

**CHOICE BETWEEN REWARDS DIFFERING
IN AMOUNT AND DELAY: TOWARD A
CHOICE MODEL OF SELF CONTROL**

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A concurrent-chain procedure was used to study pigeons' choices between rewards differing in both amount and delay. The shorter delay terminated with a 2-second access to grain whereas the longer delay terminated with a 6-second access to grain. The ratio of the delays was constant within a given condition while their absolute values were varied. Over conditions, ratios of 6:1, 3:1, and 3:2 were studied. As the absolute values of the delays to reinforcement increased, preference for the longer-delayed but larger reward decreased under both the 6:1 and 3:1 ratios, but increased under the 3:2 ratio. These results are inconsistent with choice models predicting no change in preference when the ratios of delays and amounts are held constant. In addition, the change in preference under the 3:1 ratio is inconsistent with a simple multiplicative interaction of the trade off between reinforcer amount and delay, and suggests that delay is a more potent determinant of choice than is amount. These results have implications for models that view choice between small immediate rewards and large but delayed rewards as underlying the behavior commonly called self control.

Key words: choice, self control, concurrent-chain, matching, amount, delay, key peck, pigeons

This experiment is concerned with choices between outcomes that differ both in reinforcer amount and the delay to those reinforcers. Although most studies of choice behavior have varied only one parameter (either reinforcer amount or delay) and held the other constant, few have addressed changes in choice when both variables are manipulated. Such research has implications for models that view the choice between a small immediate reward and a large but delayed reward as underlying the behavior commonly referred to as self control. We will defer discussion of that topic until the end of the paper.

In a study on the effect of delay of reinforcement on choice, Chung and Herrnstein (1967) had pigeons choose between two equal, concurrently available, variable-interval schedules that varied in the duration of blackout (delay) imposed before reinforcer delivery.

They observed matching of relative rate of response for a given alternative to the relative immediacy of reinforcement provided by that alternative. That is, the pigeons distributed their responses in inverse proportion to the relative delays of reinforcement. The study provided evidence for delay of reinforcement as a parameter similar to rate of reinforcement in its effects on the distribution of responses. That is:

$$\frac{R_1}{R_1 + R_2} = \frac{d_2}{d_1 + d_2} \tag{1a}$$

$$= \frac{r_1}{r_1 + r_2} \tag{1b}$$

where R_1 and R_2 are responses to the two alternatives, d_1 and d_2 are the delays to the outcomes, and r_1 and r_2 are the rates of reinforcement in the two alternatives. The matching law can also be represented as simple ratios:

$$\frac{R_1}{R_2} = \frac{d_2}{d_1} \tag{2a}$$

$$= \frac{r_1}{r_2} \tag{2b}$$

Results inconsistent with matching have been obtained in studies of delay of reinforcement

Supported by NIMH grant 1 RO 3 MH32655-01 and Sigma Xi Grant-in-Aid of Research to Leonard Green. Our thanks to the members of our lab group for their outstanding assistance in the running of the experiment. Mark Snyderman is now at the Department of Psychology and Social Relations, Harvard University. Reprints may be obtained from Leonard Green, Department of Psychology, Washington University, St. Louis, Missouri 63130.

ment using a concurrent-chain procedure involving choice between different terminal-link fixed intervals (FI) (Herrnstein, 1964; Killeen, 1970; MacEwen, 1972; Williams & Fantino, 1978). In particular, MacEwen (1972) found that with a constant ratio between the FI schedules, preference for the key associated with the shorter terminal link increased with increasing absolute FI values. The matching law based on the ratio measure predicts constant preference at all FI values as long as the ratio of the FI values remains constant.

Many of the results from concurrent-chain studies can be accounted for by a model proposed by Fantino (1969):

$$\frac{R_1}{R_1 + R_2} = \frac{T - t_1}{(T - t_1) + (T - t_2)} \quad (3)$$

(when $t_1 < T, t_2 < T$)

= 0 (when $t_1 > T, t_2 < T$)

= 1 (when $t_2 > T, t_1 < T$)

where R_1 and R_2 are responses on the two alternatives during the initial link, T is the average time to primary reinforcement from the onset of the initial link, and t_1 and t_2 are the two terminal-link intervals. Preference is thus determined by the reduction in delay to primary reinforcement signaled by entry into one terminal link relative to the reduction in delay to primary reinforcement signaled by entry into the alternative terminal link. In the MacEwen (1972) study, the average time from onset of the initial link to entry into a terminal link was constant. Therefore, the relative reduction in delay provided by the shorter terminal link increased with the absolute value of the FI schedules even though the ratio of terminal-link FI's remained constant. In addition, Equation 3 appears consistent with the data from Chung and Herrnstein (1969). A reanalysis of their data revealed that preference for the key associated with the shorter delay increased, the greater the absolute value of the delays (Williams & Fantino, 1978).

The matching law is better able to account for data from studies on choice and reinforcer amount. Catania (1963) found that pigeons matched their relative rate of response to the relative duration of reinforcement. With both concurrent and concurrent-chain schedules, both matching (Brownstein, 1971; Iglauer & Woods, 1974; Neuringer, 1967; Schwartz, 1969;

Ten Eyck, 1970) and undermatching (Pliskoff & Hawkins, 1967; Schneider, 1973; Todorov, 1973; Walker & Hurwitz, 1971; Walker, Schnelle & Hurwitz, 1970) to reinforcer amount have been obtained. In undermatching, preference for the alternative leading to the larger reinforcer is less than predicted by matching.

Such undermatching is handled by Baum's (1974) generalized power-ratio matching analysis (applied to reinforcer amount):

$$\frac{R_1}{R_2} = k \left(\frac{a_1}{a_2} \right)^x \quad (4)$$

where R_1 and R_2 are responses, a_1 and a_2 are reinforcer amounts delivered in the two alternatives, and k is a measure of bias. A k value other than 1.0 indicates preference for one alternative when apparent equality of reinforcement would lead to a prediction of indifference. x is the slope of the line relating log response ratio to log amount ratio. $x = 1$ represents perfect matching while $x < 1$ corresponds to undermatching, a common finding in choice studies with reinforcer amount.

