

PIGEONS' CHOICES BETWEEN FIXED-INTERVAL AND RANDOM-INTERVAL SCHEDULES: UTILITY OF VARIABILITY?

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Pigeons' choosing between fixed-interval and random-interval schedules of reinforcement was investigated in three experiments using a discrete-trial procedure. In all three experiments, the random-interval schedule was generated by sampling a probability distribution at an interval (and in multiples of the interval) equal to that of the fixed-interval schedule. Thus the programmed delays to reinforcement on the random alternative were never shorter and were often longer than the fixed interval. Despite this feature, the fixed schedule was not strongly preferred. Increases in the probability used to generate the random interval resulted in decreased preferences for the fixed schedule. In addition, the number of consecutive choices on the preferred alternative varied directly with preference, whereas the consecutive number of choices on the nonpreferred alternative was fairly constant. The probability of choosing the random alternative was unaffected by the immediately prior interval encountered on that schedule, even when it was very long relative to the average value. The results loosely support conceptions of a "preference for variability" from foraging theory and the "utility of behavioral variability" from human decision-making literatures.

*Key words:* choice, variability, foraging, fixed interval, random interval, key peck, pigeon

Variable schedules of reinforcement typically are specified in terms of the arithmetic averages of the interreinforcer intervals (IRIs) or ratios. Herrnstein (1964) argued that the assumption implicit in this arithmetic averaging is inappropriate, for when he gave pigeons repeated choices between fixed-interval (FI) and variable-interval (VI) schedules in a concurrent chains procedure, pigeons chose the VI schedule more frequently than predicted by the matching law or by arithmetic averaging. For example, when given the choice between a VI 15 s and FI 4 s (with a reinforcer-rate ratio of 1:3.75), 2 of 4 pigeons distributed their responses nearly equally between the two initial-link keys. Although Herrnstein concluded that arithmetic

averaging was inappropriate, he did not identify a suitable alternative.

Fantino (1967), using fixed-ratio (FR) and mixed-ratio schedules, suggested that preference was better predicted by geometrically averaged reinforcer rates, and Killeen (1968), with FI and VI schedules, found that his results were best described by a harmonic transformation of IRIs. Davison (1969) investigated FI versus mixed-interval schedules and found his results were best described by a reciprocal with exponent transformation. Davison's transformation was the general case of the one used by Killeen, but the value of the exponent that best fitted Davison's data was  $-3$ , whereas that value was  $-1$  for Killeen's results. The results of these various experiments were consistent with Herrnstein's suggestion that the smaller values (interval or ratios) in a variable schedule are weighted more than the larger ones (Herrnstein, 1964), which is consistent with the geometric, harmonic, and exponential transformations of Fantino, Killeen, and Davison. Because these small values are weighted more, the subjective "value" of the schedule is greater than a fixed schedule that contains no small values.

Fantino and Navarick (1974) termed the question of whether fixed and variable schedules can be scaled similarly the "averaging problem." Herrnstein's (1964) original dem-

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This paper is dedicated to Doug Field whose friendship, mentoring, and humor is, and will be, missed.

Portions of the experiments presented served as part of a doctoral dissertation submitted by the first author to Temple University. He thanks Philip J. Bersh, Donald Hantula, Michael C. Davison, Ronald Baenninger, T. U. C. Jarbe, Kimberly C. Kirby, and Paul Neuman for their comments and assistance on earlier versions of this paper. Portions of the research reported here were presented at the 1996, 1997, and 1998 Association for Behavior Analysis conventions.

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doi: 10.1901/jeab.2005.30-04

onstration, and Fantino's (1967), Killeen's (1968), and Davison's (1969) various averaging techniques, assumed that fixed and variable schedules of reinforcement could be assessed on a similar dimension, a reinforcer-rate dimension in which the averaging rules are fairly constrained and determinable. This unidimensional account of schedule values makes some predictions in situations in which subjects choose between fixed and variable alternatives. Consider a concurrent-chain arrangement in which a pigeon chooses between FI-A and VI-B, in the terminal links. If a pigeon prefers the VI-B schedule, but prefers a third schedule VI-C to VI-B, then through transitive logic we would predict that the subject would prefer VI-C to FI-A also. Moreover, if an averaging rule can somehow quantify A, B, and C, such that C is higher than B and B is higher than A ( $A < B < C$ ), we are moving toward a unidimensional theory of choice (and strong stochastic transitivity).

In a series of experiments, Navarick and Fantino (1972) demonstrated the difficulty with a unidimensional account of schedule value. Using FI versus VI as well as FR versus VR schedules of reinforcement as the terminal links in a concurrent-chains procedure, they found that the predicted ("strong stochastic") transitive relations often did not hold. One procedure involved presenting two schedules, and adjusting one until choice proportions were equal, and then comparing each of those schedules to a third schedule. A second procedure involved presenting each of two schedules to a third schedule until choice proportions were equal, and then comparing the first two schedules with one another. In both procedures, invariance according to a single scaling principle would predict that all three schedules would be functionally equivalent and that transitivity should hold. Although there was a good deal of variability in their results, Navarick and Fantino suggested that a unidimensional account for comparing fixed and variable schedules of reinforcement is troublesome because predictions based on functional equivalence did not always hold in their experiments.

A possible solution to the averaging problem was proposed by Mazur and Coe (1987) using the hyperbolic function:

$$V = \sum_{i=1}^n p_i \frac{A}{1 + kD_i} \quad (1)$$

where  $A$  is the amount, or magnitude of the reinforcer,  $D_i$  is the delay to the  $i^{\text{th}}$  reinforcer,  $p_i$  is the probability of encountering the  $i^{\text{th}}$  delay, and  $k$  is an individual bias parameter. In this account, the value of an alternative ( $V$ ) is the sum of the probability of the  $i^{\text{th}}$  delay ( $p_i$ ), times the amount of reinforcer ( $A$ ) times the reciprocal of the  $i^{\text{th}}$  delay ( $1/D_i$ ) multiplied by a bias parameter ( $k$ ) with 1 added to it. The addition of 1 to the denominator is required because as delays approach zero, the value of an alternative would approach infinity, irrespective of amount, which would contradict many findings varying reinforcer magnitude (Neuringer, 1967). This hyperbolic construal of value may improve the tenability of a unidimensional account of schedule value. If there is a single dimension along which the value of a reinforcement schedule can be scaled, then the results from Herrnstein (1964), Fantino (1967), Killeen (1968), Davison (1969), and Navarick and Fantino (1972) may be resolvable by Mazur's (1984, 1986) hyperbolic account because it weighs smaller within-schedule components more heavily.

In a series of experiments focused on other issues, but proving to be pilot work for the experiments reported here, Flannery and Himeline attempted to find a stable preference for an FI schedule over a random-interval (RI) schedule rather than the converse. In an RI schedule, reinforcers are set up with a probability  $p$  sampled every  $x$  s. The mean (expected) value of an RI is computed by dividing the sampling interval by the probability ( $x/p$ ). Theoretically, the relative frequency distribution of IRIs of the RI approximates a geometric distribution.

In the Flannery and Himeline work, pigeons repeatedly chose between an FI 60 s and RI 120 s, in which the sampling interval and probability used to generate the RI were manipulated while maintaining the same arithmetic average IRI. Although the reinforcer rate on the RI schedule was half that of the FI schedule, strong preferences for the RI were obtained when the sampling interval was 6 s and the probability was .05. In the second condition of their experiment, in an attempt to weaken the strong preferences,

the sampling interval was changed to 12 s and  $p$  to .10, thus doubling the size of the smallest interval of the variable IRI distribution. Despite this adjustment, strong preference for the RI was maintained, although slightly less than the in the first condition. When the sampling interval was changed to 60 s with  $p$  of .5, choice proportions for the fixed alternative increased to between .88 and .45 for the 4 pigeons; two of the four preferences were close to indifference even though the minimum IRI on the RI was never less than the FI, and the reinforcement rate of the RI was half that of the FI.

