement (right panel) during Experiment 1. The left panel shows results for each bird in the order of exposure to the lean percentage (50 vs. 25) and rich percentage (100 vs. 50) conditions. In the right panel, preference for each bird is shown as a function of reinforcer duration.

forcer duration. In cases of extreme preference levels (Bird S6), the obtained percentages of reinforcement occasionally deviated from programmed percentages.

Discussion

All pigeons in Experiment 1 showed a clear preference for the schedule providing the higher percentage of reinforcement, a finding consistent with previous studies that have used mixed percentage-reinforcement schedules (Kendall, 1974, 1985; Schneider, 1968). The level of this preference was not systematically affected in the present study by variations in either the absolute percentages of reinforcement on the two sides (keeping the relative differences between them equal), or in the magnitude of reinforcement on both sides. Thus, the present results fail to extend the generality of previous findings (Leventhal et al., 1959; Spear & Pavlik, 1966) that reward magnitude is a factor that affects rats' choices between unreliable and reliable rewards, and consequently do not provide additional support for the idea that aversion to nonreward (and hence preference for more reliable schedules) is stronger in the context of larger rewards (cf. Spear & Pavlik, 1966). Nor was there any indication of an increased risk aversion during the conditions providing high levels of food availability (cf. Barnard & Brown, 1985; Caraco, 1983).

The results of the present experiment also do not support Extension A of the delay-reduction hypothesis to choice for mixed percentage-reinforcement schedules. This extension, which is analogous to that used by Navarick and Fantino (1976) when applying the hypothesis to choice between different reinforcer magnitudes, results in the prediction that preference for the more reliable alternative should vary inversely with both the absolute percentage of reinforcement and the absolute magnitude of reinforcement on the two sides. That is, preference should be most extreme in the lean percentage and lean magnitude conditions, a prediction that is clearly not supported.

However, the present results are consistent with Extension B, which predicts that preference for the more reliable schedule should be insensitive to variations in either the absolute percentage of reinforcement or the magnitude of reinforcement on both sides.

EXPERIMENT 2

The durations of the initial and terminal links of concurrent chains have been shown to affect preference in percentage-reinforcement procedures. Using multiple percentage-reinforcement concurrent chains, Kendall (1985) found that preference for unreliable (50%) versus reliable (100%) reinforcement became more extreme when the terminal-link durations were increased. Kendall (1974, 1985) also reported greater preference for the unreliable alternative with shorter initial-link schedules, again in a multiple percentage-reinforcement procedure.

Experiment 2 explores similar manipulations in a mixed percentage-reinforcement concurrent-chains procedure. In this experiment, we examined the effect of varying the durations of equal initial-link schedules and of equal terminal-link schedules on choice between unequal percentages of reinforcement (100% vs. 33%). If the delay-reduction hypothesis models choice in this type of procedure, then variations of both the initial-link and the terminal-link schedules should have orderly effects on preference. According to the model (in terms of Extension A or B), preference for the more reliable schedule should increase with increases in the terminal-link schedules, and should decrease with increases in the initial-link schedule. In other words, these variations in the initial- and terminal-link schedules should have an effect on choice between different percentages of reinforcement similar to that found on choice between different delays to reinforcement (e.g., Wardlaw & Davison, 1974; Williams & Fantino, 1978) and on choice between different magnitudes of reinforcement (Ito, 1985; Ito & Asaki, 1982; Navarick & Fantino, 1976). Interestingly, the expected effects are opposite in direction to those demonstrated in multiple percentage-reinforcement procedures (Kendall, 1974, 1985).

In addition to providing a further test of the general applicability of the delay-reduction model to choice in mixed percentage-reinforcement procedures, Experiment 2 provides another situation in which the two proposed ways of extending the model yield somewhat divergent predictions. Although both extensions result in qualitatively similar predictions for the initial- and terminal-link manipulations, the quantitative predictions differ as shown in Table 3.

METHOD

In this experiment, birds chose between a schedule that provided 33% reinforcement and one that provided 100% reinforcement. The initial links were always equal VI schedules, and the terminal links were always equal FI schedules. Outcome durations were 4 s throughout the experiment.

Phase 1: Terminal-Link Manipulations

During this phase, each of the 4 birds was tested with terminal-link FI schedules of 1 s, 5 s, 15 s, 25 s, and 40 s. The order of exposure to the five schedules varied among the birds (see Table 2). VI 90-s schedules were in effect during the initial links throughout this phase.