Of greater interest, however, are the effects that variations in both delay and reinforcer amount have on choice behavior. Scant attention has been paid to this area of research (Logan, 1965; Logan & Spanier, 1970; Navarick & Fantino, 1975, 1976; Rachlin & Green, 1972; Green, Fisher, Perlow, & Sherman, Note 1). Rachlin and Green (1972) adopted a matching model to account for choice when both variables are manipulated. Reinforcer delay and amount were assumed to contribute equally to the "value" of the reinforcer in much the same way as rate of reinforcement does under the matching law. That is,

$$\frac{V_1}{V_2} = \left(\frac{d_2}{d_1} \right) \cdot \left(\frac{a_1}{a_2} \right) = \frac{R_1}{R_2} \quad (5)$$

where V is the value of an alternative, d is the delay of reinforcement, a is reinforcer amount, and R is the number of responses to that alternative. Preference is inversely related to the ratio of reinforcer delays and directly proportional to the ratio of amounts, and is unaffected by the absolute values of these parameters.

Navarick and Fantino (1976) tested Equation 5 in two experiments using pigeons responding under a concurrent-chain procedure with FI terminal links. In both experiments the initial links were equal variable-interval

(VI) schedules, and the amount of reward provided by one terminal link was three times more than in the other terminal link ($a_1/a_2 = 3$). In their first experiment, the terminal-link FI schedules were increased in absolute value while a constant difference of 10 sec was maintained between them. The longer-delay alternative was always associated with the larger reinforcer amount. d_2/d_1 thus approached 1.0 as the absolute value of the delays increased. As predicted by Equation 5, preference for the key associated with the larger reinforcer amount tended to increase somewhat with absolute delay.

In their Experiment 2, the delays to reinforcement were equal in the terminal links ($d_2/d_1 = 1.0$), but the absolute value of these delays was increased. Here Equation 5 predicts a constant preference, in the ratio of a_1/a_2 , for the key associated with the larger reinforcer amount. However, Navarick and Fantino found that preference for the larger amount terminal link increased with the absolute value of the delays.

If delay and amount of reinforcement for each terminal link are converted to terminal-link seconds per unit-time access to food, these new values can be substituted for t_1 and t_2 in Equation 3, on the assumption that delay and amount combine multiplicatively and are equivalent in their effects upon choice. After the appropriate conversions, Equation 3 predicts the observed increase in preference for the key leading to the larger reinforcer amount.¹

Navarick and Fantino (1976) varied absolute delays of reinforcement while keeping the delay ratio constant at 1.0. Equations 3 and 5 make quite different predictions if the delay ratio is other than unity. The present experiment utilized a concurrent-chain procedure with equal variable-interval (VI) initial links and varied the FI terminal links. The ratio of reinforcer amount was held constant throughout at 3:1 as in Navarick and Fantino (1976); the absolute delays to reinforcement were varied while delay *ratio* was held constant at 6:1, 3:2, or 3:1.

Under a 6:1 delay ratio, Equation 5 predicts

that the pigeons will prefer the smaller reward twice as much as the more delayed, greater reward, and that this preference will remain constant as the absolute delays are varied. Equation 3 predicts that preference for the key associated with the longer delay will decrease as the delays increase.

Under a 3:2 delay ratio, Equation 5 now predicts a preference for the larger reward which does not change as delays are changed, while Equation 3 predicts increasing preference for the larger delay as the delays increase.

Both models make identical predictions for responding under a 3:1 delay ratio. The Rachlin-Green formula predicts indifference (relative rate = .50) between the two outcomes. After the appropriate conversions, Equation 3 also predicts indifference at all delays.

METHOD

Subjects

Eight male, White Carneaux pigeons were maintained at 80% of their free-feeding body weights. All had previously served as subjects in an autoshaping experiment (Green & Schweitzer, 1980). Water and grit were continuously available in their home cages. Four were studied at 6:1 and 3:2 delay ratios and a different four at the 3:1 ratio.

Apparatus

A sound-insulated, pigeon test chamber (Gerbrands Co.) measured 36.2 cm long by 33.7 cm wide by 40.6 cm high. The two response keys were 1.9 cm in diameter, 8.9 cm from each side wall, and 21.6 cm from the grid floor. Each key could be rear-illuminated with white, red, or green light, and required a force of at least 10 g (.10 N) to operate and produce a feedback click. General chamber illumination was provided by two 7-W white lights mounted on the ceiling. The reinforcer was limited access to mixed grain via a food hopper situated between and below the response keys. During reinforcement, all lights in the chamber were extinguished, and the food hopper was elevated and lighted by two 7-W white bulbs. White noise was continuously present and an exhaust fan provided ventilation. All scheduling and recording were performed by electromechanical equipment located in an adjoining room.

¹It can be seen that this experiment has now become equivalent to MacEwen's (1972). The converted terminal-link delays differ by a constant ratio of 3:1 as the absolute values of the delays increase.

Procedure

A concurrent-chain procedure with variable-interval 1-min initial-link schedules and various fixed-interval terminal-link schedules was used. During the initial choice link, both response keys were transilluminated with white light and entrance into the terminal links was arranged by two independent VI timers on a concurrent variable-interval 1-min variable-interval 1-min schedule (*conc* VI 1-min VI 1-min). The intervals were derived from the distribution of Fleshler and Hoffman (1962). When entrance into one of the mutually exclusive terminal links was scheduled by either VI timer, it stopped, but the other VI timer continued to operate. The next response on the appropriate key produced the terminal-link stimulus (either red or green illumination) associated with that key, and the other key was darkened and inoperative. Further responding on the lighted key produced the reinforcer according to the requirements of the FI schedule. During a terminal link, both VI timers stopped. The relative rate of responding on the two initial-link keys was the measure of preference for the terminal-link outcomes.