### EXPERIMENT 1

The results of Flannery and Hinline's final procedure described above were obtained with pigeons whose extensive histories included RI schedules with minimum IRIs much smaller than the FI alternative. Preference for the FI never approached exclusiveness in this pilot work, although given these pigeons' extensive histories with various sampling intervals, some shorter than the fixed alternative, the experience with occasional brief IRIs might have influenced the results of later comparisons. If pigeons were given repeated choices between an FI schedule and an RI schedule with a minimum interval equal to the FI, as Flannery and Hinline did in their final condition, then no unidimensional account could predict preference for the RI because no averaging method could scale longer IRIs as less than the FI. An additional dimension would be needed to explain why a pigeon would choose the RI when it was never better than the FI. Therefore, in a series of three experiments, we used a concurrent-chains procedure to assess the degree of preference for FI schedules over RI schedules in which the intervals that comprised the RI were never smaller than the constant size of the alternative, FI schedule. Pigeons were given repeated choices between these two schedules as terminal links following completion of brief initial links.

### METHOD

#### *Subjects*

Three experimentally naive male White Carneau pigeons served as subjects. They were obtained from the Palmetto Pigeon

Plant in Sumter, SC, and were designated P1, P5, and P6. Throughout the experiment, they were maintained at approximately 80% of their free-feeding weights by means of supplemental feedings at the end of each day and on weekends.

#### *Apparatus*

Each of three identical Gerbrands pigeon operant chambers was equipped with three translucent response keys, spaced 55 mm apart along the back wall and 225 mm from the floor. Only the two outside keys were used in these experiments; the center key was dark and inoperative throughout. The two operative response keys (left and right) could be illuminated either yellow or red using 28-V DC lamps with translucent plastic covers. A grain hopper, accessible through a circular opening 50 mm in diameter, 100 mm below the center response key, provided 2.75 s access to mixed grain as the reinforcer. During food delivery, both side keys were dark and two 28-V DC lamps illuminated the hopper. Each chamber was contained within a sound-attenuating cabinet, which was equipped with a fan that ventilated the chamber and provided some masking noise during sessions. Experimental procedures were arranged and recorded via a personal computer in an adjacent room. Experimental events for the first six conditions were programmed by a real-time version of Basic<sup>®</sup> through a Walter/Palya digital controller interfaced with an IBM<sup>®</sup>-compatible personal computer (Palya, Walter, & Chu, 1995). The final conditions were run by Med-PC<sup>®</sup> for Windows (Versions 1.06, 1.13, and 1.14) running on a Pentium<sup>®</sup>-class personal computer.

#### *Procedure*

Following hopper training accomplished with a variable-time (VT) 60-s schedule of food presentations, pecking was shaped by reinforcing successive approximations. Five sessions were required to establish reliable pecking in all subjects. Subjects were then transitioned directly into Condition 1 of the experiment.

Each session entailed 40 discrete trials, and the procedure resembled a concurrent-chains procedure with an FI schedule versus an RI schedule as terminal links. The schedules were correlated with key color whereas

Table 1  
Sequence of conditions and number of sessions in Experiment 1.

Condition	Fixed schedule	Random schedule	Minimum IRI (s)	Probability Pr[RI]	Number of sessions	Procedural features
1	FT 30 s	RI 60 s	30	.50	42–43	
2	FT 30 s	RI 60 s	30	.50	66–67	Colors reversed
3	FT 15 s	RI 30 s	15	.50	32–35	
4	FT 30 s	RI 60 s	30	.50	35–38	
5	FI 30 s	RI 60 s	30	.50	29–30	
6	FI 30 s	RI 45 s	30	.67	138–146	
7	FI 30 s	RI 45 s	30	.67	36–38	Equipment change
8	FI 30 s	RI 120 s	30	.25	67–69	
9	FI 30 s	RI 120 s	30	.25	30–31	Colors reversed
10	FI 30 s	RI 60 s	30	.50	127–133	

*Note.* The total number of sessions per condition varied somewhat across pigeons due to equipment failures and experimental errors that resulted either in a pigeon not running on a particular day or the data file being compromised.

sides were randomized across trials to eliminate position bias. A trial began with the illumination of both keys, and the initial links were concurrent FI 3-s schedules. Thus, after 3 s had elapsed, the next (often the first) peck on one key produced a transition to the terminal link with the key color unchanged and the other key turned off. Pecks on the dark key during the terminal link had no programmed consequences. Completion of the terminal link turned off the keylight, turned on the hopper lights, and produced access to mixed grain for 2.75 s, which was followed immediately by the onset of the next trial. FI 3-s schedules in the initial links, as opposed to longer VI schedules that are more typical in concurrent-chains experiments, were chosen to minimize the influence of initial-link length on preference for the two schedules (Fantino, 1969). Alternatively, FR 1 schedules were not used as initial links because these do not allow for switching between the alternatives and might result in random pecks serving to complete the initial link thereby increasing the likelihood of choices of the nonpreferred alternative.

During all conditions of the experiment, the RI was programmed in the following way: after a period of  $x$  seconds had elapsed, a reinforcer was set up with a probability  $p$ . If a reinforcer was not set up, the delay of  $x$  seconds was reinstated and the process repeated until one was set up. A single peck on the key after a reinforcer was set up produced access to mixed grain. Thus the programmed times to reinforcement were always multiples of  $x$ ,

distributed in a geometric fashion. The fixed alternative was always programmed with value of  $x$  seconds. Due to a programming oversight, in the first four conditions the fixed alternative in the terminal link was arranged as a fixed-time (FT) schedule rather than an FI, an error corrected for the remaining six conditions. Although the results from the first four conditions were similar to the results from the last six conditions, data from the four FT conditions may have contributed extra variability; we differentiated those conditions in all figures and analyses. However, even though the pigeons were exposed to an FT schedule, rather than an FI, they were never exposed to a variable schedule with briefer IRIs than the fixed alternative. In any given condition, therefore, the minimum IRI of the random schedule was equal to the fixed schedule [FT  $x$  s/FI  $x$  s vs. RI (min =  $x$ , with  $p$ ) s]. The minimum IRI and probability were manipulated across 10 conditions; the combinations of values are displayed in Table 1.

Condition 2 was a reversal of the relations between key color and schedules of reinforcement in Condition 1, and Condition 9 was a reversal of the contingencies from Condition 8. The transition between Conditions 6 and 7 represented a change in control equipment. Although the contingencies were programmed to be identical, these conditions are differentiated in case any unforeseen differences occurred. Stability of preference across blocks of sessions was assessed by visual examination of graphs showing the number of FI choices (defined as the number of ini-

Table 2

Proportion of fixed-alternative choices ( $\pm$  SEM) for the last 10 sessions of each condition for each pigeon.

Condition	Schedules	Pigeon			Procedural features
		P1	P5	P6	
1	FT 30 s vs. RI 60 s	0.640 (0.031)	0.785 (0.027)	0.915 (0.025)	
2	FT 30 s vs. RI 60 s	0.818 (0.016)	0.580 (0.024)	0.763 (0.034)	Colors reversed
3	FT 15 s vs. RI 30 s	0.848 (0.015)	0.875 (0.023)	0.845 (0.030)	
4	FT 30 s vs. RI 60 s	0.550 (0.039)	0.725 (0.017)	0.818 (0.040)	
5	FI 30 s vs. RI 60 s	0.565 (0.046)	0.690 (0.026)	0.895 (0.014)	Change FT to FI
6	FI 30 s vs. RI 45 s	0.505 (0.036)	0.362 (0.026)	0.783 (0.021)	
7	FI 30 s vs. RI 45 s	0.498 (0.020)	0.445 (0.033)	0.705 (0.014)	Equipment change
8	FI 30 s vs. RI 120 s	0.775 (0.016)	0.855 (0.021)	0.918 (0.028)	
9	FI 30 s vs. RI 120 s	0.820 (0.025)	0.825 (0.028)	0.903 (0.017)	Colors reversed
10	FT 30 s vs. RI 60 s	0.637 (0.021)	0.723 (0.017)	0.673 (0.027)	

tial-link completions associated with the FI terminal link). Conditions were changed when choices by all 3 pigeons appeared stable thereby maintaining equal exposure to the particular conditions.