Phase 2: Initial-Link Manipulations

In Phase 2, the terminal-link schedules were held constant throughout, with values of FI 1-s for Bird R2, FI 5-s for Birds R3 and R4, and FI 15-s for Bird S1, while the initial-link VI schedules were varied. Each bird was tested with initial-link VI schedules of 45 s, 90 s, and 180 s, in differing orders (see Table 2).

RESULTS

All analyses were based on the mean data from the last nine sessions in each condition. Figure 3 shows choice proportions for each of the 4 birds at the five terminal-link durations tested in Phase 1. The points not joined by lines indicate the choice proportions obtained during replications. As can be seen from the figure, preference for the side providing 100% reinforcement was more extreme with longer

Table 2

Results of each condition in Experiment 2 in order of presentation. "C.P." and "Time" refer to choice proportions and time allocation during initial links on the key correlated with the higher percentage-reinforcement schedule. Response rates are in terms of responses per second.

Bird	Initial-link duration (sec)	Terminal-link duration (sec)	C.P.	Time	Obtained percent reinf. left/right	Initial-link responses	Terminal-link responses left/right	Sessions
R2	90	5	.74	.52	1.00/.33	.88	2.65/2.71	20
	90	40	.93	.82	1.00/.30	.21	1.44/.83	15
	90	25	.95	.77	1.00/.38	.29	1.78/1.20	17
	90	15	.94	.75	1.00/.26	.42	2.02/1.37	17
	90	5	.69	.50	1.00/.32	.72	3.22/2.86	20
	90	1	.69	.59	1.00/.32	.80	1.54/1.77	18
	180	1	.68	.63	1.00/.34	.66	1.90/2.07	26
	45	1	.76	.78	1.00/.33	1.37	2.05/1.70	21
	90	1	.69	.67	1.00/.33	1.16	2.34/2.08	25
R3	90	40	.98	.89	1.00/.41	.27	.55/.70	21
	90	5	.60	.64	1.00/.34	.41	1.05/.95	17
	90	25	.63	.63	1.00/.32	.57	.94/.89	18
	90	15	.90	.89	1.00/.34	.46	1.07/1.08	22
	90	40	.95	.87	1.00/.32	.40	1.00/.59	15
	90	1	.50	.39	1.00/.33	.50	1.11/1.03	29
	180	5	.49	.38	1.00/.32	.59	.21/.20	20
	45	5	.59	.49	1.00/.33	.83	.96/.89	21
	90	5	.51	.38	1.00/.34	.64	1.20/1.43	21
R4	90	25	.95	.89	.30/1.00	.63	1.02/.78	20
	90	5	.87	.87	.34/1.00	1.00	1.93/1.38	15
	90	15	.94	.91	.34/1.00	1.05	1.49/1.45	15
	90	1	.74	.79	.32/1.00	1.01	1.41/.60	18
	90	40	.92	.92	.32/1.00	.79	.83/.83	20
	90	25	.98	.95	.32/1.00	.83	1.20/1.04	18
	45	5	.88	.89	.33/1.00	.84	2.71/1.60	22
	180	5	.72	.80	.30/1.00	.86	2.11/1.30	24
	90	5	.74	.78	.34/1.00	.97	2.07/1.62	15
S1	90	40	.97	.72	.33/1.00	.46	1.29/1.37	20
	90	5	.74	.81	.33/1.00	.99	3.14/3.22	16
	90	25	.92	.87	.34/1.00	.71	2.14/1.92	25
	90	15	.93	.93	.34/1.00	1.15	2.55/2.32	18
	90	40	.98	.93	.36/1.00	.80	1.73/1.56	15
	90	1	.75	.76	.32/1.00	1.10	1.82/2.36	29
	45	15	.96	.88	.33/1.00	.97	2.54/2.34	20
	180	15	.76	.75	.32/1.00	1.11	3.05/1.81	21
	90	15	.89	.90	.34/1.00	.98	2.69/2.41	21

terminal-link FI schedules. A repeated-measures analysis of variance indicated a significant effect of terminal-link FI duration on choice proportions [$F(4,12) = 9.66, p < .001$].

Figure 4 shows choice proportions for each of the 4 birds as a function of initial-link schedule in Phase 2. For all birds, preference for the side providing 100% reinforcement became less extreme as the initial-link VI duration increased. A repeated-measures analysis of variance revealed a significant effect of initial-link VI schedule on choice proportions [$F(2,6) = 15.33, p < .005$].

