

PIGEONS' PREFERENCE FOR VARIABLE-INTERVAL WATER REINFORCEMENT
UNDER WIDELY VARIED WATER BUDGETS

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Water budget of pigeons was varied to assess the dependence of risk-sensitive preferences upon economic context such as has been reported for energy-budget manipulations with small animals in behavioral ecology research. Fixed- and variable-interval terminal-link water schedules reinforced choice between equal variable-interval initial-link schedules arranged on two pecking keys. While keeping a severely restrictive budget the same across three phases of the experiment, a contrasting distinct ample budget was arranged in each. To mimic typical methods in behavioral ecology studies, in each ample budget a more than three-fold increase in amount of water per reinforcer presentation was instituted simultaneously with significantly increased overall access to water. Total choice response rates plummeted in the ample budgets, and body weights either increased significantly or remained unchanged in different phases as expected by the nature of the different manipulations. Clear preferences for the variable-interval schedule were found throughout the experiment, except for rare instances of key bias. The results agree with similar operant food-reinforcement studies and extend conditions under which risk preference apparently does not depend upon economic context.

Key words: choice, water reinforcement, water budget, concurrent chains, reinforcer delay, risk preference, behavior ecology, closed economy, key peck, pigeons

In studies of risk-sensitive preference, an organism typically chooses between outcomes that share mean schedule values (e.g., amount of reinforcement) but that differ in the variability, or reliability, of the outcomes. One of the earliest studies in the operant tradition was conducted by Herrnstein (1964). It assessed food-deprived pigeons' choice between variable-interval (VI) and fixed-interval (FI) 15-s schedules of food reinforcement that were arranged in the terminal links of a concurrent-chains schedule (Autor, 1960). As indicated by relative rates of responding during identical VI 60-s schedule initial links (choice phase), all 4 subjects preferred the terminal-link VI schedule (the "risky" choice) by a ratio of 3:1 or more.

This strong preference has been replicated in other psychology laboratories (e.g., Navarick & Fantino, 1975: mean choice proportion = .85). Clear preference for variability has

also been extended to mixed-interval schedules in place of VI schedules (Davison, 1972: $M = .67$), and to variable-time (VT) or mixed-time (MT) versus fixed-time (FT) schedules (Cicerone, 1976: M [MT over FT] = .64; Rider, 1983: M [MT over FT] = .70; Zabludoff, Wecker, & Caraco, 1988: M [VT over FT] = .65). Preference for variability has also been found with variable-ratio and fixed-ratio contingencies in place of temporal schedules (Navarick & Fantino, 1972: $M = .74$). Data consistent with preference for risk involving reinforcer delay have been found in many other studies (Ahearn, Hineline, & David, 1992; Davison, 1982; Fantino, 1967; Frankel & Vom Saal, 1976; Gibbon, Church, Fairhurst, & Kacelnik, 1988; Hursh & Fantino, 1973; Kendall, 1987, 1989; Killeen, 1968; Logan, 1965; Mazur, 1984, 1985, 1987, 1991; Mazur & Romano, 1992; Pubols, 1962; Sherman & Thomas, 1968). Investigations of risky choice involving reinforcer amount, however, have yielded conflicting results in different studies. About as many studies have reported results consistent with variability preference (Essock & Reese, 1974; Hastjarjo, Silberberg, & Hursh, 1990; Hill, Riopelle, & King, 1983; Leventhal, Morrell, Morgan, & Perkins, 1959; Mazur, 1988; Young, 1981) as have reported results apparently inconsistent with it (Battalio, Kagel, & MacDonald, 1985; Hamm & Shettleworth, 1987; Hastjarjo et al., 1990; Ka-

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gel, MacDonald, Battalio, White, & Green, 1986; Logan, 1965; Menlove, Inden, & Madden, 1979). Also, in a typical study preferences tended not to be as strong or as consistent across individuals as in the interval, time, and ratio studies. Whatever the interpretation of this discrepancy, risk aversion and preference for risk both have presented a longstanding theoretical challenge. For example, neither is predicted by Herrnstein's (1970) influential reinforcement theory of choice.

An intriguing theoretical perspective on this problem has arisen from another research tradition—behavioral ecology (e.g., Caraco, Martindale, & Whittam, 1980). The starting assumption of one ecological approach is that evolutionary adaptation should favor conservative foraging choices under relatively unchallenging conditions, along with a shift over to risk taking under desperate conditions. Studies conducted from this perspective have used positive resource budgets, in which subjects readily obtained ample amounts of food or water, and negative resource budgets, in which intake is severely restricted even to the point of being insufficient for survival were the experiment extended. The results of several studies are consistent with this interpretation of risk-sensitive choice, because they demonstrate the predicted crossover of preference as a function of the resource budget: preference for risk in a negative energy budget and risk aversion in a positive energy budget (Barnard & Brown, 1985b; Caraco, 1981, 1982, 1983; Caraco & Lima, 1985; Caraco *et al.*, 1980, 1990; Gillespie & Caraco, 1987; Real, Ott, & Siverfine, 1982). The species represented in these studies include a variety of small animals (e.g., insects, song birds, and mammals).

Other studies appear to be inconsistent with the prediction based upon this foraging theory (Barnard & Brown, 1985a; Battalio *et al.*, 1985; Hastjarjo *et al.*, 1990; Hill *et al.*, 1983; Kagel *et al.*, 1986; Kendall, 1989; Rachlin, Logue, Gibbon, & Frankel, 1986; Silberberg, Murray, Christensen, & Asano, 1988; Wunderle, Castro, & Fetcher, 1987; Wunderle & O'Brien, 1985; Zabludoff *et al.*, 1988). This is not necessarily problematic for the theory, because of the specific evolutionary pressures on different species. However, evidence has been notably lacking for the reversal of risk-

sensitive choice depending upon economic context in larger animals with relatively low metabolism rates (pigeons: Hamm & Shettleworth, 1987; rats: Hastjarjo *et al.*, 1990, and Mazur, 1988; humans: Rachlin *et al.*, 1986, and Silberberg *et al.*, 1988). (In the Discussion, we critically consider possibly exceptional studies of relatively large species showing a weaker form of budget dependence.) Larger species presumably have larger energy storage capacity than the otherwise similar species for which positive evidence supporting the foraging analysis was obtained. Perhaps species with relatively large energy stores are more sensitive to dynamic changes in economic context involving water requirements compared to changes in their energy needs.