RESULTS

Table 2 shows the average proportion of fixed-alternative choices over the last 10 sessions of each of the 10 conditions for each pigeon. Most generally, it shows that preferences for the fixed alternative were never exclusive even though the random schedule, with larger mean IRIs, never included component intervals shorter than the fixed schedule. In only 3 of 30 determinations was preference for the FI greater than .90. Two of the 3 pigeons never chose the constant (FT or FI) alternative more than 87.5% of the time.

Although stability of preference was assessed visually and included the absence of any trend and no new highs or lows, the lack of formal stability criteria necessitates post hoc stability measures to ensure the quantitative absence of any trends. In addition, because no standard method exists for post hoc stability assessment, several analyses were conducted. As can be seen in Table 2, measures of variability (standard error of the mean

[SEM]) were low for the last 10 sessions in each condition for each pigeon. However, whereas SEM describes how the measurements differed from one another, slopes of the best-fit linear functions of choice proportions over sessions may better assess trends. None of the slopes was exactly 0, but all were near 0. The slopes of best-fit lines for the last 10 sessions for each condition, for each pigeon, represented a range of change that was  $\pm$  2.2% (range, -1.0% to 2.2%, mean 0.3%). Because the magnitude of the slope is determined in part by the magnitude of the scores, the slope was standardized around 1.0, such that the slope equaled the predicted change from session to session as a percentage. In addition, the 10 slopes for each pigeon were analyzed further with a sign test to determine if there were different numbers of positive versus negative slopes, and thus a possible experimenter bias towards switching conditions when the pigeons' choice proportions were transitioning in a consistent direction. For the 3 pigeons, negative slopes were obtained in 3, 6, and 5 of the 10 conditions; associated probabilities of these results in the context of the sign test are .17, .83, and .62, respectively, all greater than the typical standard of .05 in a statistical test. Therefore, it appears that

from both the measures of variance and slopes of the best-fit lines that choice preferences were fairly stable and not changing systematically when conditions were changed.

Figure 1 summarizes and compares, in three ways, the mean proportions of fixed-alternative choices (number of initial-link completions associated with the fixed terminal link) from the last 10 sessions of each condition. The top three panels explore the relation between the proportion of FI choices and the probability used to generate the RI ( $\text{Pr}[\text{RI}]$ ). Most generally, the proportion of FI choices increased with decreases in the  $\text{Pr}[\text{RI}]$  (note the reversed  $x$ -axis). Lines fitted to the data from the six conditions employing the FI, and not the FT, are also plotted and measures of variance accounted for ( $r^2$ ) averaged .74 across the 3 subjects, the highest obtained with Pigeon P5 (.87) and the lowest with Pigeon P6 (.50). As can be seen, choice proportions were more consistent across replications when the fixed terminal link was an FI rather than an FT schedule.

The middle three panels explore the relation between the proportion of fixed choices and the differences between the values of the two alternatives computed from the actual encountered intervals of the RI, in terms of Equation 1. The obtained distribution of IRIs was used with Equation 1 with  $A$  and  $k$  both set equal to 1. (Because  $A$  and  $k$  both equal 1 in all subsequent calculations, they are not included in any further equations.) The difference was obtained by subtracting  $V_{\text{RI}}$  from  $V_{\text{FI}}$ . When the  $\text{Pr}[\text{RI}]$  was low (e.g., .25), the  $V$  of the RI was small, thereby making the difference between the FI and RI ( $V_{\text{FI}} - V_{\text{RI}}$ ) greater than when the probability associated with the RI was high (e.g., .67). The obtained distributions of values encountered were used because even though the  $\text{Pr}[\text{RI}]$  was arranged experimentally, slight deviations from the idealized distribution were seen. Once again, lines were fitted only to the results from the six conditions utilizing the fixed interval as one of the terminal links. Typically, as the difference in the  $V$ s increased (on the  $x$ -axis from left to right), the mean proportion of FI choices increased. These panels show that the differences in  $V$ s accounted for, on average, .74 of the variance of the mean proportion of FI choices (FT data were excluded).

The bottom three panels in Figure 1 investigate the relation between the ratios of the  $V$ s (the same measures used in the middle panels) and the mean proportion of RI choices. On average, the ratios of the  $V$ s obtained accounted for .73 of the variance.

The main difference between the middle and bottom analyses is how the data from Condition 3 are treated. In Condition 3, an RI 30 s was pitted against an FT 15 s. The ratio of the obtained  $V$ s was roughly the same as in Conditions 1, 2, 4, 5, and 10 (RI 60 s vs. FT 30 s or FI 30 s). However, the differences in  $V$ s were larger for Condition 3 than for Conditions 1, 2, 4, 5, and 10. Contrasting the results in terms of differences and in terms of ratios of the  $V$ s reflects contemporary quantitative theories of choice, those based on differences (e.g., delay reduction hypothesis; Fantino & Goldshmidt, 2000) and those based on ratios (e.g., the matching law). These experiments, however, were not designed to compare the usefulness of various models but rather to look at preference for variable schedules in counter-intuitive situations.

#### *Within-Session Choice Patterns*

Within-session choice patterns were analyzed by computing the number of consecutive choices ("runs") on one alternative over the course of the experiment, where a choice was defined as the completion of one of the initial links rather than the response pattern in the initial link. Figure 2 shows the logarithm (base 2) of the average run length for the last 10 sessions of each condition as a function of the ratio of preferred to nonpreferred choices. The preference ratio is a relative reinforcement measure, for it is the ratio of reinforcers earned on the alternatives. This analysis resembles one presented by Baum, Schwendiman, and Bell (1999, Figure 5) with concurrent schedules in which the mean visit duration (pecks per visit) was plotted as a function of the preference ratio (number of pecks on the rich alternative/number of pecks on the lean alternative). In the present experiment, the length of a run was related to the degree of preference.

When preference for the two alternatives was equal (for Pigeons P1 and P5), run lengths averaged about two choices per alternative. Run lengths on the nonpreferred al-