Food was delivered in the terminal links according to various fixed-interval schedules. The terminal links differed with respect to the fixed-interval schedule and the duration of access to food. At the end of the food-delivery period, the initial-link keys were both reilluminated with white light and both VI timers resumed operation. If, however, both VI timers had programmed entrance into their respective terminal links, the terminal link not entered remained available upon return to the initial link.

Sessions were conducted seven days a week, with each session lasting until 40 food reinforcers were obtained. Each bird remained in an experimental condition until the following stability criteria were attained: (a) the bird was on the condition for at least 30 days; (b) median relative rates of responding for the last three successive blocks of five sessions each showed neither an upward nor a downward trend; and (c) there was no visible trend in either relative or absolute rates of responding during the final five days.

The absolute delays of reinforcement (FI schedules in the terminal links) were varied

while the ratio of the delay values remained constant within an experimental condition. Two different reinforcer durations were used, 2-sec and 6-sec access to food, with the longer hopper duration associated with the greater FI delay. Tables 1, 2, and 3 summarize the conditions and their order of presentation.

Experimental Conditions

Condition 6:1: The FI values were in the ratio 6:1. The actual pairs of FI values were: 12 vs. 2 sec, 24 vs. 4 sec, 60 vs. 10 sec, and 120 vs. 20 sec. Birds 23, 24, 25, and 26 were each studied on at least three of these pairs. For Birds 23 and 24, the left terminal link was signaled by a green keylight and the right terminal link by a red keylight. The reverse was true for Birds 25 and 26.

Condition 3:1: The FI values were in the ratio of 3:1, and the actual values were: 6 vs. 2 sec, 30 vs. 10 sec, 60 vs. 20 sec, and 120 vs. 40 sec. Birds 10, 15, 27, and 28 were each studied on at least three of these pairs. The key was green during the left terminal link and red during the right terminal link.

Condition 3:2: The pairs of FI delays were in a 3:2 ratio. The actual pairs of FI values were: 6 vs. 4 sec, 30 vs. 20 sec, 60 vs. 40 sec, and 120 vs. 80 sec. Birds 23, 24, 25, and 26 were each also studied on at least three of these pairs. For Birds 23 and 24, red and green keylights signaled the left and right terminal links, respectively, whereas the reverse held for Birds 25 and 26.

Preliminary Conditions

Prior to these experimental conditions, there were two preliminary conditions. In the first, birds chose between equal hopper durations (2 sec) and equal FI's in the terminal links (Condition 6:1: FI 2-sec vs. FI 2-sec; Condition 3:1: FI 2-sec vs. FI 2-sec; Condition 3:2: FI 4-sec vs. FI 4-sec). This tested key bias.

In the second preliminary condition, the length of the FI in the preferred terminal link was increased to the appropriate delay ratio while food duration remained constant at 2 sec for each link. Thus, for Condition 6:1, the pigeons now chose between FI 12-sec and FI 2-sec; for Condition 3:1, FI 6-sec vs. FI 2-sec; and for Condition 3:2, FI 6-sec vs. FI 4-sec. This determined whether the birds could discriminate the smallest programmed difference between the FI's in the terminal links.

All pigeons showed an appropriate increase in preference for the terminal link associated with the shorter delay.

Following this determination, hopper duration was increased to 6-sec in the terminal link associated with the longer FI (hopper duration remained at 2 sec in the other link). Although this was the first experimental condition, it also determined whether the birds could discriminate the difference in reinforcer durations (2 sec vs. 6 sec). All birds showed an increased preference for the terminal link now associated with the 6-sec reinforcer duration.

RESULTS

Absolute and relative response rates in the initial link as well as terminal-link response rates for each pigeon are given in Tables 1 (6:1 delay ratio), 2 (3:1 delay ratio), and 3 (3:2 delay ratio). These data are means from the last 5 sessions of each condition. Also presented are the programmed FI's and the obtained mean delays to reinforcement in each terminal link (average time from entry into the terminal link until the reinforced response). Although these values are generally greater than the programmed FI's, the actual delay ratios did not differ by more than 5% from the programmed ratios.

Figure 1 shows the relative rate of response during the initial link (proportion of responses on the initial-link key leading to the longer terminal link) as a function of the FI's in the terminal links for each bird in the three delay-ratio conditions.

In the first preliminary condition, the FI's in both terminal links were equal, as was the duration of access to grain (2 sec). The relative initial-link response rate was near indifference (.50) in 9 of 12 cases. Although 3 birds did display bias, there was no consistency in key preferred (Birds 26 and 27 preferred the left key; Bird 10 preferred the right key). Under the second preliminary condition, an increase in delay to reinforcement associated with the key preferred in the first preliminary condition decreased preference for that key for all birds. The magnitude of preference change varied from .063 to .390. The greatest decreases in preference occurred for birds under the 6:1 delay ratio. There was no apparent difference in the amount of decrease between birds in the 3:1 and those in the 3:2 delay-

ratio conditions. Clearly, all subjects were sensitive to the smallest difference in delays to reinforcement.

Sensitivity to differential reinforcer amounts was demonstrated under the first experimental condition. Delay to reinforcement remained as in the previous condition, but access to grain was increased from 2 sec to 6 sec for the key