In the present study we investigated this possibility by varying the water budget of pigeons responding for water reinforcement. A comparable study was conducted with rats by Kagel *et al.* (1986; see the present Discussion), although it involved reinforcer-amount risk instead of reinforcer-delay risk. An ample water budget was arranged in three different ways in separate parts of the experiment; this ample budget was contrasted against a highly restrictive water budget. In the first two parts, overall access to water remained high in the ample-budget manipulation over a continuous block of daily sessions, whereas in the last part, restrictive budget circumstances provided a steady baseline performance against which results of intermittent ample-budget probes were compared. In some respects, this probe method more closely resembles behavioral ecology methods than the sustained-testing methods that are more typical of operant studies. An ample budget was achieved in Part 2 by using a 19-hr-per-day procedure similar to a closed economy (Hursh, 1980), thereby in this fashion perhaps more closely simulating natural foraging environments. In the ample budget, the amount of water per reinforcer presentation was increased to 1.0 ml from the 0.3 ml used in the restrictive budget, while simultaneously increasing overall access to water. This was done to mimic typical methods in behavioral ecology studies, where the rationale presumably was to insure an unmistakable change from negative to positive budgetary conditions. A concurrent-chains choice procedure, similar to the one used by Herrnstein (1964), was employed to

assess risk sensitivity. In summary, the present experiment systematically extends the conditions under which pigeons' risk-sensitive choice has been tested for dependence upon economic context using particular methods more likely to replicate the positive results that have been obtained in the behavioral ecology tradition with other species.

METHOD

Subjects

Four young adult male pigeons obtained from a local commercial breeder were subjects. They were common-type, variety unknown. Mean ad libitum body weights were established in home cages equipped with amply filled food and water cups. These weights ranged between 510 and 540 g. The birds' key pecking had been studied in food-deprivation operant-reinforcement experiments lasting over a year.

Just prior to the present research, total daily water intake was precisely measured in a typical pigeon chamber in 1.5-hr sessions. The chamber had been previously used for operant conditioning but was equipped with a U tube and an automatically controlled electric pump that kept the tube filled with water to a specified level. During the assessment, all water for a day had to be consumed in the timed 1.5-hr period of otherwise unlimited access. Pigeon chow pellets, milo seed, and grit were freely available in cups both in home cages and in the chamber. Intake was steady day to day over several weeks and was reliable in a reassessment after a gap of several months. Daily drinking totals roughly correlated with ad libitum weights (data not shown). The totals averaged 30, 31, 36, and 26 ml for Subjects R75, R63, R56, and G74, respectively.

Apparatus

A single two-key operant conditioning chamber, equipped with a solenoid-operated water dipper, was used to study preference between schedules of water reinforcement. The pigeon's space was 50 cm high and 40 cm wide and long. The response keys were translucent circular disks 2.5 cm in diameter and symmetrically located side by side at the center of an aluminum intelligence panel that comprised one wall of the chamber. The keys

were located 30 cm above the chamber floor and were 10 cm apart. They could be illuminated from the rear by 12-stimulus IEEE® projectors. The stimuli on the keys were diffuse colored lights that filled the key area and were either white, red, or green. The water dipper was accessible through an aperture in the panel (6 cm wide, 10 cm high) centered between the keys and beneath them, 5 cm above the floor. The dipper cup held either 0.3 or 1.0 ml of water, depending upon the condition (see Procedure). A miniature lamp located behind the panel and above the aperture was illuminated when the solenoid raised the dipper within reach. A houselight was located in the upper left corner of the panel opposite the door-wall of the chamber. The door-wall, the remaining walls, and the ceiling were constructed from clear Plexiglas, and the floor consisted of aluminum rods suspended above a tray of wood shavings. Air access holes perforated the ceiling and plastic walls, and the chamber was placed under a loosely constructed plywood box for visual isolation. The box was tipped up about 2 cm on the side behind the intelligence panel, thus permitting easy circulation of air from the large, ventilated experimental room. White noise was continuously presented to mask possible disturbing sounds. All events were controlled and monitored by electro-mechanical equipment located in an adjacent room.

Procedure

No special training was needed to initiate key pecking for water reinforcement, presumably because of the pigeons' lengthy history of food-reinforced key pecking in similar chambers. Key pecking was reinforced on a two-alternative concurrent-chains schedule of reinforcement. In this schedule, simultaneously available initial links, correlated with the two white-light illuminated keys, respectively, were concurrent VI 90-s VI 90-s schedules of access to terminal links. On a concurrent schedule of reinforcement, two (or more) responses are each reinforced on their own schedules over the same time period. In a VI schedule, the first response is reinforced after an interval of variable length has elapsed; the mean of the intervals is the schedule parameter. The present distribution of VI intervals was exponential and was de-

Table 1
Order of conditions, numbers of sessions, and results of Part 1.

Subject	Initial FI side, color ^a	Budget condition ^a	Sessions	Percentage body weight ^b	Response rate ^c (per minute)	Choice proportion ^{c,d}
R75	right, green	restrictive	10	80	14.8 (4.3)	.70 (.07)
		reversal	42	80	31.8 (3.4)	.76 (.03)
		ample	30	89, 96	4.7 (1.0)	.77 (.03)
R63	left, red	restrictive	15	80	51.0 (12.3)	.68 (.04)
		restrictive	10	81	21.6 (3.2)	.84 (.07)
		ample	41	95, 106	3.2 (1.4)	.70 (.04)
R56	right, green	reversal	28	95, 105	3.5 (2.5)	.90 (.04)
		restrictive	16	78	29.8 (3.7)	.75 (.05)
		restrictive	10	80	35.0 (9.1)	.78 (.04)
G74	left, red	ample	42	93, 98	1.2 (0.4)	.90 (.06)
		reversal	86	89, 93	2.4 (1.7)	.68 (.08)
		restrictive	15	80	34.2 (6.2)	.65 (.04)
G74	left, red	restrictive	10	81	22.0 (5.8)	.77 (.04)
		reversal	50	82	22.8 (2.8)	.57 (.02)
		reversal	18	79	20.0 (2.4)	.68 (.01)
		ample	49	98, 104	6.2 (0.8)	.77 (.04)
		restrictive	15	81	26.6 (0.9)	.77 (.02)

^a Budgets during reversal are indicated in the previous condition. In a reversal, FI side and color are the alternate ones to those listed.

^b Ample-budget entries are subject weights measured before and after sessions, in that order. Data are means of the last five sessions.

^c Data are means of the last five sessions, with standard deviations in parentheses.

^d Proportions are in terms of preference for the VI 15 s.

terminated according to the method of Fleshler and Hoffman (1962).

Upon completion of an initial link on a key, its keylight changed color to the stimulus correlated with the terminal-link schedule on that key, and the other key darkened and became inoperative. After water reinforcement at the completion of a terminal-link schedule, the two white keys again became available and their concurrent VI VI schedules resumed. These initial-link schedules were arranged interdependently according to the method of Stubbs and Pliskoff (1969)—that is, when one schedule had timed out, both schedules ceased operating until a response on that key completed the contingency. This insured that access to terminal links alternated unpredictably across sessions, no matter how strong the preference for one alternative. It also resulted in roughly equal numbers of reinforcers per session on each alternative.