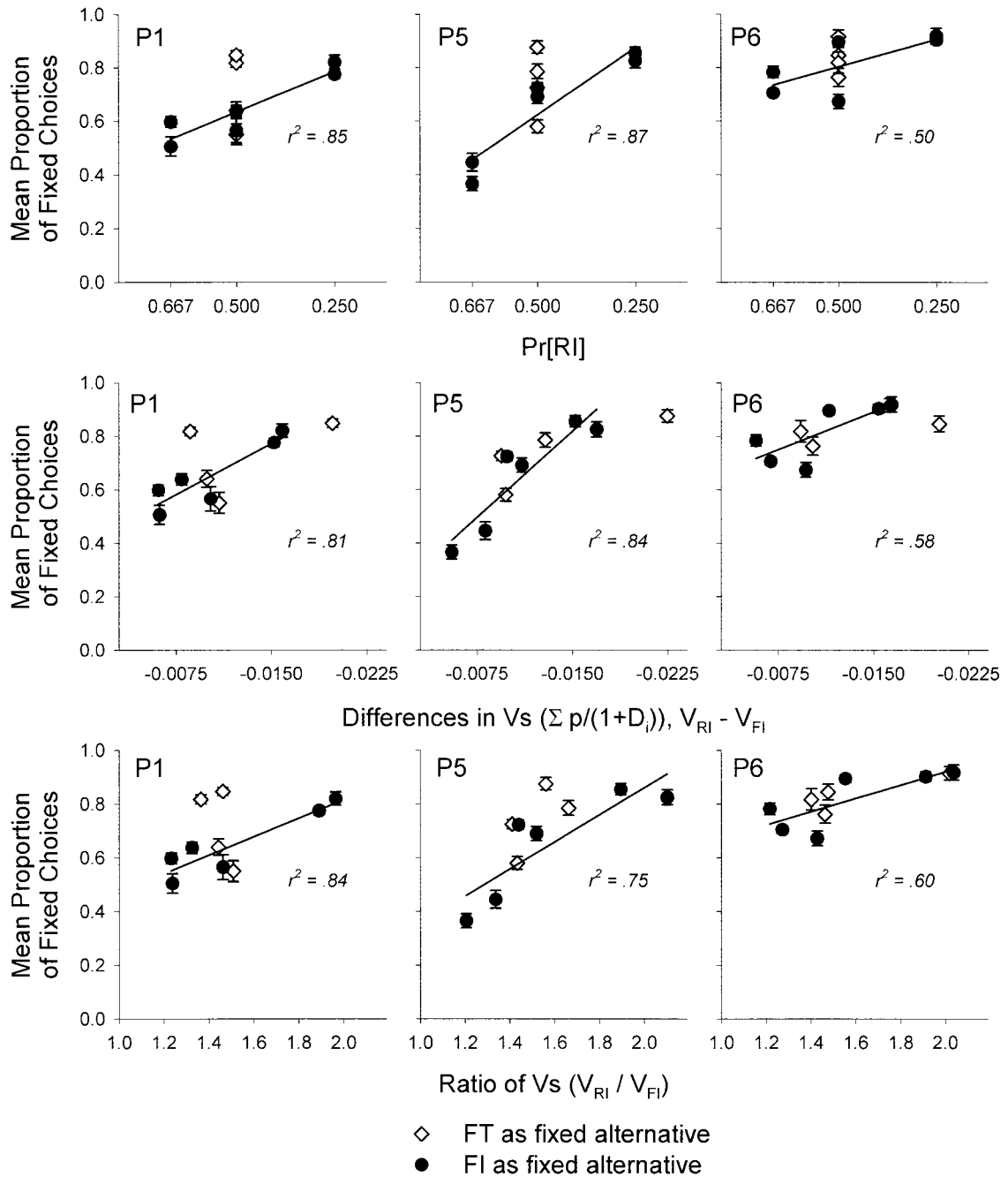


Fig. 1. Mean proportion of choices of the fixed alternative ( $\pm$  SEM) for each of the 3 pigeons in Experiment 1 over the final 10 sessions of each of the 10 conditions. In the top row of panels this measure is plotted as a function of the probability used to generate the RI (Pr[RI]). Note that the values along the x axis decrease from left to right. The middle panels show the same proportion of fixed choices as in the top panels, except the mean proportions are plotted as a function of the differences between values of the two schedules, computed using Mazur's (1986) hyperbolic function. The bottom three panels show the mean proportions as a function of the ratio of values (again, Mazur's  $V$ ). Closed symbols represent choice proportions during conditions employing FI schedules, and open symbols represent FT schedules.

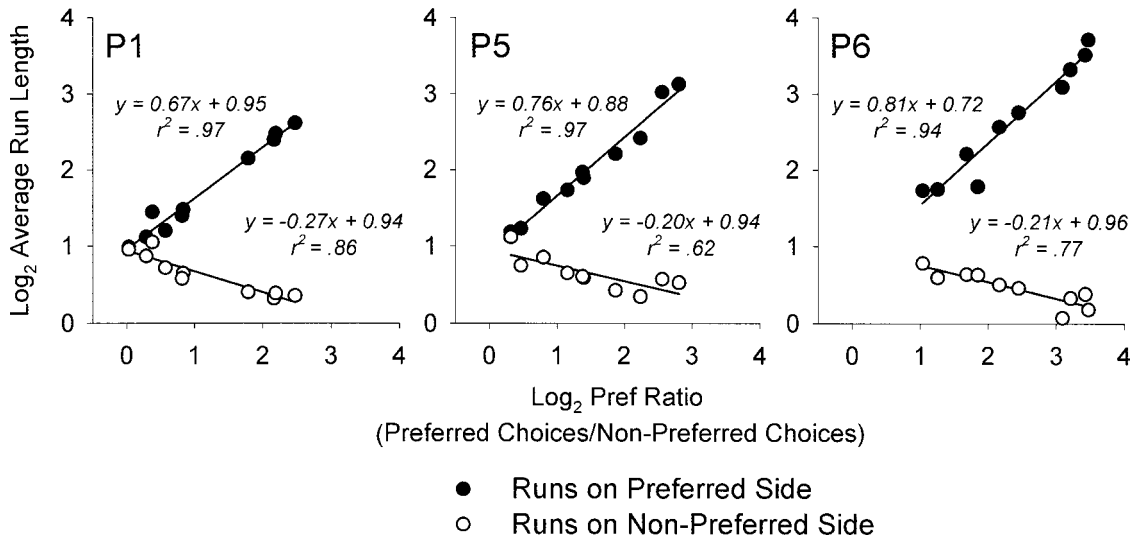


Fig. 2. Logarithm (base 2) of the average run length (number of consecutive choices of the preferred or non-preferred alternative) as a function of the logarithm (base 2) of the preference (or reinforcer) ratio, for each of the 3 pigeons in Experiment 1.

ternative were between one and two choices and decreased slightly across the range (average slope =  $-0.23$ ) of obtained preference ratios. The far end of the preference ratios obtained, it should be noted, was near 16:1 [ $\log_2(16) = 4$ ]. Runs on the preferred alternative (usually the FI), in contrast, changed proportionally more than the runs on the nonpreferred alternative. Linear regression accounted for, on average, .96 and .75 of the variance for run lengths on the preferred and nonpreferred alternatives, respectively.

Figure 3 shows the conditional probability of choosing the RI after encountering a particular RI duration in the previous trial. For example, after encountering an RI component of 120 s, what is the proportion of those opportunities that were followed by another RI choice? One might predict that encounters with larger intervals on the RI, relative to the fixed alternative, would produce switches over to the fixed. The first 10 sessions of each condition were excluded from this analysis to eliminate the influence of transitions from

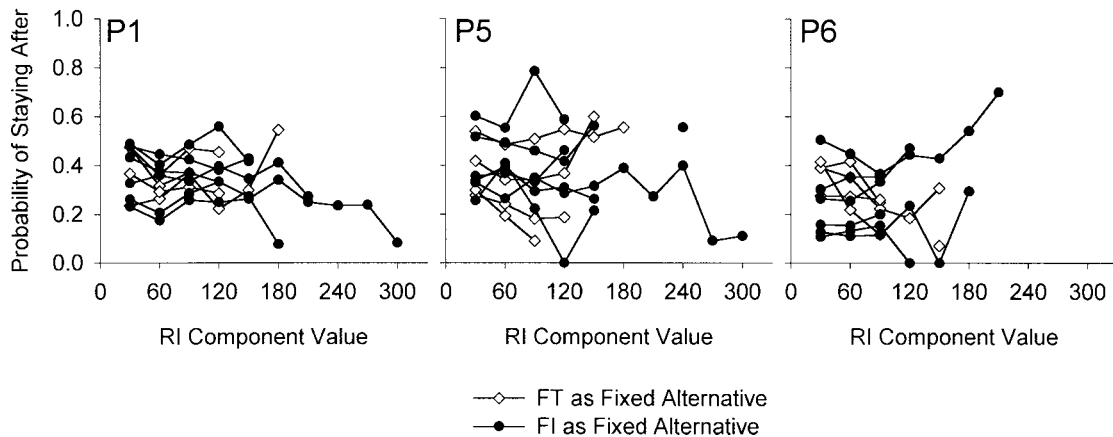


Fig. 3. Conditional probability of choosing the RI alternative after a previous RI choice, plotted as a function of the duration of the RI on the previous trial, for each of the 3 pigeons in Experiment 1. Open symbols represent data from the first four conditions of Experiment 1 employing an FT; filled symbols represent data from the last six conditions using an FI schedule.

prior experimental conditions. Additionally, RI component values were excluded if there were fewer than 10 opportunities to switch following a particular RI interval because of a limited sample. For example, during Condition 1, Pigeon P1 encountered an RI alternative of 120 s fewer than 10 times; hence there is no data point on the figure representing the probability of staying after 120 s for Condition 1.

The conditional probability of staying was fairly constant, or at least unsystematically changing, across pigeons and conditions. The slopes of the best-fit linear functions of these conditional probabilities (not shown) were negative in 16 of the conditions and positive in the other 14 conditions. Typically, the slopes bunched around 0 and appeared flat. Thus, of the 30 conditions represented, although some variability was noted, no systematic deviation from zero, either in terms of the individual pigeon or the individual conditions, was observed.