Table 2 shows the absolute response rates in the initial and terminal links as well as the time-allocation measures for the initial links for both Phases 1 and 2. The time-allocation measure (relative time on the reliable side during the choice phase) showed significant effects of both terminal-link duration [$F(4,12) = 3.5, p < .05$] and initial-link duration [$F(2,6) = 8.34, p < .02$] that were consistent with those seen for the choice proportion data. At all levels of preference, the obtained percentages closely approximated those programmed.

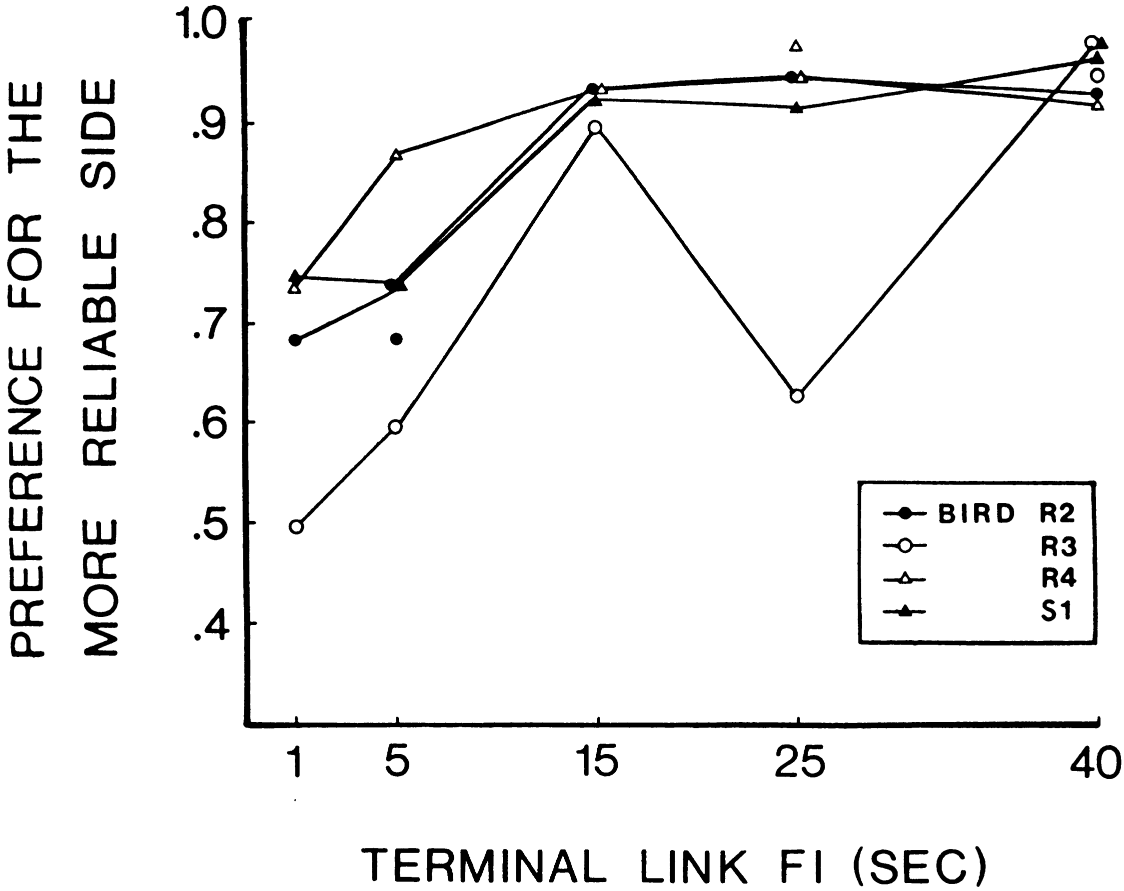

Fig. 3. Preference for the side providing reliable (100%) reinforcement as a function of terminal-link FI duration for the 4 birds in Experiment 2. The data points not joined by lines are from replications of the first condition under which each bird was tested.

Discussion

Pigeons' preference for the 100% reinforcement alternative increased systematically with increases in the terminal-link duration and decreased systematically with increases in the initial-link duration. Both of these effects are predicted by the delay-reduction hypothesis and therefore support application of this model to choice in mixed percentage-reinforcement concurrent-chain procedures.