One terminal link was a VI 15-s schedule of water reinforcement, and the other was an FI 15-s schedule providing identical reinforcement. In an FI schedule, the first response is reinforced after a constant interval has elapsed, specified by the schedule parameter. Either the VI or the FI terminal-link

schedule was correlated with a red keylight, and the other was correlated with a green keylight. These colors and the sides of the terminal links were counterbalanced across subjects (Table 1). The association of colors and sides with the terminal-link schedules was reversed across conditions as described below (see also Table 1). Sessions usually were not conducted on weekends except during the 19-hr procedures of Part 2.

One highly restrictive water budget and three types of ample water budget were arranged in the different parts of the experiment. That is, the restrictive budget was repeated identically throughout all parts while the method of arranging the ample budget varied across the experiment. The restrictive budget consisted of (a) holding body weight constant at approximately 80% of ad lib weight through supplemental drinking in the home cage as needed; (b) using a 0.3-ml volume of water reinforcement; and (c) terminating sessions after 40 reinforcer presentations, 20 for each alternative. In each of the ample budgets, more water was given to drink, either inside or outside experimental sessions, than in the restrictive budget; in addition, the volume of water per reinforce-

ment was 1.0 ml instead of the 0.3 ml used in the restrictive-budget conditions (with one individual exception in Part 2; see below).

In the ample-budget conditions of Part 1, pigeons were given access to amply filled water cups in the home cage for approximately 1 hr after daily sessions. The birds thus were deprived for only 23 hr in this ample water budget. Sessions were arranged to end after either 40 reinforcer presentations or 1.5 hr, although the maximum number of presentations was never reached in any session. Subjects began Part 1 in the restrictive-budget condition; usually, the restrictive and ample budgets alternated thereafter in successive conditions. In one exception to this, side reversals were conducted during Part 1 to assess key bias. The terminal-link schedules were switched on the two keys while the stimuli on them were kept the same. For 2 subjects (R75 and G74) the side reversal was conducted under conditions of restrictive budget, and for the other 2 it was conducted during the ample budget (Table 1). A second side reversal was conducted for 1 subject (G74) after it failed to reverse its preference completely the first time (Table 1 and Results). Unless indicated otherwise, the side and stimulus assignment then remained the same until the end of the experiment. The first condition was in effect for 10 sessions for all subjects, and subsequent conditions were continued until choice performance met a visual stability criterion.

In Part 2, 19-hr sessions resembling a closed economy were used to achieve an ample water budget. Thus, other than the larger volume of water per reinforcer (with the exception of R75's first ample-budget replication), the same schedules used in the short-session restrictive-budget condition were available for 19 hr per session in the ample-budget conditions. Additional water either was or was not given in the home cage in different ample-budget replications in this part (Table 2). Subjects R75 and R56 were studied in conditions in which the 19-hr sessions occurred every day; the other 2 pigeons and R75 were studied when sessions occurred every other day (Table 2). R56's pattern of choices was investigated more extensively than the rest in a series of additional budget manipulations and in two further side reversals of the schedules. R75 also was studied

more than the remaining subjects to provide control observations for the intensive exploration of R56's apparently atypical preferences (see Results and Discussion). In Part 2, restrictive-budget conditions were always 15 sessions, but ample-budget conditions were always only 10 sessions, because the longer sessions seemed to provide comparable, adequate exposure.

In each of the first two parts, conditions comprised of numerous sessions alternated; body weights changed with budget manipulations accordingly. By contrast, in Part 3 ample-budget probe sessions were superimposed periodically on an otherwise steady restrictive-budget baseline. Body weights therefore did not change appreciably across this part of the experiment. Specifically, after obtaining steady responding over several sessions in Part 3, an ample-budget probe session was conducted after a set of three successive daily baseline restrictive-budget sessions. This four-session sequence was then repeated in a series of eight replications. In the probe sessions, the pigeons were given pre-session access to 40 ml of water in their usual water cups in their home cage, essentially all of which they consumed immediately. As in Part 1, sessions could end after either 40 reinforcer presentations or 1.5 hr, but the maximum number of reinforcers was never reached in the available time. R56 was not studied in Part 3 because of its more extensive study in Part 2.

RESULTS

Individual-subject mean results for Parts 1 through 3 are shown in Figures 1 through 3, respectively. Plotted in the top panels of each figure are individual-subject mean choice proportions in each budget condition, averaged either over five sessions of stable responding at the ends of conditions and then averaged over all replications (Parts 1 and 2) or averaged over all replications (Part 3). The bottom panels contain the total choice response rates in these samples. Results from restrictive budgets are displayed with solid bars. The choice data are plotted in terms of preference for the unpredictable-delay terminal link (i.e., the VI schedule). The error bars in Figure 3 represent 1 *SD* above the individual-subject means of the ample-budget single-session probe replications and, similar-

Table 2
Order of conditions and results of Part 2.

Subject	Maximum session duration (hr)	Home cage water	Session frequency	Percentage body weight	Response rate (per minute)	Choice proportion
R75 ^a	19	yes	daily	86	0.6 (0.1)	.77 (.02)
	19	yes	bidaily	97	0.5 (0.4)	.82 (.03)
	19	no	daily	89	22 (7.9)	.73 (.07)
	19	yes	bidaily	98	0.3 (0.1)	.69 (.03)
	1.5	no	daily	79	28 (1.8)	.73 (.09)
	19	yes	daily	92	0.3 (0.1)	.77 (.02)
	1.5	no	daily	80	21 (4.4)	.73 (.04)
	19	no	daily	90	22 (8.8)	.80 (.03)
	19 ^b	no	daily	92	7.0 (3.1)	.75 (.08)
	1.5	no	daily	83	27 (3.3)	.70 (.01)
R63	19	yes	bidaily	103	0.3 (0.2)	.95 (.04)
	1.5	no	daily	79	32 (4.2)	.77 (.03)
R56	19	yes	daily	92	0.1 (0.2)	—
	1.5	no	daily	80	47 (7.3)	.75 (.04)
	19	no	daily	93	0.2 (0.1)	.50 (.02)
	1.5	no	daily	82	34 (4.8)	.83 (.03)
	19	no	daily	92	0.1 (0.1)	.42 (.17)
	1.5	no	daily	81	42 (15)	.82 (.02)
	19	no	daily	94	0.2 (0.1)	.34 (.09)
	1.5	no	daily	80	46 (2.9)	.78 (.03)
	19	no	daily	92	0.1 (0.1)	.43 (.06)
	19 ^c	no	daily	96	0.3 (0.1)	.82 (.09)
	1.5	no	daily	79	32 (8.8)	.35 (.05)
1.5 ^c	no	daily	78	37 (10)	.78 (.04)	
G74	19	yes	bidaily	99	2.4 (0.8)	.76 (.06)
	1.5	no	daily	79	26 (1.7)	.87 (.03)

Note. See Table 1 notes for other details. Missing choice data of R56 were deemed unreliable due to extremely low response rates.