#### DISCUSSION

Experiment 1 demonstrated that when given a choice between an FI or FT schedule of reinforcement and an RI schedule of reinforcement with a minimum value and sampling interval equal to the fixed alternative, pigeons' preference for the fixed alternative increased as the RI increased and the difference in  $V$  between the two alternatives increased (Figure 1). It is important to note, however, that these preferences were never exclusive. One limitation of the present experiment was the limited range of sampling intervals (and sizes of FIs) used. In only one condition was a sampling interval other than 30 s used (15 s, in Condition 3). This factor limits the likelihood that the difference measures or ratio measures would account differentially for the results. Further research should expand the range of sampling intervals to investigate the predictive utility of the two general accounts.

Baum et al. (1999) reported that choice patterns in a concurrent schedule arrangement (as distinct from the present concurrent-chains, discrete-trial arrangement) conformed to the predictions made by Houston and MacNamara (1981). In that research, Baum et al. showed that visits to the lean alternative (nonpreferred) were short (be-

tween one and two responses) across a range of preferences and that visit lengths (runs) on the rich alternative (preferred) were a direct function of the preference ratio, increasing with a slope roughly equal to unity. Qualitatively, the present results also appear to conform to the "fix-and-sample" pattern demonstrated by Baum et al. That is, subjects generally "fixed" on the preferred alternative (usually the FI) and occasionally "sampled" the nonpreferred alternative (usually the RI). Visits to the nonpreferred alternative in the present research were short, between one and two choices, and changed less across the range of preference ratios investigated than the visit durations (run lengths) on the preferred alternative (Figure 2). It is important to note that the analyses on run lengths represent absolute values, rather than relative ones. In other words, if a pigeon were to exhibit a relative preference of .5, an infinite number of local choice patterns could produce the relative preference of .5 (e.g., 20 consecutive FI choices followed by 20 consecutive RI choices, or strict alternation). The pigeons in the present experiment, however, made between one and two FI choices followed by one to two RI choices when the relative preference was .5, but the number of consecutive nonpreferred choices changed little with changes in the preference ratio. In contrast, the absolute length of consecutive choices on the preferred side changed to a greater degree, thus resembling the fix-and-sample pattern demonstrated by Baum et al. The present experiment is apparently the first demonstration of this type of choice patterning in a concurrent-chains arrangement.

The lack of relation between the probability of staying with the RI and duration of the interval (Figure 3) suggests that runs of "bad luck" (e.g., encountering a long RI component) had no systematic effect on the likelihood of subsequent RI choices. One could see this as evidence that these pigeons did not fall into the trap known as the "gambler's fallacy," the idea that the probability of a random outcome changes as a function of the previous, more or less fortuitous, outcomes. In other words, if the pigeons were to fall for the gambler's fallacy, the probability of choosing the RI would increase following a long RI component because they would be "due" for a shorter component interval.

One (and perhaps the most newsworthy) feature of the present results is counterintuitive and goes against many qualitative predictions made by either molar- or momentary-maximizing models of choice. Because the minimum IRI on the RI was always equal to the FI, the smallest interval that the subject could encounter on the RI was what it could always encounter on the FI. Additionally, the RI often was worse (i.e., reinforcers more delayed) than the FI. If they were to have maximized either reinforcer rate (a molar view), or the likelihood of the less-delayed reinforcer (a molecular view), then the subjects should have approached exclusive preference for the FI. In the present arrangement, there were no fortuitous “sooner” intervals on the RI to be weighted more heavily; the minimum interval was always equal to the FI. Yet, the RI was chosen, and sometimes chosen more often than the FI (see Table 2, e.g., Pigeon P5 in Conditions 6 and 7).

## EXPERIMENT 2

Although some systematic relations were found in the first Experiment—between choice proportions, run lengths, the probability of staying on the RI, and certain quantitative characteristics of the RI—possible effects of inadvertent exposure to an FT (rather than an FI) schedule on subsequent choice proportions were undetermined. Therefore, the second Experiment sought to replicate the findings of Experiment 1 without exposure to an FT schedule. In addition, because models of optimal foraging and of stochastic decision making often assume the subjects’ “perfect knowledge” of the available alternatives, the present conditions were kept in place for many sessions to ensure that more extended exposure would be unlikely to change the result. This experiment also included variation in the sampling probability used to generate the RI schedule.

## METHOD

### *Subjects*

Three experimentally naive male White Carneau pigeons served as subjects. They were obtained from the Palmetto Pigeon Plant in Sumter, SC and were designated MJ1, MJ2, and MJ3. Throughout the experiment, they were maintained at approximately 80%

Table 3

Sequence of conditions and number of sessions of Experiment 2.

Condition	Fixed schedule	Random schedule	Minimum IRI	Probability Pr[RI]	Number of sessions
1	FI 30 s	RI 60 s	30 s	.5	204
2	FI 30 s	RI-/40 s	30 s	.75	122

of their free-feeding weights by supplemental feedings at the end of the day.

### *Apparatus*

The experimental chambers used were identical to those used in Experiment 1. All conditions were conducted with Med-PC® for Windows running on a Pentium®-class personal computer.

### *Procedure*

Preliminary training was identical to that of the first Experiment. The procedure was identical to that in Experiment 1 except that the schedule in the terminal link of the fixed alternative was always an FI. Table 3 summarizes the conditions in Experiment 2.

## RESULTS

The top panel of Figure 4 shows the mean proportion of FI choices made during the last 10 sessions of each condition for each subject as a function of the probability used to generate the RI, whereas the bottom panel plots the run lengths as a function of the preference ratio. Even though the 3 pigeons in Experiment 2 had extensive exposure to the procedure and values of the independent variable, once again the absence of a formal stability criterion requires post hoc assessment, identical to the one conducted on the data from Experiment 1. In accordance with the results of the first experiment, the obtained variability in the present experiment was small as shown in Figure 4, and the slopes of the best-fit lines to choice proportions over the final 10 sessions in each condition, as a measure of trend, averaged 0.8% (range, -0.8% to +1.8%) and -0.3% (-1.2% to 0.7%) for Conditions 1 and 2, respectively. Thus choice proportions appeared stable.

The mean proportion of FI choices decreased with the increase in probability used

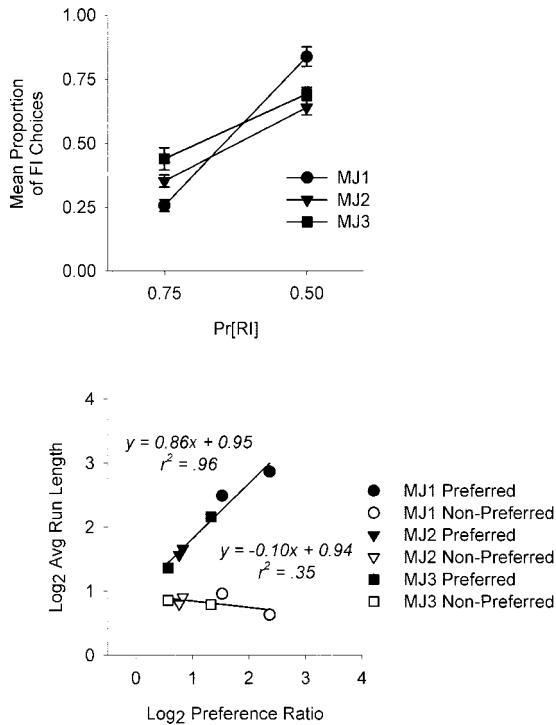


Fig. 4. Top panel: mean proportion of choices of the FI alternative ( $\pm$  SEM) for each of the 3 pigeons in Experiment 2 as a function of the probability used to generate the RI (Pr[RI]). Bottom panel: logarithm (base 2) of the average run length (number of consecutive choices of the preferred or nonpreferred alternative) as a function of the logarithm (base 2) of the preference (or reinforcer) ratio for each of the 3 pigeons in Experiment 2.

to generate the RI. Although the results from Pigeons MJ2 and MJ3 were fairly consistent with one another, the degree of preference for the FI shifted more for Pigeon MJ1 than for the other pigeons (note the steeper line). The bottom panel of Figure 4 shows that visits to the preferred alternative increased as a function of the preference ratio, whereas visits to the nonpreferred side showed a small decrease as a function of the preference ratio. These results are similar to the results of Experiment 1 (cf. Figures 1 and 2), although the slopes of the best-fit linear functions are group fits, as opposed to single-subject fits, because of only two data points per pigeon.