Although the qualitative predictions of both proposed extensions of the delay-reduction model are supported in the present experiment, Table 3 shows that Extension B provides a closer quantitative fit to the present results. Extension A consistently underestimated the obtained level of preference. Extension B, on the other hand, tended to overestimate the level of preference, but the mean deviation between predicted and obtained values was considerably less than that for Extension A.

The results reported here contrast with Kendall's (1974, 1985) findings that, in multiple percentage-reinforcement procedures, preference for the unreliable alternative is greater with shorter initial-link and longer terminal-link durations. Potentially critical distinctions between mixed and multiple procedures will be addressed in our General Discussion.

EXPERIMENT 3

In this study, pigeons chose between two alternatives that provided equal percentages

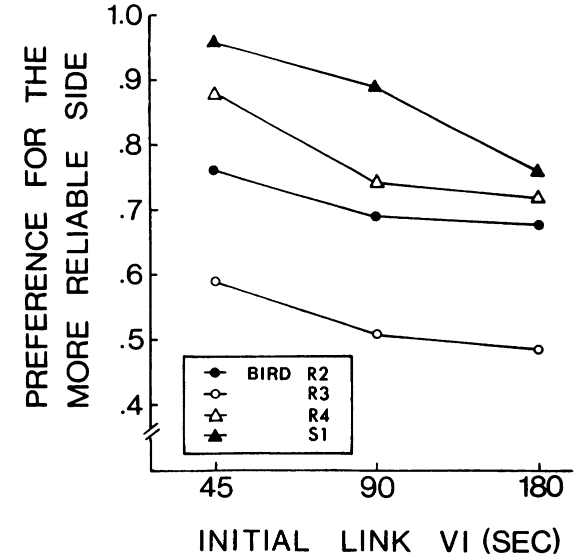

Fig. 4. Preference for the side providing reliable (100%) reinforcement as a function of initial-link VI duration in Experiment 2.

Table 3

Obtained and predicted choice proportions for each condition of Experiment 2.

Initial-link duration (sec)	Terminal-link duration (sec)	Choice proportions		
			Predicted values	
		Obtained values	Extension A	Extension B
90	1	.67	.51	.76
90	5	.74	.56	.78
90	15	.93	.67	.84
90	25	.86	.78	.89
90	40	.95	.94	.98
45	1	.76[a]	.52	.76
180	1	.68[a]	.51	.75
45	5	.74	.61	.81
180	5	.61	.53	.77
45	15	.96[a]	.83	.92
180	15	.76[a]	.58	.79
Mean deviation from obtained values:			−.15	+.04
Mean absolute deviation from obtained values:			.15	.06

[a] Data from only a single subject.

of reinforcement but unequal delays to reinforcement. The two proposed ways of extending the delay-reduction hypothesis make different predictions about the effect of this manipulation on preference for the shorter delay to reinforcement. According to Extension A, decreasing the percentage of reinforcement provided by the two alternatives should be equivalent to increasing the delay for both and should make preference for the shorter delay more extreme. According to Extension B, changes in the percentage of reinforcement should not affect preference because these would produce proportional changes in both of the delays correlated with terminal-link entry, and in the overall time to reinforcement: The *relative* reduction in delay signaled by the two alternatives would therefore remain constant across variations in percentage of reinforcement.

The qualitative predictions of both Extension A and Extension B are in apparent conflict with results reported by Moore (1976, Experiment 1). Moore investigated choice with equal initial links and unequal delays in multiple percentage-reinforcement concurrent-chain procedures. The design also included several control conditions that parallel the experimental conditions explored here—that is, choice between unequal delays with equal mixed percentage reinforcement. In these conditions, Moore reported decreasing preference for the shorter delay as the equal percentages of reinforcement on the two alternatives decreased. However, there may be problems with this description: Preference was averaged over position-reversal conditions at the highest percentage (100%) and lowest percentage (15%), but the immediate condition (50%) was not reversed. Thus, the apparent trends for the mixed conditions of Experiment 1 in Moore's Figure 2 may be misleading. If only first determinations at each percentage (prior to the position reversals) are compared, preference in the mixed percentage-reinforcement procedures does not appear to vary systematically with absolute percentages. Preference levels for the shorter delay in the 100%, 50%, and 15% mixed conditions are, respectively, .78, .89, and .78 for Subject B-22; .70, .78, and .83 for Subject B-20; and .91, .95, and .91 for Subject 2958. Thus, in the conditions similar to those explored in the present study, there is no unequivocal evidence of a trend.

