DELAY AND AMOUNT OF REWARD
IN A CONCURRENT CHAIN

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Eight pigeons responded under a concurrent-chain schedule for rewards differing in both delay and amount, the larger reward being associated with the longer delay. Preference was examined as the absolute durations of the terminal-link delays were increased at four different delay ratios. Difficulties with other experiments of this type were controlled for by the use of (a) a single-tape initial link to equalize terminal-link entries, (b) a blackout following the more immediate reward to equalize terminal-link length, and (c) a photocell to measure reinforcer duration more accurately. Preference for the larger reward changed systematically as delays increased in all conditions, decreasing for the 6:1, 3:1, and 3:2 ratios, and increasing for the 1:1 ratio. These results were similar to, but significantly different from, those of previous investigations. The implications of these results for various models of concurrent-chain behavior are discussed.

Key words: concurrent chain, delay of reinforcement, self-control, pigeons

In recent years a number of investigators have examined choice between rewards differing in both delay and amount (Ainslie, 1974; Ainslie & Herrnstein, 1981; Christensen-Szalanski, Goldberg, Anderson, & Mitchell, 1980; Green, Fisher, Perlow, & Sherman, 1981; Green & Snyderman, 1980; Grosch & Neuringer, 1981; Ito & Asaki, 1982; Mazur & Logue, 1978; Navarick & Fantino, 1975, 1976; Rachlin & Green, 1972; Solnick, Kannenberg, Eckerman, & Waller, 1980). Five of these experiments (Green & Snyderman, 1980; Ito & Asaki, 1982; Navarick & Fantino, 1975, 1976; Rachlin & Green, 1972) used a concurrent-chain procedure (Autor, 1960); the others employed some form of discrete-trial choice. In a typical concurrent chain, equal independent variable-interval (VI) schedules are programmed on two keys. The reinforcement provided by each key in this initial link is entrance into the terminal link associated with that key. In the studies above, the terminal links are generally delay periods followed by food reward. Discrete-trial procedures differ from concurrent chains, in

that the initial links provide continuous reinforcement (CRF). The concurrent chain offers an advantage over discrete-trial methods in a quantitative analysis of behavior because the intermittent reinforcement in the initial link tends to produce partial rather than all-or-none selection, as is usually the case with discrete trials. Thus, exact choice proportions, in addition to ordinal measures of preference, may be obtained using a concurrent chain. Given that investigations of delay and amount of reward have implications for the study of self-control (Ainslie, 1975; Rachlin, 1974), the concurrent chain may make it easier to model self-control behavior.

The derivation of a utility function for delay and amount of reward using a discrete-trial procedure would require an indifference curve analysis (Krantz, Luce, Suppes, & Tversky, 1971). Unfortunately, an adequate study of this type might prove to be too unwieldy to be practical (cf. Logan, 1965). On the other hand, by utilizing degrees of preference other than indifference, as in a concurrent chain, one is afforded a short cut to an accurate representation of reinforcer value.

There are, however, a number of interpretational problems with data from concurrent chains. Foremost is the finding that the length of the initial link may affect preference, even if the two initial-link schedules are equal. Although Fantino (1969) has developed a model

that can account for this phenomenon, the mere existence of this problem indicates that a concurrent chain may in some sense be an impure measure of reinforcer utility. Fantino's model, and an alternative formulation, are discussed later in this paper.

Two further difficulties with concurrent-chain data are exemplified by Green and Snyderman's (1980) delay-amount experiment. They used a concurrent chain with independent VI 60-sec initial links and fixed-interval (FI) terminal links, which varied in length as well as the duration of access to grain they provided. In general, Green and Snyderman's results supported a model derived from Fantino (1969) as opposed to a simpler model used by Rachlin and Green (1972), though neither model provided a very good fit to their data. Interpretation of these findings was complicated, however, by the fact that the number of terminal-link entries was allowed to vary across alternatives. Thus the relative rate of reinforcement for the more preferred key may have been greater than for the less preferred. This increase in reinforcement rate might have further increased the relative rate of responding for that key. Ideally, in studies in which delay and amount of reward are varied, the relative rate of reinforcement should remain constant across alternatives.

Another problem is the fact that Green and Snyderman did not equate the total length of the two terminal links. Preference for the shorter terminal link may therefore have been influenced both by the fact that it provided a shorter delay to reinforcement and that it led to a quicker return to the initial links, and hence a higher overall reinforcement rate. A study by Gentry and Marr (1980) provides some support for this hypothesis. They replicated an earlier experiment by MacEwen (1972), which found that relative responding for the shorter of two terminal links providing equal amounts of reward increased as the absolute terminal-link delays increased. However, when Gentry and Marr added a blackout after the more immediate reward in order to equate total terminal-link duration, MacEwen's effect disappeared. Both the problem of terminal-link duration and that of unequal terminal-link entries are common to most concurrent-chain experiments.