The conditional probabilities of staying on the RI side after encountering various component intervals of the RI are presented for all pigeons in Figure 5. The conditional probability of staying remained roughly constant in Condition 2, but decreased in Condition

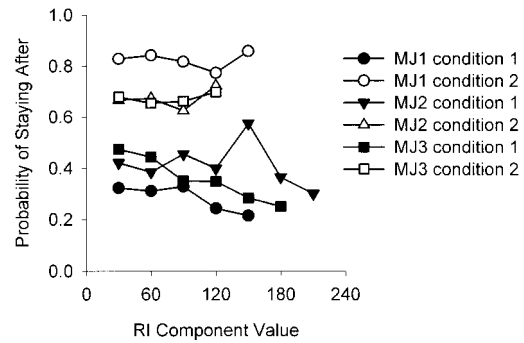


Fig. 5. Conditional probability of choosing the RI alternative after a previous RI choice, plotted as a function of the duration of the RI on the previous trial, for each of the 3 pigeons in Experiment 2.

1. The small decrease in the probability of staying does not approach zero and appears counterintuitive.

### DISCUSSION

One purpose of the present experiment was to assess whether prior exposure to an FT schedule affects subsequent choice proportions. In the present experiment, a response was always required in the terminal link, unlike Conditions 1 through 4 of Experiment 1. Qualitatively, the results of the present experiment were similar to those of Experiment 1. Analyses of visit durations revealed that run lengths changed as a function of the preference ratio as well, although the functions were based on group data. One limitation of this analysis, however, is the small number of comparisons used. Compensating for this were the many sessions run in each condition. This extended exposure and the post hoc confirmation of stability make it clear that the pigeons' persistently and consistently choosing the RI schedule a substantial proportion of the time, despite these schedules never yielding reinforcers more quickly than was always afforded by the FI alternative, could not be attributed to inadequate sampling of the RI schedules.

### EXPERIMENT 3

Experiment 2 seems to have ruled out the influence of exposure to the noncontingent feature of an FT schedule because the pigeons in both Experiments 1 and 2 had lengthy experience with the conditions. The

experiment also included provision for sufficient sampling of the variable distributions to ensure adequate exposure to the “conditions of stochasticity.” Experiment 3 used a parametric design to replicate and extend the results of Experiment 1 and Experiment 2.

## METHOD

### *Subjects*

Six White Carneau pigeons (Jim, Jo, Jan, Jay, Jes, and Jules) were used in Experiment 3. They had participated in two similar experiments investigating repeated choice between FI and RI schedules. In those experiments, the duration of the smallest component interval of the RI was never less than that of the FI.

### *Apparatus*

The experimental chambers and controlling equipment used were identical to those used in Experiment 2.

### *Procedure*

As in Experiments 1 and 2, a concurrent-chains procedure was employed permitting repeated discrete-trial choices between an FI and RI whose minimum value and sampling interval were always equal to the FI (i.e., 30 s). The initial links were two FI 3-s schedules, and the terminal links were FI 30 s and RI  $x$  s. However, the probability used to generate the RI schedule changed after a minimum of 10 sessions (range 10 to 17) at any particular probability (probabilities were selected randomly without replacement and were the same for all 6 pigeons). The probabilities used to generate the RI in Experiment 3 were, in their order of presentation: .500, .333, .667, .167, and .833. Sessions lasted for 40 choices (reinforcers) or until 2 hr had elapsed. The behavior of interest was the preference for the FI schedule measured as the proportion of FI choices out of 40 trials per session over the last five sessions at each probability value.

## RESULTS

The mean proportion of FI choices over the last five sessions at each probability used to generate the RI ( $\text{Pr}[\text{RI}]$ ) is plotted in Figure 6. As in Experiments 1 and 2, no formal stability criteria were used as bases for chang-

ing conditions; however, post hoc stability analyses indicated stability. For example, moving 5-day regression slopes suggested little change in the last five sessions at each probability level. Although slightly higher than in Experiments 1 and 2, 26 of 30 regression slopes (6 pigeons at five probability levels) fell in the range of  $\pm 5.0\%$  (the complete range was  $-7.0\%$  to  $+8.0\%$ ). A sign test on each pigeon's slopes did not indicate any systematic bias.

For each of the 6 pigeons, the proportion of FI choices increased with decreases in the probability used to generate the RI schedule (note the reversed  $x$ -axis). Linear best-fit functions account for between .17 and .93 of the variance (mean  $r^2 = .62$ ). The slopes of the functions (range, .20 to .75, mean = .37), which indicate the degree of change from one probability to another, were smaller than those obtained in Experiment 1 (Figure 1: range, 0.39 to 0.96, mean = 0.64). For Pigeons Jo and Jan, although the best-fit lines are unsatisfactory, the slopes are consistent with the other 4 pigeons. A repeated measures analysis of variance (ANOVA) was conducted on the proportions of RI choices, with probability as one factor and sessions as the other factor, using choice proportions over the last five sessions of each condition. This revealed evidence of an effect of probability used to generate the RI ( $\text{Pr}[\text{RI}]$ ),  $F(4, 125) = 14.75$ ,  $p < .01$ , but no statistical difference across sessions,  $F(4, 125) = 0.33$ ,  $p = .85$ , or interaction,  $F(16, 125) = 0.34$ ,  $p = .99$ . The results of the ANOVA further support the contention that choice proportions were stable (no statistical effect of sessions) and that probability used to generate the RI, alone, was influencing choice proportions.

The fix-and-sample analysis used in Experiments 1 and 2 was conducted on run lengths in the present experiment. The mean run length, that is, consecutive choices on one alternative, was computed separately for the preferred and nonpreferred schedules across the five probabilities used to generate the RI. Figure 7 shows, for each pigeon, the logarithm (base 2) of mean run length on the preferred and nonpreferred alternatives at each probability used to generate the RI plotted as a function of the ratio of preferred/nonpreferred choices. The data from the last five sessions of each probability value were