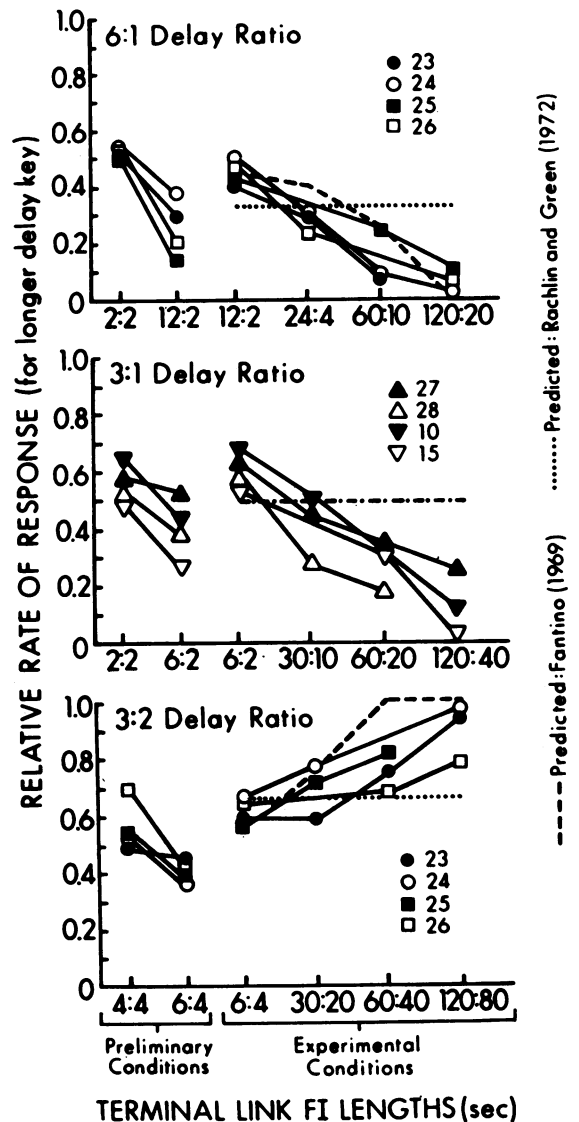


Fig. 1. Relative rate of response for the longer terminal link as a function of the duration of the terminal links for each bird under each delay ratio. Predictions from Rachlin and Green (1972) and Fantino (1969) are represented by dotted and dashed lines, respectively. (Both models make the same predictions under the 3:1 delay ratio, represented by the alternating dot-dash line.)

..... Predicted: Rachlin and Green (1972)
 - - - - - Predicted: Fantino (1969)

Table 1

Results from the 6:1 delay ratio for each pigeon. The obtained durations of the terminal links are presented along with the programmed FI. Initial-link and terminal-link response rates (responses/min) are the means from the last 5 sessions of each condition. Standard deviations are in parentheses. The order in which each pigeon experienced the conditions and the number of sessions for each are presented.

Bird ^a	Order	No. of sessions	6:1 Delay Ratio											
			Programmed term. link FI (sec)		Mean obtained term. link length (sec)		Sec. access to grain		Initial link resp. rate		Relative resp. rate ^b		Term. link resp. rate	
			left	right	left	right	left	right	left	right	left	right	left	right
23	1	35	2.0	2.0	2.23	2.29	2	2	20.93 (2.69)	23.21 (2.21)	.53 (.01)	217.08 (10.42)	184.10 (12.98)	
	2	30	2.0	12.0	2.17	12.45	2	2	30.38 (2.31)	13.01 (1.25)	.30 (.01)	217.68 (6.43)	61.69 (6.14)	
	3	75	2.0	12.0	2.21	12.45	2	6	24.13 (2.50)	16.29 (1.91)	.40 (.04)	211.19 (7.85)	41.17 (3.75)	
	5	30	4.0	24.0	4.18	24.79	2	6	28.00 (2.80)	12.31 (2.79)	.30 (.03)	117.72 (24.08)	38.20 (4.35)	
24	4	40	10.0	60.0	10.73	60.18	2	6	26.71 (12.32)	2.35 (1.73)	.08 (.03)	79.30 (6.12)	41.84 (6.12)	
	1	54	2.0	2.0	2.21	2.19	2	2	25.03 (.45)	22.83 (2.16)	.54 (.04)	225.17 (15.27)	236.69 (2.99)	
	2	38	12.0	2.0	12.35	2.11	2	2	16.85 (1.67)	27.34 (3.65)	.38 (.01)	60.30 (10.69)	237.38 (7.48)	
	3	34	12.0	2.0	12.40	2.11	6	2	21.77 (1.69)	22.01 (2.41)	.50 (.02)	72.55 (4.99)	248.07 (2.90)	
25	6	30	24.0	4.0	24.19	4.25	6	2	20.69 (1.16)	46.56 (2.92)	.31 (.02)	76.35 (6.48)	190.59 (6.22)	
	5	33	60.0	10.0	60.61	10.70	6	2	4.99 (.75)	52.87 (4.60)	.09 (.02)	35.43 (2.24)	57.96 (13.76)	
	4	30	120.0	20.0	123.08	20.91	6	2	.88 (.35)	31.13 (4.80)	.03 (.01)	32.25 (3.90)	30.50 (7.38)	
	1	30	2.0	2.0	2.19	2.16	2	2	19.07 (1.27)	18.25 (.79)	.51 (.02)	184.01 (13.35)	234.97 (13.35)	
26	2	30	12.0	2.0	12.27	2.26	2	2	3.90 (.91)	22.90 (1.02)	.15 (.03)	82.37 (4.84)	116.89 (11.28)	
	3	31	12.0	2.0	12.32	2.17	6	2	12.93 (3.60)	17.16 (.82)	.43 (.02)	80.58 (6.41)	149.25 (20.79)	
	5	30	60.0	10.0	60.24	9.92	6	2	6.65 (1.21)	20.64 (2.13)	.25 (.05)	52.99 (6.78)	82.25 (5.90)	
	4	38	120.0	20.0	122.70	19.80	6	2	2.60 (.84)	23.02 (2.71)	.10 (.02)	53.45 (3.92)	65.71 (9.72)	
26	1	30	2.0	2.0	2.14	2.17	2	2	28.85 (1.75)	24.90 (1.01)	.54 (.01)	242.05 (7.76)	195.41 (2.24)	
	2	36	12.0	2.0	12.24	2.16	2	2	9.17 (1.55)	34.13 (1.46)	.21 (.03)	69.17 (7.35)	224.45 (8.46)	
	3	30	12.0	2.0	12.22	2.17	6	2	21.77 (2.66)	24.62 (1.39)	.47 (.02)	81.52 (10.36)	236.39 (8.31)	
	4	34	24.0	4.0	24.49	4.18	6	2	7.40 (1.88)	23.19 (3.27)	.24 (.05)	51.64 (9.82)	187.54 (4.83)	
	5	30	120.0	20.0	123.71	20.69	6	2	2.08 (.67)	28.41 (3.85)	.07 (.03)	32.17 (.75)	36.79 (3.81)	

^aFor Birds 23 and 24, the left terminal-link key was green and the right terminal-link key was red. The reverse held for Birds 25 and 26.