The present experiment provides another investigation of the effects of equal mixed reinforcement percentages on choice between

Table 4

Results of each condition in Experiment 3 in order of presentation. "C.P." and "Time" refer to choice proportions and time allocation during the initial links on the key correlated with the shorter delay to reinforcement. Response rates are in terms of responses per second.

Bird	Scheduled percent reinf. left/right	C.P.	Time	Obtained percent reinf. left/right	Initial-link responses	Terminal-link responses left/right	Sessions
R1	50/50	.71	.72	.49/.49	1.35	1.96/2.52	17
	100/100	.99	.94	1.00/1.00	1.56	2.60/3.21	30
	75/75	.99	.93	.74/.74	1.68	3.40/3.98	17
S2	100/100	.62	.65	1.00/1.00	1.57	1.81/4.39	23
	50/50	.59	.57	.50/.50	1.63	2.40/4.77	20
	75/75	.72	.75	.73/.77	1.18	4.41/3.62	25

unequal delays. In different conditions, the two alternatives each provided either 100% reinforcement, 75% reinforcement, or 50% reinforcement.

Method

In this experiment, the initial links were VI 90-s schedules and the terminal links were VI 20-s in one alternative and VI 40-s in the other. The percentages of reinforcement in the two schedules were always equal but were varied across conditions. In one condition, both schedules provided 100% reinforcement; in another, both provided 75% reinforcement; and in a third condition, both provided 50% reinforcement. The order of exposure to these three conditions differed for the 2 birds, as shown in Table 4. Outcome duration was 3 s throughout.

Results and Discussion

All analyses were based on the mean data of the last nine sessions of each condition. Figure 5 shows the birds' preference for the shorter delay to reward as a function of percentage reinforcement. Detailed results are shown in Table 4. Preference was not systematically affected by changes in the percentage of reinforcement. Certainly preference for shorter delays does not become more extreme with lower percentages of reinforcement, as predicted by Extension A of the delay-reduction hypothesis. Thus, Extension B again appears to be a preferable way of applying the delay-reduction equation to mixed percentage-reinforcement choice procedures.

GENERAL DISCUSSION

The present results provide further evidence that pigeons usually prefer the more reliable reinforcement schedule in mixed (i.e., unsignaled) percentage-reinforcement concurrent chains. The experiments reported here extend previous work (Kendall, 1974, 1985; Schneider, 1968) by examining the effect of several variables on this preference. In the first experiment, the level of preference for the more reliable schedule with 100% versus 50% reinforcement was not significantly different from that obtained with 50% versus 25% reinforcement, and the magnitude of the reinforcer (1.5-, 3-, or 4.5-s access to grain) had no significant effects on this preference. In contrast, Experiment 2 demonstrated that preference for the more reliable schedule was systematically affected by variation in both the terminal-link durations and initial-link durations. Preference became more extreme as the durations of equal terminal links were increased from 1 to 40 s. Preference became less extreme as the durations of equal initial links were increased from 45 to 180 s.

The present studies also extend previous work by examining the viability of the delay-reduction hypothesis of conditioned reinforcement within percentage-reinforcement procedures. The systematic effect of initial-link and terminal-link durations on choice between differing mixed percentages of reinforcement demonstrated here parallels the effects of these variables on choice between differing delays to reinforcement (e.g., Wardlaw & Davison, 1974; Williams & Fantino, 1978) and between differing magnitudes of reinforcement

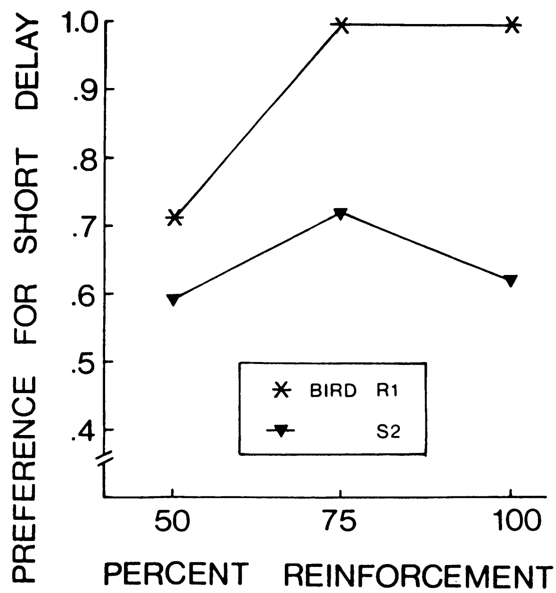

Fig. 5. Preference for the shorter delay to reinforcement as a function of absolute percentage of reinforcement for the 2 birds in Experiment 3; the percentages of reinforcement were always equal within a given procedure, for the alternatives with differing delays.