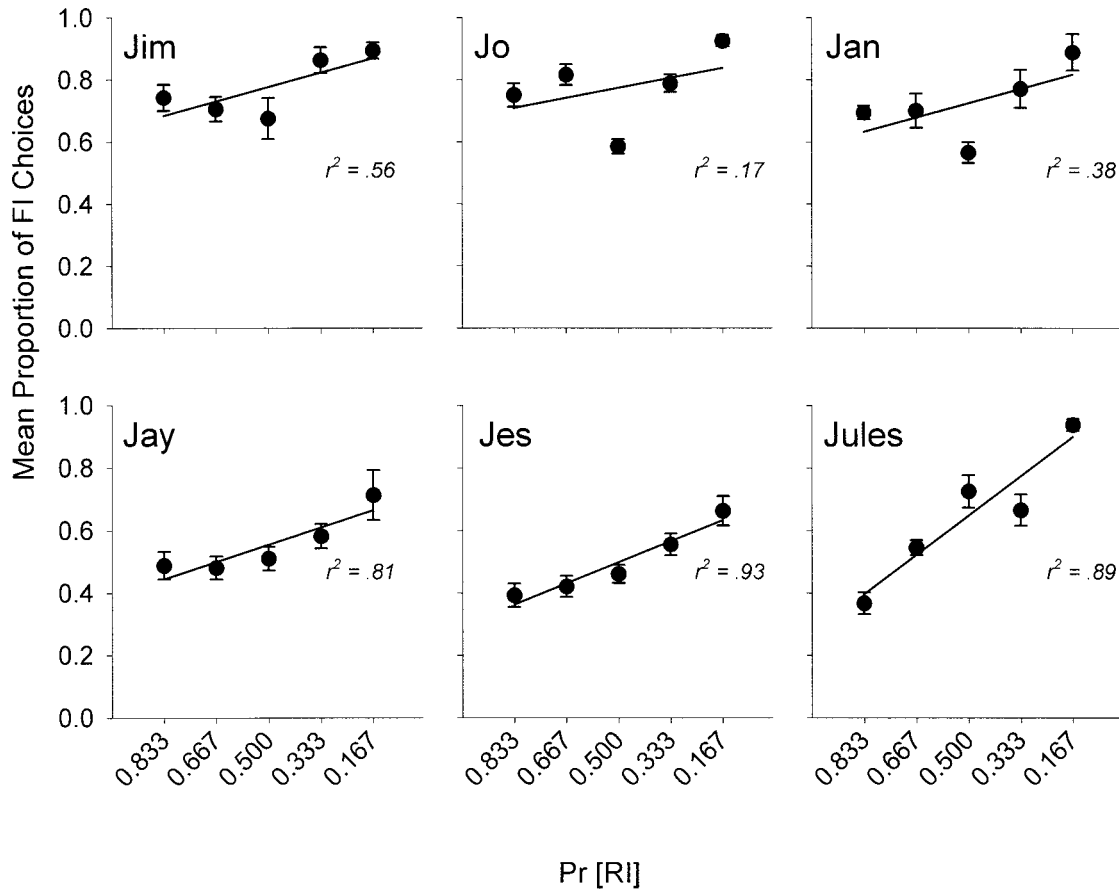


Fig. 6. Mean proportion of choices of the FI alternative ( $\pm$  SEM) for each of the 6 pigeons in Experiment 3, in which the RI schedule was manipulated by varying the probability (Pr[RI]) that was sampled every 30 s; the alternative schedule was always FI 30 s.

used (identical to the sessions used for Figure 6).

As was found in Experiment 1, for all pigeons, preferred run lengths increased with increases in the preference ratio. Nonpreferred run lengths decreased, but to a lesser degree than the increases seen in preferred runs. Changes in the preference ratio accounted for more variance in preferred alternative run length than in nonpreferred run length, consistent with the results of Experiment 1 (average  $r^2 = .98$  and  $.60$ , respectively). Most dramatically, though, the slopes and y-intercepts of the fitted functions in Figure 7 were nearly identical to each other and to those obtained in Experiment 1 (Figure 2).

#### DISCUSSION

The present experiment was designed as a systematic replication of Experiment 1 and

Experiment 2 with different subjects and with a greater number of probabilities used to generate the RI schedule. As in Experiment 1 and Experiment 2, the present findings demonstrated that preference for the FI schedule increased with decreases in the sampling probability used to generate the RI schedule. Also as before, even though the minimum interval of the RI was always equal to the FI, the pigeons in the present experiment often chose the RI.

The pattern of those choices in Experiment 3 also conformed to the pattern seen in Experiment 1. That is, an analysis of runs, or number of consecutive choices on one alternative or the other, revealed that runs on the nonpreferred alternative (again, usually the RI, but not exclusively) were between one and two choices and decreased slightly as a

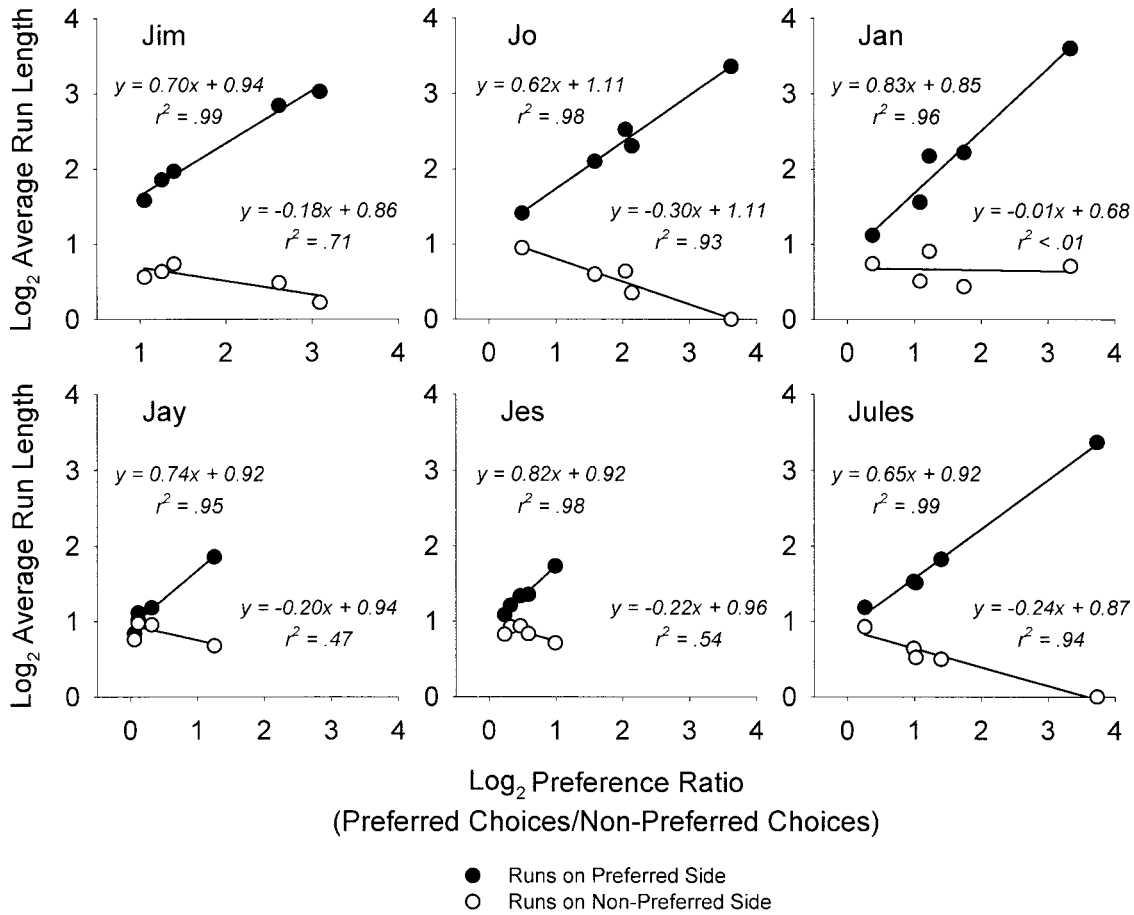


Fig. 7. Logarithm (base 2) of the average run length (number of consecutive choices of the preferred or non-preferred alternative) as a function of the logarithm (base 2) of the preference (or reinforcer) ratio, for each of the 6 pigeons in Experiment 3, in which the probability generating the RI schedule was varied.

function of changes in the preference ratio, which is equal to the obtained reinforcer ratio. Runs on the preferred alternative (usually the FI), increased substantially and systematically with increases in the preference ratio. The absolute values of the slopes of the best-fit lines indicate that there was greater adjustment to the preferred alternative than to the nonpreferred side alternative.

To some degree, the results of the run analyses would be expected because as the proportion of preferred choices changed across the probabilities used to generate the RI schedule, some change in mean run length had to occur. That is, if a particular pigeon's mean preferred preference was .80 at a particular probability, then on average, for every one nonpreferred choice, the pigeon was

making four preferred choices. If that preference changed to .5 at a new probability level, then on average, the pigeon was making one FI choice and one RI choice. However, identical choice proportions can be obtained with different runs of preferred and nonpreferred choices. For example, if a pigeon were making, on average, four consecutive nonpreferred choices followed by 16 consecutive preferred choices, preference would be .80. Therefore, the interesting finding here relates to the run lengths and their changes across the five probability values, in contrast to the choice proportions. Although not constant, runs on the nonpreferred side were usually between one and two choices, and decreased toward one choice per run at large preference ratios (with correspondingly low

probabilities used to generate the RI). In other words, choice runs were generally not 4 and 16 (a choice proportion of .80), but rather 1 and 4 (also a choice proportion of .80).

These patterns of responding in concurrent-chains procedures are similar to those reported with pigeons on concurrent schedules (Baum et al., 1999). Baum et al. found that pigeons spent most of their time pecking on the alternative with the higher reinforcer rate (the "rich" alternative) while occasionally sampling the alternative with the lower reinforcer rate (the "lean" alternative). Visits to the lean alternative were brief, usually one peck, and after that peck, the pigeons returned to the rich alternative. Visit durations on the rich alternative changed as a function of the response ratio across the two alternatives (analogous to a preference ratio in the present experiments). This fix-and-sample pattern is the optimal choice pattern on such schedules, as pointed out by Houston and MacNamara (1981), because it maximizes overall reinforcer rate. Exclusive preference for the rich alternative results in "missing" reinforcers set up on the lean alternative, whereas occasional brief visits to the lean alternative result in an overall increase in rate of reinforcement.