^a Reinforcer amount was 0.3 ml instead of 1.0 ml in this subject's first 19-hr ample-budget condition only.

^b Limit of total reinforcers on each alternative increased from 40 to 68.

^c Schedules were reversed between the two sides.

ly, 1 *SD* above the individual-subject means of the three-session average performances in the restrictive-budget condition that was interspersed between ample-budget probe sessions.

With the exception of Subject R56 in Part 2, subjects clearly preferred unpredictable reinforcer delays in each part under both restrictive and ample budgets (top panels of Figures 1 through 3). The VI terminal link was preferred in both budgets in Part 1, for example, by a 3:1 ratio on average over subjects. Moreover, in no case in the entire experiment did an individual reliably prefer the predictable reinforcer delay. In addition, all subjects reversed their preferences when the terminal-link schedules were reversed. The strength of preferences, the preference reversibility, and the close similarity of results

across the different parts lessen the chance that a failure to find preference for (or more choice of) the reliable delay under an ample water budget is a fortuitous consequence of particular methods of instantiating them in this study.

Every subject always responded faster in the restrictive-budget conditions than in the ample-budget conditions (bottom panels of Figures 1 through 3). These results, along with the expected changes in body weight in Parts 1 and 2 (Table 1), validate the budget manipulations.

A representative subject's entire session-by-session performance from Part 1 is shown in Figure 4. The dependent variables plotted with the continuous lines are the same as in the previous figures. Also shown are the obtained average relative reinforcer immediacy

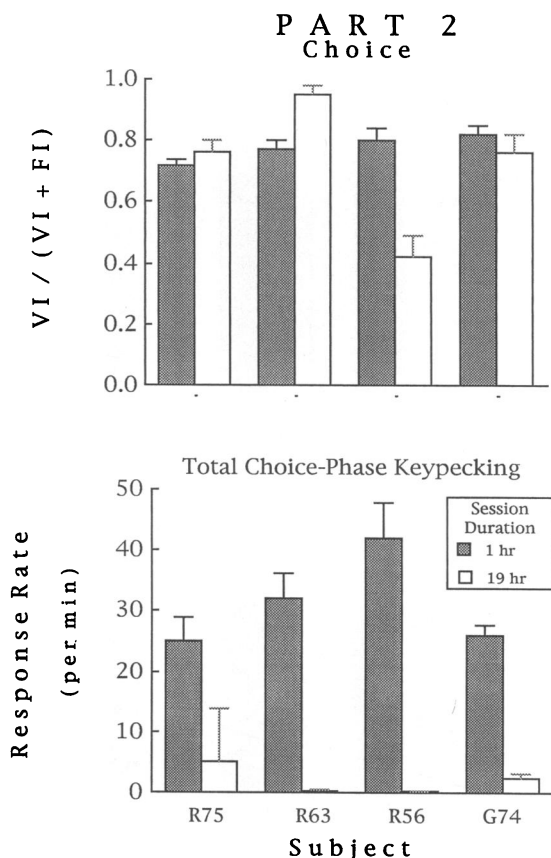
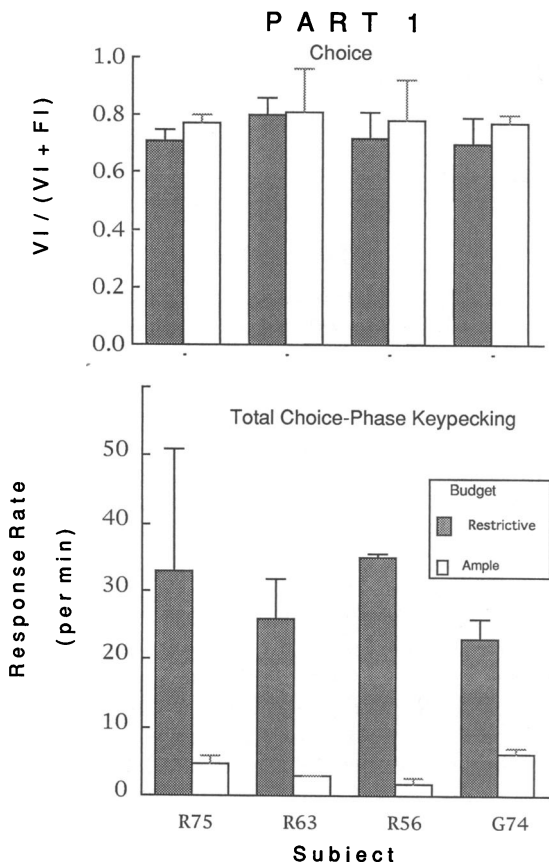


Fig. 1. Individual-subject mean proportions of VI choice responses (top) and total choice-phase (i.e., initial-link) key pecks per minute (bottom) in Part 1. Most data are based upon the last five sessions in a condition, then averaged over replications and plotted as a function of ample versus restrictive water budget (legend). Because only one ample-budget replication was conducted for Subjects R75 and G74, these data are based upon the last five sessions of those conditions only. Error bars are one standard deviation in length.

Fig. 2. Individual-subject mean data in Part 2. Data are plotted as in Figure 1 except in this case as a function of session duration. Data for Subject R56 are from the first four replications only.

in the terminal links (i.e., the inverse of relative average terminal-link delay; unconnected points in the top panel) and the proportion of reinforcers obtained on the VI terminal-link schedule (unconnected crosses; the proportions are not shown in the restrictive-budget conditions because the procedure insured that equal numbers were obtained in every session). These data illustrate both typical day-to-day variability and, during side reversal of schedules, the regularity of choice responding and the rate of preference change. With regard to typical variability, note that in the ample-budget condition,

peaks in total choice responding are apparent (bottom panel, third section). These peaks do not reflect random variation alone; rather, they only occurred in sessions conducted on Mondays. That is, the peaks apparently reflect imprecision in arranging the same deprivation over the weekend as had been arranged during the regular work week. Nevertheless, such unplanned variation illustrates in a different way both the sensitivity of total response rates to deprivation conditions and the simultaneous insensitivity of choice behavior to those changes.