(Ito, 1985; Ito & Asaki, 1982; Navarick & Fantino, 1976).

Two ways of computing the reduction in delay signaled by terminal-link stimuli in mixed percentage-reinforcement procedures were examined. In the first of these (Extension A), percentage reinforcement was assumed to directly affect only terminal-link values. Calculation of the overall average time to reinforcement (the referent for delay reductions) was only indirectly affected by the incorporation of transformed terminal-link values. This extension parallels that proposed by Navarick and Fantino (1976) as a means of applying the delay-reduction hypothesis to choice between unequal reward magnitudes. The alternative extension proposed here (Extension B) assumed that a critical feature of percentage reinforcement is the effect on overall density of reinforcement in both initial and terminal links of the chains. In this method, the overall average time to reinforcement is used as the referent delay, and the actual delay reduction signaled by onset of the terminal-link stimulus is computed accordingly.

In the first experiment, the two extensions generated qualitatively different predictions, and the pattern of results obtained was consistent with Extension B. The results of the second experiment supported the qualitatively similar predictions of both extensions, but the predictions of Extension B provided a better quantitative fit to the data.[1] Experiment 3 provided another test of the two extensions. In this experiment, choice between unequal delays to reinforcement was not systematically affected as the absolute percentage of reinforcement on both chains was varied from 50% to 100%. Again, this pattern of results was consistent with Extension B and inconsistent with Extension A.

In general, the results obtained here are consistent with the existing literature on mixed percentage-reinforcement concurrent-chains procedures. However, the results of the second two experiments stand in contrast to those obtained with similar manipulations in multiple procedures. The effects of initial- and terminal-link manipulations on choice between different multiple percentages of reinforcement observed by Kendall (1974, 1985) are opposite those obtained in Experiment 2. Furthermore, the absence of a consistent trend in Experiment 3 contrasts with Moore's (1976) report of a trend toward indifference between unequal delays as the absolute percentage of reinforcement decreased. Although the trend reported for the mixed percentage-reinforcement conditions in Moore's first experiment may be an artifact of inappropriate averaging (as discussed earlier), 2 of the 3 birds did show a systematic trend in the *multiple* conditions of his first experiment not attributable to this artifact. Moreover, this trend toward indifference with decreasing percentages of reinforcement was also apparent for both mixed and multiple conditions in Moore's second experiment, which involved unequal initial and terminal links. The trend in Moore's procedure with mixed schedules is inconsistent with the current application of the delay-reduction hypothesis and suggests that some modification

[1] Although Navarick and Fantino (1976) did not include parameters for the rate of primary reinforcement correlated with each chain (cf. Squires & Fantino, 1971), we explored alternative ways of including such parameters in the calculation of Extension A predictions. In some cases, the quantitative fit to the data obtained in Experiment 2 improved; however, the qualitative predictions remained inconsistent with the results of Experiments 1 and 3.

of the equation may be necessary to account for the case of unequal initial links.

The contrasts between the present results with mixed percentage-reinforcement procedures and those obtained by Kendall (1974, 1985) and by Moore (1976) using multiple procedures suggest a fundamental difference between the two procedures. One critical difference may be that in multiple procedures the delay signaled by the terminal-link S+ remains constant while the referent delay (*T*) varies as a function of percentage reinforcement. Thus, in multiple but not in mixed procedures, the strength of the S+ as a conditioned reinforcer should increase as percentage reinforcement decreases (cf. Kendall, 1974, 1985; Moore 1976, 1985; see also Collins & Pearce [1985] and Pearce, Kaye, & Collins [1985] for recent experiments using Pavlovian procedures, which may provide a close analog to the distinction between mixed and multiple procedures). Kendall (1974) suggested that in multiple percentage-reinforcement concurrent-chains procedures, choice may depend on a balance between this increased strength of the conditioned reinforcer and the decreased frequency of its occurrence.

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