In virtually all delay-amount studies using pigeons, both concurrent chain and discrete

trial, reinforcer amount is defined in terms of duration of access to grain. More specifically, the length of time the hopper is raised during each reinforcement is varied. Inaccuracies may arise with this procedure because there is a brief period from the onset of hopper elevation until the pigeon begins eating. Assuming this period is approximately constant for all hopper durations, the obtained ratio of long duration to small will be larger than programmed. For studies in which only qualitative trends are being examined this may not be important, but if one is attempting to derive a utility function, the difference may be crucial.

The purpose of the present study is twofold. First, it is an attempt to replicate Green and Snyderman's (1980) experiment, as well as one of Navarick and Fantino's (1976) studies, eliminating the aforementioned problems. The difficulty with changes in the length of the initial link will not be explicitly addressed by the present experiment, though there has been at least one recent attempt to do so (Vaughan, Note 1). Second, we will attempt to move closer to an account of the effects of delay and amount of reward on choice based on concurrent-chain behavior. The discussion will include an examination of various models in this regard.

METHOD

Subjects

Eight male, White Carneaux pigeons were maintained at approximately 80% of their free-feeding body weights. Water and grit were continuously available in their home cages. All subjects had previous experimental experience.

Apparatus

A sound-insulated operant chamber measured 30 cm long by 30 cm wide by 35 cm high. One wall contained two response keys 2 cm in diameter located 8.5 cm from each side wall and 22 cm from the grid floor. Each key could be rear-illuminated with white light and required a force of at least .15 N to operate and produce a feedback click. A 5-cm opening to a hopper containing mixed grain was located in the center of the wall, 11.5 cm below the keys. A photocell mounted on the side of the hopper operated when the pigeon's head was in the hopper. The chamber could be illumi-

nated by either a white, green, or red 7.5-W Christmas tree bulb mounted on the ceiling. During reinforcement, all lights in the chamber were extinguished, and the hopper was elevated and illuminated. White noise was continuously present and an exhaust fan provided ventilation. All scheduling and recording were performed by a PDP-8 (Digital Equipment Corporation) computer located in an adjacent room.

Procedure

A concurrent chain with VI 60-sec initial-link schedules and various fixed-time (FT) terminal-link schedules was used. During the initial choice link, the white houselight was illuminated and both response keys were rear-illuminated with white light. Entrance into the terminal links was arranged by a single VI 30-sec timer, with intervals derived from the distribution of Fleshler and Hoffman (1962).

As each interval timed out, the timer stopped and reinforcement was assigned in a pseudo-random nature with equal probability to either the left or right key in the manner of Stubbs and Pliskoff (1969). In this way each terminal link was entered equally often during each session. The next response on the appropriate key darkened both response keys, extinguished the white houselight, and produced the appropriate terminal-link stimulus (left key-green houselight, right key-red houselight). Prior to terminal-link entry, pecks on the key that had not been assigned reinforcement were recorded and produced a feedback click, but had no other effect. During the terminal links, pecking either key had no effect.

When the terminal-link schedule had timed out, the houselight was extinguished and the hopper was raised and illuminated. The hopper cycle began timing when the bird had triggered the photocell by putting its head in

Table 1

Results from the 6:1 delay ratio for each pigeon. Absolute and relative response rates (responses/sec) are the means from the last five sessions of each condition. Standard deviations are in parentheses. The delays presented in each condition, the order in which each was presented, and the number of sessions for each condition are given.

Bird	Order	No. of Sessions	Term. Link FT (sec)		Sec. Access to Grain		Resp. Rate		Relative Response Rate[a]
			Left	Right	Left	Right	Left	Right	
25	3	32	12	2	6	2	.170 (.044)	.269 (.043)	.384 (.048)
	2	33	60	10	6	2	.008 (.002)	.343 (.075)	.023 (.006)
	1	37	120	20	6	2	.082 (.015)	.428 (.039)	.161 (.016)
42	1	40	12	2	6	2	.199 (.019)	.138 (.023)	.591 (.034)
	2	68	60	10	6	2	.047 (.017)	.180 (.046)	.206 (.052)
	3	25	120	20	6	2	.025 (.008)	.271 (.072)	.083 (.008)
137	1	26	2	12	2	6	.378 (.039)	.263 (.034)	.410 (.042)
	2	25	10	60	2	6	.532 (.087)	.167 (.024)	.239 (.018)
	3	25	20	120	2	6	.462 (.254)	.095 (.072)	.054 (.015)
204	3	40	2	12	2	6	.307 (.017)	.139 (.018)	.312 (.036)
	2	26	10	60	2	6	.225 (.064)	.042 (.014)	.156 (.028)
	2	26	20	120	2	6	.290 (.069)	.055 (.014)	.158 (.012)

[a]Relative rate of response for the larger reward terminal link.

the hopper. The terminal links differed with respect to the FT schedule and the duration of access to food. However, the total length of the two terminal links was equalized so as to eliminate the rate-enhancing effects of choosing the terminal link with the shorter delay. This was accomplished by adding an appropriate blackout period to the end of the lesser delayed alternative. At the end of the food delivery period (or blackout), the response keys and the white houselight were reilluminated, and the initial-link VI timer resumed operation.