Day-to-day choice results for the subject with peculiar choice data in Part 2 (R56) are plotted in Figure 5 (excluding its first condition because of extremely low response rates; also, see Table 2 for comparable data collected for R75, which shows that its previ-

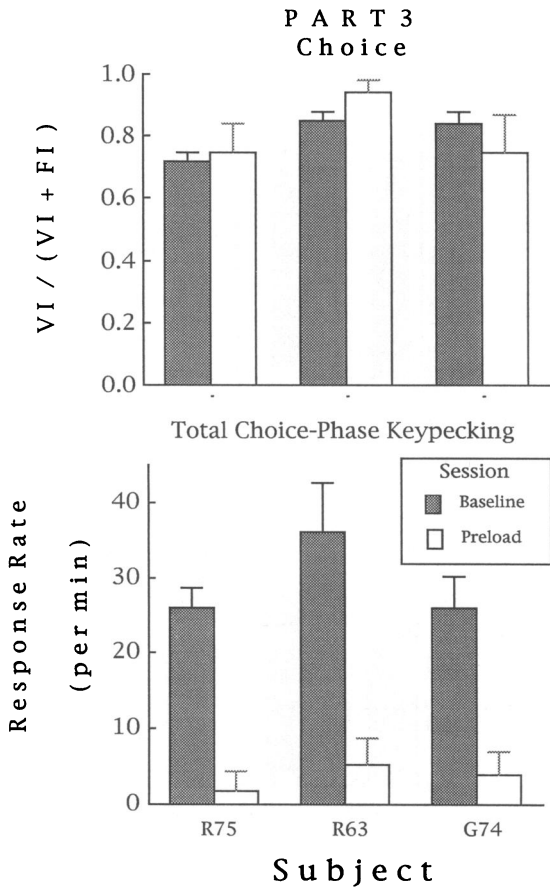


Fig. 3. Individual-subject mean data in Part 3, plotted as in Figure 1 except in this case as a function of preloading with water.

ous preferences were replicated consistently). The data initially suggested the greatest support in any phase of the experiment of at least a clear trend towards the prediction of the hypothesis motivating the present study. Moreover, with each replication of the 19-hr session ample-budget condition apparent crossover of preference towards the FI increased. However, when a reversal of the VI and FI schedules was then conducted to verify that choice continued to be sensitive to risk, the results suggested that there was instead a large key bias. Then, a further budget manipulation followed by another schedule reversal suggested, again, a virtually complete lack of sensitivity to risk, contrary to what had been exhibited in Part 1. Perhaps the most intriguing aspect of these data was the apparent reversibility of the key bias as a function of the

water budget as shown in the last four segments plotted in Figure 5. This budget-reversible key bias was in the direction of the key that had been preferred in the respective budget conditions in the first series of replications.

DISCUSSION

Except for instances of apparent key bias, the results uniformly support pigeons' preference for variable over fixed delays to water reinforcement. The results of schedule reversal in Part 1 showed that preferences were primarily a function of risk differences between alternatives, not key bias. The findings from the restrictive-budget condition are comparable to those from similar operant food-reinforcement studies (Cicerone, 1976; Davison, 1972; Herrnstein, 1964; Navarick & Fantino, 1972, 1975; Rider, 1983).

To our knowledge, the present experiment is the first to assess the effect of water budget on pigeons' preference for risk involving reinforcer delay. All other studies of choice involving reinforcer-delay risk cited in the Introduction used food reinforcement, and only Zabludoff *et al.* (1988), who studied rats, varied energy budget: As in the present work, an ample energy budget did not reliably alter preference for variable delay. We reasoned that the larger body size of pigeons might make them more sensitive to variation in water than in energy budget, compared to song birds and other small animals that have been reported to show reversal of risk preference with an increase in the richness of their energy budget. There was no evidence that risk sensitivity of choice depends upon water budget, however. The budget manipulations were validated by reliable changes in total choice response rates and in body weights. Three ways of assessing whether choice depended upon budget yielded similar results. This argues against the possibility that the failure to find an effect of budget on choice was due to peculiarities of a given method. Kagel *et al.* (1986) studied water budgets of rats in choice between constant and risky amounts of water reinforcement, but again, as in the present study, they found no effect of water budget on preference.

A few recent studies in the operant tradition require consideration here because their