^bRelative rate of response for the longer delay terminal-link.

Table 2
Results from the 3:1 Delay Ratio for Each Pigeon. (Details Same as for Table 1.)

Bird ^a	Order	No. of sessions	Programmed term.		Mean obtained term.		3:1 Delay Ratio		Initial link		Relative		Term. link	
			link FI (sec)		link length (sec)		Sec. access to grain		resp. rate		resp. rate ^b		resp. rate	
			left	right	left	right	left	right	left	right	left	right	left	right
27	1	44	2.0	2.0	2.26	2.34	2	2	26.60 (1.54)	18.45 (1.51)	.58 (.02)	169.48 (15.44)	181.20 (16.25)	
	2	50	6.0	2.0	6.26	2.64	2	2	37.27 (4.03)	34.51 (2.21)	.52 (.03)	90.74 (4.80)	136.81 (11.92)	
	3	31	6.0	2.0	6.30	2.37	6	2	36.68 (1.47)	21.60 (1.31)	.63 (.01)	76.48 (2.82)	157.44 (2.24)	
	6	37	30.0	10.0	30.93	10.05	6	2	26.95 (2.46)	32.56 (2.61)	.45 (.01)	39.64 (5.54)	126.48 (12.77)	
	4	30	60.0	20.0	60.06	20.34	6	2	20.25 (11.57)	29.63 (3.85)	.35 (.06)	36.88 (7.64)	48.18 (13.88)	
28	5	30	120.0	40.0	120.72	40.34	6	2	15.02 (7.30)	41.10 (4.03)	.26 (.09)	32.07 (9.75)	59.83 (10.64)	
	1	61	2.0	2.0	2.27	2.33	2	2	43.01 (1.06)	40.08 (1.27)	.52 (.01)	190.01 (4.03)	215.12 (10.65)	
	2	32	6.0	2.0	6.22	2.28	2	2	40.59 (6.00)	65.21 (3.13)	.38 (.04)	165.87 (7.00)	239.55 (9.46)	
	3	39	6.0	2.0	6.23	2.32	6	2	52.37 (3.62)	41.83 (4.07)	.58 (.05)	178.09 (2.81)	224.39 (23.85)	
	5	38	30.0	10.0	30.61	10.00	6	2	22.42 (3.69)	59.71 (10.99)	.28 (.06)	122.73 (12.37)	180.22 (16.11)	
10	4	31	60.0	20.0	59.41	20.55	6	2	16.14 (3.39)	73.50 (8.63)	.18 (.04)	93.12 (10.65)	144.37 (13.58)	
	1	55	2.0	2.0	2.18	2.21	2	2	25.42 (.79)	45.51 (2.67)	.64 (.02)	220.35 (2.52)	187.51 (3.72)	
	2	59	2.0	6.0	2.22	6.42	2	2	26.70 (1.91)	20.67 (.93)	.44 (.01)	206.00 (6.78)	100.88 (9.31)	
	3	30	2.0	6.0	2.41	6.98	2	6	16.74 (1.62)	34.83 (3.90)	.68 (.01)	183.06 (13.76)	53.53 (24.08)	
	4	30	10.0	30.0	10.34	32.43	2	6	22.03 (2.70)	23.02 (1.79)	.51 (.02)	83.14 (4.53)	31.95 (3.50)	
15	5	30	40.0	120.0	40.54	120.72	2	6	13.96 (2.83)	1.84 (.43)	.12 (.04)	38.79 (11.30)	22.26 (4.23)	
	1	45	2.0	2.0	2.47	2.50	2	2	30.85 (5.12)	32.94 (5.47)	.48 (.06)	128.86 (22.84)	133.11 (31.13)	
	2	30	6.0	2.0	6.18	2.17	2	2	22.74 (1.91)	61.22 (3.29)	.27 (.03)	160.22 (12.03)	293.07 (32.84)	
	3	30	6.0	2.0	6.31	2.22	6	2	43.01 (3.41)	38.50 (4.81)	.53 (.02)	173.46 (26.88)	243.64 (33.32)	
	4	37	60.0	20.0	60.36	20.91	6	2	28.28 (1.53)	62.70 (4.62)	.31 (.02)	71.93 (13.20)	77.56 (14.64)	
5	39	120.0	40.0	121.95	40.54	6	2	2.79 (.65)	99.91 (6.09)	.03 (.01)	34.83 (6.18)	84.51 (9.37)		

^aLeft terminal-link key was green; right terminal-link key was red.
^bRelative rate of response for the longer delay terminal-link.

Table 3
Results from the 3:2 Delay Ratio for Each Pigeon. (Details Same as for Table 1.)