The absolute delays of reinforcement (FT schedules in the terminal links) were varied, while the ratio of the delay values between terminal links remained constant within an experimental condition. Two different reinforcer durations were used: 2-sec access and 6-sec access to food, with the longer hopper duration associated with the larger delay. The

key associated with the larger delay and reward, and the order of presentation of conditions was counterbalanced across subjects. Tables 1, 2, 3, and 4 summarize this information.

There were four experimental conditions. Birds 25, 42, 137, and 204 served in the 6:1 and 3:2 conditions, and Birds 5, 16, 135, and 430 served in the 3:1 and 1:1 conditions. In the 6:1 condition the terminal-link FT schedule pairs used were: 12 sec vs. 2 sec, 60 sec vs. 10 sec, and 120 sec vs. 20 sec. In the 3:2 condition they were: 6 sec vs. 4 sec, 60 sec vs. 40 sec, and 120 sec vs. 80 sec. In the 3:1 condition: 6 sec vs. 2 sec, 30 sec vs. 10 sec, 60 sec vs. 20 sec, and 120 sec vs. 40 sec. In the 1:1 condition: 2 sec vs. 2 sec, 20 sec vs. 20 sec, 40 sec vs. 40 sec, and 80 sec vs. 80 sec. Subjects in the 3:1 and 1:1 conditions were studied on at least three of the four schedule pairs in each condition. The 6:1, 3:1, and 3:2 conditions are replications of Green and Snyderman's (1980) experiment.

Table 2

Results for the 3:1 Delay Ratio for Each Pigeon (details same as for Table 1).

Bird	Order	No. of Sessions	Term. Link FT (sec)		Sec. Access to Grain		Resp. Rate		Relative Response Rate[a]
			Left	Right	Left	Right	Left	Right	
5	3	30	2	6	2	6	.434 (.032)	.416 (.032)	.489 (.009)
	2	32	20	60	2	6	.680 (.082)	.196 (.043)	.223 (.039)
	1	27	40	120	2	6	.358 (.063)	.051 (.029)	.118 (.043)
16	4	30	2	6	2	6	.370 (.126)	.602 (.059)	.649 (.032)
	3	26	10	30	2	6	.454 (.077)	.484 (.076)	.516 (.008)
	2	26	20	60	2	6	.498 (.070)	.271 (.040)	.352 (.027)
	1	31	40	120	2	6	.486 (.048)	.178 (.014)	.268 (.039)
135	1	25	6	2	6	2	.297 (.086)	.145 (.056)	.676 (.045)
	2	29	30	10	6	2	.046 (.017)	.137 (.068)	.267 (.048)
	3	44	60	20	6	2	.018 (.012)	.141 (.086)	.117 (.020)
430	1	35	6	2	6	2	.355 (.050)	.376 (.031)	.485 (.021)
	2	44	60	20	6	2	.157 (.018)	.399 (.056)	.285 (.046)
	3	25	120	40	6	2	.063 (.019)	.347 (.056)	.154 (.033)

[a]Relative rate of response for the larger reward terminal link.

The 1:1 condition is the same as Navarick and Fantino's (1976).

Sessions were conducted six days a week, with each session lasting until 40 reinforcers (20 from each key) were obtained. Each bird remained in a condition for at least 25 sessions and until (a) the median relative rates of responding for the last three successive blocks of five sessions each showed neither an upward nor a downward trend, and (b) there was no visible trend in either relative or absolute rates of responding during the final five sessions.

RESULTS

Absolute and relative response rates in the initial link for each pigeon are given in Tables 1 (6:1 delay ratio), 2 (3:1 delay ratio), 3 (3:2 delay ratio), and 4 (1:1 delay ratio). These data are means from the last five sessions of each condition.

Figure 1 shows the relative rate of response during the initial link (proportion of responses on the initial-link key leading to the larger amount of reinforcement) as a function of the FTs in the terminal links for each bird in the four delay-ratio conditions.