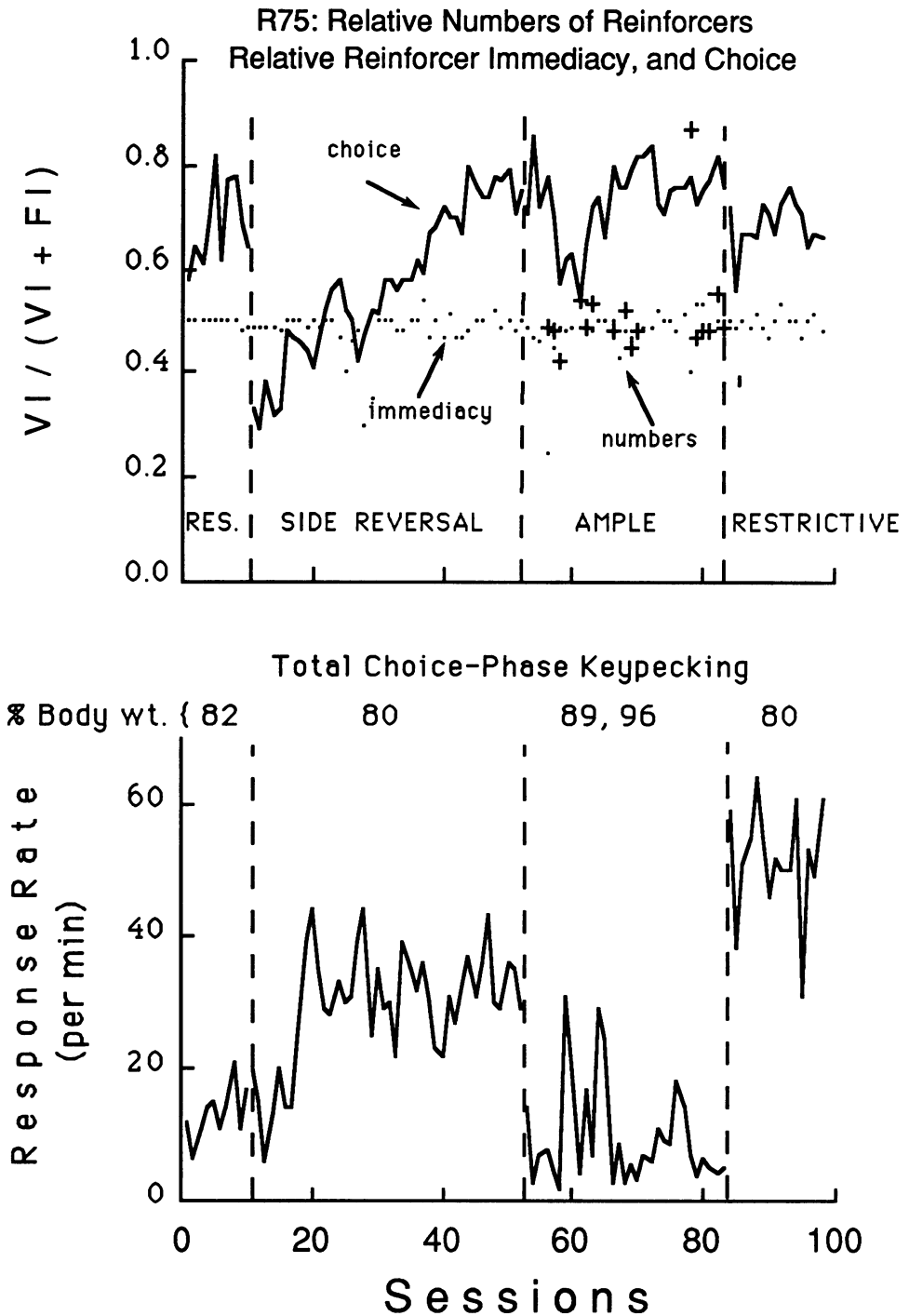


Fig. 4. Representative individual session-by-session results in Part 1 (Subject R75). Dashed lines demarcate conditions. Connected lines are the same dependent variables as plotted in Figure 1. Relative reinforcer immediacies (total session terminal-link delay to FI reinforcers divided by the sum of total session delays to FI and VI reinforcers) are shown with unconnected points in the top portion. Crosses indicate the proportion of VI reinforcers whenever it did not equal .50 in a session.

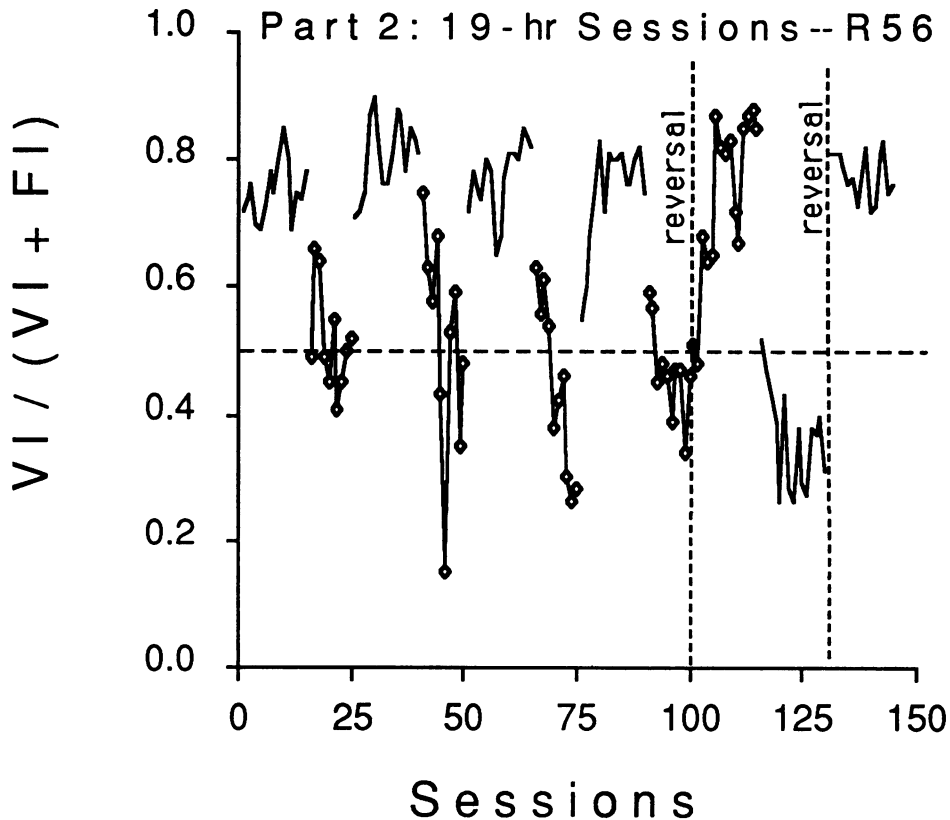


Fig. 5. Session-by-session mean choice proportions of Subject R56 in Part 2. Schedule reversals are indicated by the vertical lines. Results for ample-budget conditions, which were produced by 19-hr sessions, are indicated with the open symbols.

results, with relatively large species with relatively low metabolism rates, were interpreted as supporting budget dependence (Hamm & Shettleworth, 1987; Hastjarjo *et al.*, 1990; Mazur, 1988; Rachlin *et al.*, 1986; Silberberg *et al.*, 1990). In all three studies of nonhumans, preference varied as a function of increasing overall intake of food per session, although only in Hastjarjo *et al.*'s work did body weights increase as food resources increased. This difference may require caution in drawing conclusions. Both studies of humans employed tasks with hypothetical monetary payoffs, while budget was manipulated by varying either the interval between choice trials or the starting amount of money with which to gamble.

Unfortunately, the findings in these studies were about as diverse as the studies themselves: Hamm and Shettleworth used a simple concurrent schedule in their Experiment 1

and found a mean risk-averse choice proportion of .54 in pigeons maintained at 85% ad lib weight; this proportion increased from .52 to .57 as rate of food was increased from 80 to 270 pellets per hour (via reduction of the equal variable interreinforcement intervals of the schedules). Mazur reported "risk proneness" in rats on the basis of interpreting indifference points in a dynamic adjusting-schedule procedure (i.e., equivalent to preference for risk in a typical static choice procedure) that decreased to risk indifference as number of pellets per reinforcer increased from one to four. Hastjarjo *et al.* used a discrete-trial procedure (which forced exposure to outcomes in from 8% to 23% of the total number of trials) and found that their rats' free choice of the risky reinforcer amount both increased (Experiment 1) and decreased (Experiment 2) as food intake increased (which was achieved in Experiment 1

by increasing number of trials per day and in Experiment 2 by increasing number of pellets per reinforcer). As pointed out in the Introduction, interpretation of these results is complicated by the fact that the risky alternative had a higher mean than the constant outcome. Both studies with humans (Rachlin et al., 1986; Silberberg et al., 1990) found greater risk taking with richer budgets, although Silberberg et al. also found inconsistent effects of varying the interval between trials.

It is difficult to reconcile these reports of budget dependency among themselves (and, as noted by Houston, 1991, and Mazur & Romano, 1992, in the case of Hastjarjo et al., it is difficult to reconcile results across experiments within the same report). In no experiment did individuals' preference for risk cross over to risk aversion as has been observed in behavioral ecology research. One possible explanation for some of these results is that shifts toward indifference may reflect nonspecific reduction in experimental control.