Bird ^a	Order	No. of sessions	Programmed term. link FI (sec)		Mean obtained term. link length (sec)		Sec. access to grain		Initial link resp. rate		Relative resp. rate ^b		Term. link resp. rate	
			left	right	left	right	left	right	left	right	left	right	left	right
23	1	31	4.0	4.0	4.33	4.47	2	2	22.70 (3.13)	22.10 (5.49)	.51 (.04)	83.51 (4.49)	86.92 (7.67)	
	2	31	6.0	4.0	6.26	4.26	2	2	20.40 (3.57)	24.92 (4.73)	.45 (.01)	78.28 (9.46)	68.55 (3.94)	
	3	35	6.0	4.0	6.24	4.70	6	2	29.68 (1.94)	19.56 (1.97)	.60 (.01)	64.91 (10.33)	57.34 (18.58)	
	4	38	30.0	20.0	30.30	20.41	6	2	27.52 (5.05)	19.28 (2.02)	.59 (.04)	58.49 (4.74)	47.51 (5.16)	
	6	30	60.0	40.0	60.73	40.82	6	2	17.57 (3.41)	5.89 (1.11)	.75 (.02)	40.12 (4.03)	40.25 (3.70)	
24	5	31	120.0	80.0	117.34	82.34	6	2	26.25 (8.98)	1.61 (.67)	.94 (.02)	62.01 (2.74)	30.75 (6.22)	
	1	30	4.0	4.0	4.14	4.14	2	2	31.06 (1.19)	28.54 (3.31)	.52 (.03)	234.63 (2.08)	166.20 (9.98)	
	2	36	6.0	4.0	6.26	4.29	2	2	23.20 (1.16)	39.13 (3.47)	.37 (.02)	126.36 (19.35)	161.80 (10.35)	
	3	30	6.0	4.0	6.15	4.50	6	2	33.37 (2.51)	21.41 (9.88)	.66 (.03)	118.97 (11.05)	116.90 (9.73)	
	5	30	30.0	20.0	30.46	20.83	6	2	33.70 (4.65)	10.07 (2.99)	.77 (.05)	34.79 (6.14)	30.42 (6.31)	
25	4	49	120.0	80.0	117.42	82.08	6	2	36.46 (7.62)	0.90 (.15)	.98 (.01)	37.95 (3.75)	14.29 (2.67)	
	1	35	4.0	4.0	4.18	4.19	2	2	18.70 (1.74)	15.84 (1.43)	.54 (.01)	172.84 (10.65)	192.16 (3.13)	
	2	36	6.0	4.0	6.21	4.23	2	2	17.12 (.95)	25.29 (1.84)	.40 (.02)	136.43 (7.53)	165.97 (4.42)	
	3	58	6.0	4.0	6.30	4.23	6	2	18.81 (1.83)	14.14 (.80)	.57 (.02)	134.59 (9.73)	147.06 (9.62)	
	4	35	30.0	20.0	30.77	20.83	6	2	14.63 (1.42)	5.69 (.46)	.72 (.01)	27.97 (2.91)	33.45 (4.62)	
26	5	41	60.0	40.0	60.61	40.54	6	2	29.00 (2.25)	6.21 (.42)	.82 (.01)	23.86 (1.61)	30.66 (4.39)	
	1	65	4.0	4.0	4.23	4.19	2	2	36.83 (2.76)	16.18 (.91)	.69 (.01)	174.05 (10.15)	201.03 (8.50)	
	2	54	6.0	4.0	6.45	4.33	2	2	16.32 (1.79)	20.55 (2.60)	.44 (.03)	104.95 (10.13)	111.80 (18.38)	
	3	32	6.0	4.0	6.24	4.45	6	2	23.24 (2.07)	12.15 (.75)	.66 (.02)	114.49 (9.32)	93.19 (14.21)	
	4	31	60.0	40.0	60.79	41.10	6	2	19.35 (3.67)	8.82 (1.01)	.68 (.02)	26.70 (1.47)	25.03 (2.56)	
26	5	30	120.0	80.0	121.70	80.65	6	2	16.07 (2.89)	4.22 (1.07)	.79 (.06)	25.67 (4.51)	22.87 (4.04)	

^aFor Birds 23 and 24, the left terminal-link key was red and the right terminal-link key was green. The reverse held for Birds 25 and 26.
^bRelative rate of response for the longer delay terminal-link.

associated with the longer delay. Once again, there were large changes in relative rates of response for all subjects: preference increased for the longer delay key, which now provided longer access to food. The magnitude of the preference change varied from .108 to .304. The pattern of relative response rates within the remaining conditions under each delay ratio was highly consistent among birds. As the delays to reinforcement in the terminal links increased, the relative rate of response in the initial link on the key associated with the longer delay decreased under both the 6:1 and 3:1 ratios, but increased under the 3:2 ratio condition.

Differential delay and amount of reinforcement appear primarily to have affected relative response rates, as examination of the overall absolute initial-link response rates reveals no systematic variation across conditions. However, response rates in each of the terminal links tended to decrease as the delay increased. In addition, terminal-link response rates tended to be higher for the smaller of the pair of delays under the 6:1 and 3:1 ratios, while it was higher for the larger of the pair of delays under the 3:2 ratio. This is consistent with the preference functions.

DISCUSSION

Relative response rates in the initial links agreed more with Fantino's (1969) model than with Rachlin and Green's (1972). The broken lines in Figure 1 are the relative response rates for the longer-delay key predicted by these two formulations. Both the decrease in relative rate under the 6:1 delay ratio, and the increase under the 3:2 delay ratio with increasing terminal-link delays are predicted by Fantino (1969). Rachlin and Green (1972) predict a constant preference with increasing terminal-link length when the ratio is held constant. Choice is clearly more than simply a function of the ratios of amount and delay of reinforcement.

Although the Fantino (1969) predictions fairly well describe the data on 6:1 and 3:2 ratios, they are, however, only one of a number of possible predictions from Equation 3. The different predictions arise because there are various ways to convert delay and amount of reinforcement to a single variable for use in Equation 3. Remember that Equation 3

deals only with terminal-link delay. Navarick and Fantino (1976) proposed converting delay and amount to a single measure of delay by calculating terminal-link seconds per some-unit access to food (assuming a simple multiplicative interaction between delay and amount). The predicted points in Figure 1 were obtained using estimates of terminal-link time per 6-sec access to food. Clearly, any unit could be chosen as the standard access to food, yielding different terminal-link delay estimates and different predictions from Equation 3. While all the possibilities predict the same general trend in relative rates, the points presented most closely fit the data. Unfortunately, there is no way to determine a priori which conversion will succeed best.

Regardless of the conversion chosen, neither Fantino (1969) nor Rachlin and Green (1972) predicts the data for the 3:1 delay ratio. Since the delay ratio is equal and opposite to the ratio of reinforcer amounts, both models predict constant indifference (relative rate = .50) at all experimental values. Clearly, this was not the case. There was, in fact, a marked decrease in preference for the key associated with the longer delay as the delays increased. Apparently, the effects of the 3:1 delay ratio were greater than those of the counterbalancing changes in reinforcer amounts.