In the present experiments, an approximation to the fix-and-sample pattern was observed, albeit at a different level of analysis. That is, visits to (runs of or consecutive choices of) the nonpreferred alternative (usually the RI) in the concurrent-chains arrangement were brief, averaging between one and two consecutive choices, whereas visits to the preferred were longer and changed more with changes in the reinforcer ratio (and preference ratio). In the present arrangement, however, this pattern cannot be optimal in the same sense as that obtained by Baum et al. (1999) and as argued for by Houston and MacNamara (1981). Optimality theories would predict that in the present procedures, pigeons should always choose the FI because the opportunity to pick up additional reinforcers on the RI side is not available under the concurrent-chains procedure. In the present experiment, choices of the RI (lean alternative) reduced overall reinforcer rate by interposing longer delays to reinforcement.

#### *Experimental Design Features and Possible Limitations*

Several features of the experimental design and interpretation of the data may raise concerns about the present results in the context of current quantitative models of choice. First, in all three experiments, the initial links were FI 3 s and terminal-link entries were not equated, which meant that on most trials a single peck completed the initial link. These features equate choice with relative reinforcers received, and thus choice proportions might never become exclusive because reinforcers continue to be received at both alternatives. In contrast to the present experiments, most contemporary research on choice using concurrent-chain procedures uses relative rates of initial-link responding as the measure of preference and equates terminal link entries. However, if terminal link entries were equated, reinforcers would also be received at both alternatives, only at equal rates. In addition, measuring preference by relative initial-link response rate in a situation in which reinforcers are equated can never allow exclusive preference if the pigeon is forced to respond at both alternatives to continue in the experiment (i.e., if terminal-link entries are equated). Thus we elected to use independent scheduling to allow for exclusive preference.

Second, in several conditions the RI schedule was preferred over the FI, which might appear paradoxical because, if the probability used to generate the RI were 1, thus making the RI an FI, one might think that the pigeons should be indifferent. Choice between two equal FI schedules, however, would be unconstrained because any pattern of choice would produce the same reinforcer rate. Although this latter concern may undermine one's confidence in the data, the finding that all 12 pigeons repeatedly and consistently chose the RI schedule suggests some other variable at work. Moreover, the focus of the present research was on the nature of choice between fixed and variable schedules when the IRIs of a variable schedule were never smaller than the fixed alternative, and not explicitly on quantitative choice models. Thus it is possible that the present results do not contribute to the development or refinement of those models. Those models, however, might

need to accommodate a robust and counter-intuitive aspect of the present results.

*Why Choose the Random Alternative?*

Why do pigeons ever choose the random alternative in these procedures? More to the point, why, after extensive exposure to the procedure, do they persist in choosing the RI a substantial portion of the time? One possible interpretation comes from a model of decision-making behavior offered by Siegel and colleagues (Siegel, 1959; Siegel & Goldstein, 1959). Siegel primarily worked with human subjects in a decision-making context and suggested that there was a subjective utility (value) to behavioral variability. In the traditional probability-matching experiment, two mutually exclusive probabilistic outcomes (with probability of Event A =  $p$ , and probability of Event B =  $1 - p$ ;  $p \geq .5$ ) are presented, and the participant is asked to predict the next outcome. A strategy that maximizes the number of correct predictions is the repeated and consistent selection of the event with the higher probability (resulting in  $p$  correct predictions, or  $p \times 100\%$ ). Human subjects, though, “match” their relative predictions to the probabilities; an event that occurs on 75% of the trials is selected about 75% of the time (which would result in roughly 62.5% correct choices in the long run, instead of 75%). These results formed the basis of Estes’ statistical learning model (Estes, 1950, 1954), as well as the Bush-Mosteller (Bush & Mosteller, 1955) model. However, Bitterman (1965) found that nonhuman primates, pigeons, and rats responded in patterns that maximized correct predictions more than the human subjects in the studies by Estes (1950, 1954), by Bush and Mosteller, and by Siegel and Goldstein.

A comparison of the various preparations shows that each correct choice in the experiments with nonhuman animals resulted in food reinforcement, whereas each correct choice in the studies with human subjects was said to produce “satisfaction.” Siegel (1959) argued that the maximizing strategy (choosing the more frequent outcome exclusively) was “kinesthetically and cognitively” unexciting and additional strategies of “trying to outwit the experimenter” or “playing the game” may have influenced choice. He also argued that the “value” of satisfaction when the less-

frequent outcome was chosen and confirmed might be greater when compared to the satisfaction of choosing the more-frequent event and having that choice confirmed. Therefore, a disproportionate number of lower probability alternative choices would be made. Siegel’s model helped explain the disconfirming evidence of probability matching seen in nonhuman subjects, for when Siegel and Goldstein (1959) increased the value of correct predictions with monetary rewards and decreased the value of incorrect predictions by imposing a monetary penalty, they obtained choice proportions in humans that were very close to maximizing.

Houston and MacNamara (1981) suggest that a fix-and-sample pattern of choice results in near maximization of overall subjective utility. They analyzed data from concurrent schedules, in which subjective utility is defined over a brief period of time, namely a session or several sessions. Nevertheless, if we consider the evolutionary history of a species and its relation to foraging patterns, a fix-and-sample pattern also has intuitive appeal. That is, if an animal spends all of its time foraging in a rich patch and no time in lean patches, changes in the rate of return in the rich patch could have devastating effects. If the rich patch suddenly expires or is destroyed by pests, our animal may perish due to lack of exposure to other, less good, patches. But an animal with experience foraging in multiple patches, some better than others, may survive abrupt changes in the rate of return from rich patches. In this case, “behavioral variability” is selected for in an organism’s repertoire. Given that the relative quality of patches is variable, behavioral variability then seems appropriate.

Behavioral stability, however, also could be selected, especially if directed toward rich patches and at the expense of time in less rich patches. In time, it would be likely that animals concentrating their efforts in rich patches would be larger, stronger, and healthier than their counterparts more sensitive to variation. They would be better able to fend off predators, defend territory, and challenge for potential mates than their smaller “varying” brethren. As noted earlier, however, a sudden change in the rich patches, a loss of fruit in an orchard because it is harvested by humans, for example, may leave these ani-

mals struggling to survive, whereas others may have experience foraging in less rich ("wild") patches and subsequently manage better. It seems that some compromise between the patterns of variability and stability might be most successful. As part of this combined pattern, a foraging animal spends most of its time in rich patches, but occasionally "checks out" leaner alternatives. In addition, the lengths of those visits to the lean alternatives are fairly constant and brief, whereas visit durations to the rich alternatives are adjusted depending on the overall rate of return across the alternatives. Implicit in this account is that the number of switches (moving from one alternative to the other) decreases as the preference for the rich alternative increases. This type of fix-and-sample strategy maintains a balance between behavioral variability and behavioral stability, ensuring high returns in rich patches and a response to changing conditions.

Siegel (1959) assessed the degree of variation seen in certain decision-making situations employing the expression "the utility of behavioral variability." Perhaps Siegel's model, that variation of behavior was selected in certain contexts, overlaps Houston and MacNamara's (1981) fix-and-sample model in the sense that both models attempt to characterize the repeatedly observed fact that animals distribute their responses across alternatives, often at the expense of overall reinforcer rate. Quantitatively, Siegel's model predicts that preference for the RI will increase as the probability used to generate that schedule increases, all else being equal (e.g., the fixed alternative in the present experiments), but that the RI will continue to receive some attention, as does the "fix and sample" model. Most other models of choice would predict exclusive preference for the fixed alternative because they maximize overall reinforcer rate or decrease the delays to reinforcers. More research is needed to assess these relations and the usefulness of Siegel's model. The present results appear to require some formulation of a "pure" preference for variability that does not appeal to momentary highly favorable fluctuations.

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Received May 3, 2004

Final acceptance January 5, 2005