At any rate, the present data offer no support for the possibility that choice for variable delays would be reversed or lowered in ample-budget conditions. Only the unusual results of Subject R56 in Part 2 (Figure 5) showed such a decline in preference. In several replications, its preference appeared to be reliably controlled by budget. However, these data may be interpreted in terms of bias to different keys (that depended upon the budget) because schedule reversals following these replications showed that the bird's choices had become essentially insensitive to risk, counter to the results in Part 1. Therefore, in future investigations of ecology's budget rule as an account of risk-sensitive choice, it seems worthwhile to assess the possibility that resource budget influences key bias as distinct from altering risk preference. The present study illustrates one adequate analytic approach: Once risk-sensitive choice is found to vary with budget manipulations as predicted by the hypothesis, schedule reversals should be conducted under the same set of budgets.

The present data do not speak directly to the positive evidence that has been collected to support foraging-based theory, data that come virtually entirely from studies employ-

ing other species. It still must be acknowledged that risk sensitivity may be a species-specific feature of behavior that results from differential evolutionary pressures. On the other hand, all the positive evidence comes from studies of reinforcer-amount risk. An adequate account of extant data must accommodate (a) circumscribed evidence on budget dependence, (b) both risk aversion and, in different studies, preference for risk involving reinforcer amount, and (c) consistent preference for risk when reinforcer-delay risk is involved. This pattern of results may constitute a challenge for foraging theory and for several theories of risk preference outside the behavioral ecology tradition as well (e.g., Hamm & Shettleworth, 1987; Kahneman & Tversky, 1984; Mazur, 1984, 1989; Rachlin et al., 1986; Staddon & Reid, 1987). The modified foraging model of McNamara and Houston (1987), although perhaps coming closest to accommodating extant data, is more flexible in its predictions than other theories and has the additional limitation of treating post-reinforcement time interchangeably with reinforcer delay (see Hursh & Fantino, 1973, and Logue, Smith, & Rachlin, 1985, for contrary evidence).

In summary, although with inclusion of the present experiment there are now just two published reports, never have budget manipulations yielded positive evidence in studies of reinforcer delay. Therefore, a major factor that might account for the difference in the present results with those showing an effect of budget on risky choice is that we studied preference for variable versus fixed delays, whereas the studies reporting positive evidence involved variable versus fixed amounts. We avoided studying amount because the operant literature, at least, is so mixed in its outcome. We had thought that by using water deprivation, an effect of budget might be obtained because of the possibility that water deprivation carries a greater urgency than food deprivation. Despite manipulating budget in three ways, however, we failed to find an effect of budget. Instead, our results extend the finding that pigeons show clear preference for variable over fixed delays to water reinforcement under several budgetary conditions.

REFERENCES

- Ahearn, W., Himeline, P. N., & David, F. G. (1992). Relative preferences for various bivalued ratio schedules. *Animal Learning & Behavior*, *20*, 407-415.
- Autor, S. M. (1960). *The strength of conditioned reinforcers as a function of the frequency and probability of reinforcement*. Unpublished doctoral dissertation, Harvard University.
- Barnard, C. J., & Brown, C. A. J. (1985a). Competition affects risk-sensitivity in foraging shrews. *Behavioral Ecology and Sociobiology*, *16*, 379-382.
- Barnard, C. J., & Brown, C. A. J. (1985b). Risk-sensitive foraging in common shrews (*Sorex araneus L.*). *Behavioral Ecology and Sociobiology*, *16*, 161-164.
- Battalio, R. C., Kagel, J. H., & MacDonald, D. N. (1985). Animals' choices over uncertain outcomes: Some initial experimental results. *The American Economic Review*, *75*, 597-613.
- Caraco, T. (1981). Energy budgets, risk and foraging preference in dark-eyed juncos (*Junco hyemalis*). *Behavioral Ecology and Sociobiology*, *8*, 213-217.
- Caraco, T. (1982). Aspects of risk-aversion in foraging white-crowned sparrows. *Animal Behaviour*, *30*, 719-727.
- Caraco, T. (1983). White-crowned sparrows (*Zonotrichia leucophrys*): Foraging preferences in a risky environment. *Behavioral Ecology and Sociobiology*, *12*, 63-69.
- Caraco, T., Blanckenhorn, W. U., Gregory, G. M., Newman, J. A., Recer, G. M., & Zwicker, S. M. (1990). Risk-sensitivity: Ambient temperature affects foraging choice. *Animal Behaviour*, *39*, 338-345.
- Caraco, T. & Lima, S. L. (1985). Foraging juncos: Interaction of reward mean and variability. *Animal Behaviour*, *33*, 216-224.
- Caraco, T., Martindale, S., & Whittam, T. S. (1980). An empirical demonstration of risk-sensitive foraging preferences. *Animal Behaviour*, *28*, 820-830.
- Cicerone, R. A. (1976). Preference for mixed versus constant delay of reinforcement. *Journal of the Experimental Analysis of Behavior*, *25*, 257-261.
- Davison, M. C. (1972). Preference for mixed-interval versus fixed-interval schedules: Number of component intervals. *Journal of the Experimental Analysis of Behavior*, *17*, 169-176.
- Davison, M. C. (1982). Preference in concurrent variable-interval fixed-ratio schedules. *Journal of the Experimental Analysis of Behavior*, *37*, 81-96.
- Essock, S. M., & Reese, E. P. (1974). Preference for and effects of variable- as opposed to fixed-reinforcer duration. *Journal of the Experimental Analysis of Behavior*, *21*, 89-97.
- Fantino, E. (1967). Preference for mixed- and fixed-ratios. *Journal of the Experimental Analysis of Behavior*, *10*, 35-42.
- Fleshler, M., & Hoffman, H. S. (1962). A progression for generating variable-interval schedules. *Journal of the Experimental Analysis of Behavior*, *5*, 529-530.
- Frankel, P. W., & Vom Saal, W. (1976). Preference between fixed-interval and variable-interval schedules of reinforcement: Separate roles of temporal scaling and predictability. *Animal Learning & Behavior*, *4*, 71-76.
- Gibbon, J., Church, R. M., Fairhurst, S., & Kacelnik, A. (1988). Scalar expectancy theory and choice between delayed rewards. *Psychological Review*, *95*, 102-114.
- Gillespie, R. G., & Caraco, T. (1987). Risk-sensitive foraging strategies of two spider populations. *Ecology*, *68*, 887-899.
- Hamm, S. L., & Shettleworth, S. J. (1987). Risk aversion in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, *13*, 376-383.
- Hastjarjo, T., Silberberg, A., & Hursh, S. R. (1990). Risky choice as a function of amount and variance in food supply. *Journal of the Experimental Analysis of Behavior*, *53*, 155-161.
- Herrnstein, R. J. (1964). A periodicity as a factor in choice. *Journal of the Experimental Analysis of Behavior*, *7*, 179-182.
- Herrnstein, R. J. (1970). On the law of effect. *Journal of the Experimental Analysis of Behavior*, *13*, 243-266.
- Hill, C. W., Riopelle, A. J., & King, A. R. (1983). Protein deprivation and food-related risk-taking preferences of rhesus monkeys. *Animal Learning & Behavior*, *11*, 116-118.
- Houston, A. I. (1991). Risk-sensitive foraging theory and operant psychology. *Journal of the Experimental Analysis of Behavior*, *56*, 585-589.
- Hursh, S. R. (1980). Economic concepts for the analysis of behavior. *Journal of the Experimental Analysis of Behavior*, *34*, 219-238.
- Hursh, S. R., & Fantino, E. (1973). Relative delay of reinforcement and choice. *Journal of the Experimental Analysis of Behavior*, *19*, 437-450.
- Kagel, J. H., MacDonald, D. N., Battalio, R. C., White, S., & Green, L. (1986). Risk aversion in rats (*Rattus norvegicus*) under varying levels of resource availability. *Journal of Comparative Psychology*, *100*, 95-100.
- Kahneman, D., & Tversky, A. (1984). Choices, values, and frames. *American Psychologist*, *39*, 341-350.
- Kendall, S. B. (1987). An animal analogue of gambling. *Psychological Record*, *37*, 247-256.
- Kendall, S. B. (1989). Risk-taking behavior of pigeons in a closed economy. *Psychological Record*, *39*, 211-220.
- Killeen, P. (1968). On the measurement of reinforcement frequency in the study of preference. *Journal of the Experimental Analysis of Behavior*, *11*, 263-269.
- Leventhal, A. M., Morrell, E. F., Morgan, E. F., Jr., & Perkins, C. C. (1959). The relation between mean reward and mean reinforcement. *Journal of Experimental Psychology*, *57*, 284-287.
- Logan, F. A. (1965). Decision making by rats. *Journal of Comparative and Physiological Psychology*, *59*, 246-251.
- Logue, A. W., Smith, M. E., & Rachlin, H. (1985). Sensitivity of pigeons to preinforcer and postreinforcer delay. *Animal Learning & Behavior*, *13*, 181-186.
- Mazur, J. E. (1984). Tests of an equivalence rule for fixed and variable reinforcer delays. *Journal of Experimental Psychology: Animal Behavior Processes*, *10*, 426-436.
- Mazur, J. E. (1985). Probability and delay of reinforcement as factors in discrete-trial choice. *Journal of the Experimental Analysis of Behavior*, *43*, 341-351.
- Mazur, J. E. (1987). An adjusting schedule for studying delayed reinforcement. In M. L. Commons, J. E. Mazur, J. A. Nevin, & H. Rachlin (Eds.), *Quantitative analyses of behavior: Vol. 5. Reinforcer value: The effect of delay and intervening events* (pp. 55-73). Cambridge, MA: Ballinger.
- Mazur, J. E. (1988). Choice between small certain and large uncertain reinforcers. *Animal Learning & Behavior*, *16*, 199-205.