One can eliminate the possibility that a difference between programmed and obtained amounts of reward are responsible for the discrepancy observed under the 3:1 ratio. Reinforcer amount was measured in terms of duration of hopper elevation. There is a brief period from the onset of hopper elevation until the pigeon begins eating during which no food is being obtained. Assuming that this period is reasonably constant for both hopper durations, the obtained ratio of longer hopper duration to shorter would actually be larger than programmed. Fantino's (1969) equation would thus predict increased preference for the longer delay rather than the decreased preference observed for the 3:1 condition.

A possible problem with the present design concerns the interaction between preference and rate of reinforcement. This interaction may have exaggerated the effects observed under all delay ratios, particularly when preference was extreme. Because the two initial-link VI schedules were independent, obtained relative rate of reinforcement could vary with

relative rate of response. Any increase in relative rate for an already-preferred key could thus act to increase preference further. However, the interaction between response and reinforcement rate can only serve to heighten an effect; it cannot create a preference. Preferences might not be as extreme if relative rate of reinforcement is held constant at .50. In the present experiment, however, birds entered the two terminal links about equally often, and so relative entries into the terminal links rarely deviated from .50. In addition, the present study suffers from a difficulty common to most of the research in this area. The shorter delay alternative, in addition to providing more immediate access to food, also returns the subject to the initial link sooner than the long delay alternative. This serves to increase the rate of reinforcement for the shorter delay key. Imposing a blackout following food delivery from the shorter delay alternative so that both alternatives lead to the same amount of time away from the initial link may eliminate this confound. When Gentry and Marr (1980) essentially replicated MacEwen's (1972) study using blackouts as suggested, they also found a preference for the shorter delay alternative, but no consistent pattern of preference change was obtained as absolute delay values increased. If these results are supported in other studies utilizing postreinforcement blackouts, a critical reappraisal of the entire area of research involving choice and delay of reinforcement may be in order.

Nevertheless, the general trends in the present data remain and results from the 3:1 delay ratio indicate that delay of reinforcement is a more potent determinant of choice than is reinforcer amount. This conclusion is consistent with results from earlier studies of choice between various terminal-link FI schedules (Davison, 1969; Duncan & Fantino, 1970; Herrnstein, 1964; Killeen, 1970). In all cases, preference for the shorter terminal link was greater than predicted by matching. These results, along with the frequent finding of undermatching to reinforcer amount (Schneider, 1973; Todorov, 1973; Walker & Hurwitz, 1971; Walker, Schnelle & Hurwitz, 1970; Snyderman & Green, Note 2), provide a strong argument against the assumption that delay and amount of reinforcement are equivalent in their effects upon choice.

The differential effects of delay and amount

of reinforcement on choice behavior may be analyzed in Baum's (1979) terms as follows:

$$\frac{R_1}{R_2} = k \left(\frac{a_1}{a_2} \right)^x \cdot \left(\frac{d_2}{d_1} \right)^y \quad (6)$$

where x and y serve as measures of the potencies of delay and amount of reinforcement as determinants of choice. Equation 6 is similar to Rachlin and Green's (1972) analysis in that it uses ratios, and would therefore be inadequate in accounting for the present data. However, the ratio of the exponents, x/y , provides a measure of the relative effects of delay and amount of reinforcement on choice.

This measure may be used in converting delay and amount to a single variable for use in Equation 3. Previously, the conversion could be made by simply multiplying the smaller delay value, d_2 , by the ratio of amounts of reinforcement, a_1/a_2 . This value, along with the other programmed delay values, was then used as t_1 and t_2 in Equation 3. With the new measure of relative potency, d_2 is multiplied by $(a_1/a_2)^{x/y}$. If delay of reinforcement is a more potent determinant of choice than is amount, $(a_1/a_2)^{x/y}$ will be less than a_1/a_2 . This conversion leads to a prediction of greater preference for the shorter delay than would an assumption of equivalent potency.

Table 4 presents the mean absolute deviations between the obtained data and the predictions from Rachlin and Green (1972), Fantino (1969) and that of the present transformation. The closest fit to the data points was obtained using an x/y value of .67. This is equivalent to exponents of 1 for amount of reinforcement and 1.5 for delay. Examination of the table reveals that this transformation more accurately predicts the present results than either Equation 3 or Equation 5, particularly under the 3:1 delay ratio.

Unfortunately, while the proposed analysis provides a good *ex post facto* description of behavior, too little is known about the relevant variables to allow accurate preexperimental predictions. In addition to the previously mentioned difficulty with multiple conversion methods, there appears to be no consistent agreement on the values of the exponents x and y . Davison (1969) used a cubic transformation of delay values to obtain matching, while Killeen (1970) used an exponent of 2.5. Killeen noted that his exponent was probably lower than Davison's because he did not use a

Table 4

Average absolute deviations of the obtained from predicted data points for each condition.

Terminal link FI (secs)	(Predicted value) and average absolute deviation			Power transformation ($x/y = .67$)		
	Rachlin-Green (1972)	Fantino (1969)				
<i>6:1 delay ratio</i>						
12:2	(.33)	.12	(.45)	.04	(.44)	.04
24:4	(.33)	.05	(.40)	.12	(.37)	.09
60:10	(.33)	.19	(.25)	.11	(.15)	.08
120:20	(.33)	.26	(.00)	.07	(.00)	.07
\bar{X} deviation from predicted =		.155		.085		.070
<i>3:2 delay ratio</i>						
6:4	(.67)	.05	(.55)	.07	(.52)	.10
30:20	(.67)	.08	(.75)	.07	(.60)	.10
60:40	(.67)	.08	(1.00)	.25	(.69)	.07
120:80	(.67)	.23	(1.00)	.10	(.89)	.08
\bar{X} deviation from predicted =		.110		.123		.088
<i>3:1 delay ratio</i>						
6:2	(.50)	.11	(.50)	.11	(.49)	.12
30:10	(.50)	.09	(.50)	.09	(.42)	.09
60:20	(.50)	.22	(.50)	.22	(.35)	.07
120:40	(.50)	.36	(.50)	.36	(.19)	.10
\bar{X} deviation from predicted =		.195		.195		.095

COD. However, Herrnstein (1964) did not use a COD, and an analysis of his data on choice between two unequal FI terminal links indicates an exponent between 1.5 and 2.0 to be an appropriate transformation. Finally, while Duncan and Fantino (1970) clearly found overpreference for the shorter terminal-link FI, no single exponential transformation could consistently account for their data. The potency of reinforcer amount as a determinant of choice is also uncertain. Results of investigations of the effect of differential reinforcer amounts on choice range from matching to extreme undermatching.