- Mazur, J. E. (1989). Theories of probabilistic reinforcement. *Journal of the Experimental Analysis of Behavior*, *51*, 87-99.
- Mazur, J. E. (1991). Choice with probabilistic reinforcement: Effects of delay and conditioned reinforcers. *Journal of the Experimental Analysis of Behavior*, *55*, 63-77.
- Mazur, J. E., & Romano, A. (1992). Choice with delayed and probabilistic reinforcers: Effects of variability, time between trials, and conditioned reinforcers. *Journal of the Experimental Analysis of Behavior*, *58*, 513-525.
- McNamara, J. M., & Houston, A. I. (1987). A general framework for understanding the effects of variability and interruptions on foraging behaviour. *Acta Biotheoretica*, *36*, 3-22.
- Menlove, R. L., Inden, H. M., & Madden, E. G. (1979). Preference for fixed over variable access to food. *Animal Learning & Behavior*, *7*, 499-503.
- Navarick, D. J., & Fantino, E. (1972). Transitivity as a property of choice. *Journal of the Experimental Analysis of Behavior*, *18*, 389-401.
- Navarick, D. J., & Fantino, E. (1975). Stochastic transitivity and the unidimensional control of choice. *Learning and Motivation*, *6*, 179-201.
- Pubols, B. H. (1962). Constant versus variable delay of reinforcement. *Journal of Comparative and Physiological Psychology*, *55*, 52-56.
- Rachlin, H., Logue, A. W., Gibbon, J., & Frankel, M. (1986). Cognition and behavior in studies of choice. *Psychological Review*, *93*, 33-45.
- Real, L., Ott, J., & Silverfine, E. (1982). On the tradeoff between the mean and the variance in foraging: Effect of spatial distribution and color preference. *Ecology*, *63*, 1617-1623.
- Rider, D. P. (1983). Preference for mixed versus constant delays of reinforcement: Effect of probability of the short, mixed delay. *Journal of the Experimental Analysis of Behavior*, *39*, 257-266.
- Sherman, J. A., & Thomas, J. R. (1968). Some factors controlling preference between fixed-ratio and variable-ratio schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, *11*, 689-702.
- Silberberg, A., Murray, P., Christensen, J., & Asano, T. (1988). Choice in the repeated-gambles experiment. *Journal of the Experimental Analysis of Behavior*, *50*, 187-195.
- Staddon, J. E. R., & Reid, A. K. (1987). Adaptation to reward. In A. C. Kamil, J. R. Krebs, & H. R. Pulliam (Eds.), *Foraging behavior* (pp. 497-523). New York: Plenum.
- Stubbs, A., & Pliskoff, S. S. (1969). Concurrent responding with fixed relative rate of reinforcement. *Journal of the Experimental Analysis of Behavior*, *12*, 887-896.
- Wunderle, J. M., Jr., Castro, M. S., & Fetcher, N. (1987). Risk-averse foraging by bananaquits on negative energy budgets. *Behavioral Ecology and Sociobiology*, *21*, 249-255.
- Wunderle, J. M., Jr., & O'Brien, T. G. (1985). Risk aversion in hand-reared bananaquits. *Behavioral Ecology and Sociobiology*, *17*, 371-380.
- Young, J. S. (1981). Discrete-trial choice in pigeons: Effects of reinforcer magnitude. *Journal of the Experimental Analysis of Behavior*, *35*, 23-29.
- Zabludoff, S. D., Wecker, J., & Caraco, T. (1988). Foraging choice in laboratory rats: Constant vs. variable delay. *Behavioural Processes*, *16*, 95-110.

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