The analysis of choice between reinforcers differing in delay and amount is tantamount to the analysis of three classes of functions: those dealing with reinforcer value as a function of delay and as a function of reinforcer amount; those dealing with their interaction; and a rule to predict preference between alternatives that vary on these two dimensions.

Current best estimates indicate that reinforcer value, as measured in choice situations, is a power function of delay and amount of reinforcement. For delay of reinforcement an exponent greater than one is indicated, while the exponent transforming reinforcer amount

is generally one or less. Thus, delay to reward is a more potent determinant of choice than is amount.

A great deal of research has been devoted to finding an adequate rule for two-manipulandum choice situations. While the matching law provides accurate predictions in a wide variety of situations (see de Villiers, 1977), Fantino's (1969) equation appears better suited for the vagaries of the concurrent-chain procedure. For example, no other choice model has so accurately accounted for changes in preference as initial-link values are varied (Squires & Fantino, 1971).

Perhaps the key to understanding choice between rewards differing in delay and amount lies in the way these two variables interact. Despite its relative importance this interaction has received little attention. Both Rachlin and Green (1972) and Navarick and Fantino (1976) assumed a simple multiplicative interaction. The results of the present experiment, and the failure of either of these models to fit the data, indicate that such an assumption is incorrect. Whether some more complicated form of the interaction is sufficient, or whether an entirely different representation may be necessary, awaits further research.

Nevertheless, the results of this experiment demonstrate that there is an orderly relationship between delay and amount of reinforcement and choice, and that delay of reinforcement has a greater effect upon choice than does amount. In addition, behavior under a concurrent-chain schedule is a function of more than just the ratio of the terminal-link schedule values.

We might also note, parenthetically, that choice experiments in which delay and amount of reinforcement are both varied have relevance to the study of foraging behavior. Most studies on choice vary only one parameter: either two rewards are offered simultaneously or the same reward is obtainable after different delays. In foraging, however, the choice is between one kind of prey offered immediately and another that may be obtained later. The present procedure may thus bridge the gap between conditioning and foraging experiments.

Implications for Self Control

Several researchers have defined self control as the selection of a larger, delayed reward

over a smaller, more immediate one (Ainslie, 1974; Green, in press; Navarick & Fantino, 1976; Rachlin & Green, 1972). At a time close to delivery of the rewards, organisms will generally choose the smaller, more immediate reward. However, as the time to delivery of both outcomes increases, preference reverses toward the larger delayed reward and the animal may be said to be exhibiting self control.

This situation is illustrated in Figure 2. The two solid lines are the reward gradients for the two outcomes. Reinforcer value is assumed to decrease hyperbolically with time from reinforcer delivery (Ainslie, 1974; Green, in press). Preference reversal occurs at time T_1 where the two gradients cross. At times closer to the outcomes than T_1 , preference is for the smaller reward, while the larger reward should be chosen at times greater than T_1 .

The multiplicative-interaction assumption of the Rachlin-Green and Navarick-Fantino models predicts that the point of preference reversal, T_1 , should occur when the ratio of delays of reinforcement falls to a value equal and opposite to the ratio of reinforcer amounts. At all points to the right of T_1 , d_1/d_2 is greater than a_1/a_2 (where alternative 1 is the larger, more delayed reinforcer) whereas this situation is reversed to the left of T_1 . However, if delay of reinforcement is a more potent determinant of choice than is amount, the delay ratio must have a lower value before preference reverses.

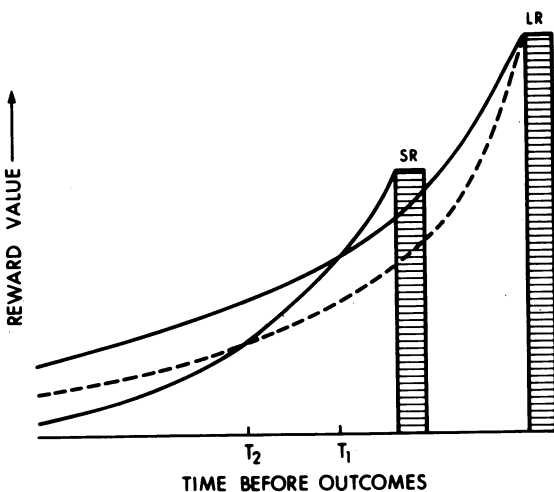


Fig. 2. Hypothetical values of two rewards differing in amount and delay as a function of the time before their outcome. The dashed line represents the change in value over time for the larger reward (LR) when delay is a more potent determinant of choice.

Delay of reinforcement must be transformed by a higher power than amount, and will not equal $(a_1/a_2)^x$ until d_1/d_2 decreases to a value less than a_1/a_2 . Thus, the larger, more delayed reward will not be preferred until farther in time from the two outcomes than predicted by Rachlin and Green (1972) or Navarick and Fantino (1976).

The effect of increased potency of delay would be to increase the rate of decay of the value of the larger, more delayed alternative relative to the smaller, less delayed alternative. This is represented by the dashed line in Figure 2. The point of preference reversal is thereby moved farther back in time to T_2 . In terms of self control, this means that organisms would be expected to exhibit more impulsiveness and less self control. The degree of impulsiveness is, of course, dependent upon the rate of decay of these two value functions. Much further research will be necessary to assess the precise effects of specific variables on these functions.

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Received December 5, 1979

Final acceptance April 16, 1980