In each condition, as the absolute delays to reinforcement increased, there was a systematic change in preference. In the 6:1, 3:1, and 3:2 conditions, relative rate of response for the larger reward (longer delay) decreased as delay increased. In the 1:1 condition, preference for the larger reward increased with increasing delay. There appears to be a slight order effect in the 6:1 and 3:2 conditions, as the birds who began with the longest delay values (Bird 25 and Bird 204 in 6:1, Bird 42 and Bird 137 in 3:2) show less difference in preference between the long- and middle-value delays than birds who experienced the shortest delay pairs first (Bird 42 and Bird 137 in 6:1, Bird 25 and Bird 204 in 3:2).

Table 3

Results for the 3:2 Delay Ratio for Each Pigeon (details same as for Table 1).

Bird	Order	No. of Sessions	Term. Link FT (sec)		Sec. Access to Grain		Resp. Rate		Relative Response Rate[a]
			Left	Right	Left	Right	Left	Right	
25	1	26	4	6	2	6	.223 (.064)	.214 (.076)	.482 (.042)
	2	48	40	60	2	6	.183 (.064)	.055 (.018)	.237 (.042)
	3	25	80	120	2	6	.076 (.032)	.015 (.008)	.153 (.032)
42	3	33	4	6	2	6	.119 (.029)	.167 (.039)	.584 (.036)
	2	26	40	60	2	6	.113 (.023)	.109 (.030)	.488 (.028)
	1	29	80	120	2	6	.067 (.025)	.049 (.027)	.424 (.021)
137	3	33	6	4	6	2	.502 (.043)	.390 (.035)	.563 (.017)
	2	40	60	40	6	2	.103 (.045)	.176 (.067)	.364 (.023)
	1	40	120	80	6	2	.046 (.080)	.083 (.140)	.329 (.026)
204	1	26	6	4	6	2	.453 (.052)	.139 (.031)	.767 (.026)
	2	31	60	40	6	2	.191 (.021)	.089 (.017)	.684 (.027)
	3	30	120	80	6	2	.025 (.008)	.028 (.004)	.483 (.031)

[a]Relative rate of response for the larger reward terminal link.

Table 4

Results for the 1:1 Delay Ratio for Each Pigeon (details same as for Table 1).

Bird	Order	No. of Sessions	Term. Link FT (sec)		Sec. Access to Grain		Resp. Rate		Relative Response Rate[a]
			Left	Right	Left	Right	Left	Right	
5	1	27	2	2	2	6	.483 (.071)	.526 (.004)	.523 (.038)
	2	31	20	20	2	6	.161 (.047)	.385 (.061)	.705 (.051)
	3	31	40	40	2	6	.074 (.024)	.174 (.141)	.746 (.038)
	4	11	80	80	2	6		stopped responding	
16	1	36	2	2	6	2	.516 (.098)	.474 (.105)	.523 (.055)
	2	30	20	20	6	2	.570 (.042)	.345 (.024)	.623 (.026)
	3	28	40	40	6	2	.461 (.044)	.147 (.030)	.758 (.044)
	4	35	80	80	6	2	.259 (.024)	.052 (.012)	.832 (.039)
135	3	28	2	2	2	6	.404 (.039)	.361 (.040)	.472 (.012)
	2	40	40	40	2	6	.144 (.019)	.244 (.023)	.631 (.029)
	1	52	80	80	2	6	.084 (.069)	.264 (.164)	.804 (.058)
430	4	31	2	2	6	2	.494 (.037)	.418 (.011)	.541 (.018)
	3	28	20	20	6	2	.300 (.021)	.210 (.020)	.588 (.027)
	2	26	40	40	6	2	.311 (.052)	.198 (.028)	.610 (.018)
	1	31	80	80	6	2	.306 (.035)	.243 (.040)	.558 (.023)

[a]Relative rate of response for the larger reward terminal link.

Absolute initial-link response rates, although not extremely consistent, did tend to decrease as the terminal-link delays increased.

DISCUSSION

The data from the present experiment are consistent with those of Green and Snyderman (1980) and Navarick and Fantino (1976), with two notable exceptions. First, the changes in preference as delays increased in the 6:1, 3:1, and 1:1 conditions were not as extreme as previously reported. Second, the pattern of change in the 3:2 condition was the reverse of that in Green and Snyderman's experiment. In their study, preference for the larger-reward key increased with increasing delay. Both this

effect and the restricted nature of the preference change may be attributed to the methodological precautions taken in the present experiment.

The use of a single-schedule initial link and equal-length terminal links eliminated additional incentive to prefer the shorter delay based on its rate-enhancing properties. Thus preference for the shorter terminal link at long delay values in the 6:1 and 3:1 conditions was not as extreme as previously reported. In contrast, the use of a photocell in timing access to grain made the obtained ratio of hopper durations less extreme than it would be without the photocell and thereby favors the key leading to less food. The reversal of trend in the 3:2 condition and the limited range of the 1:1 data are consistent with the idea that the smaller re-
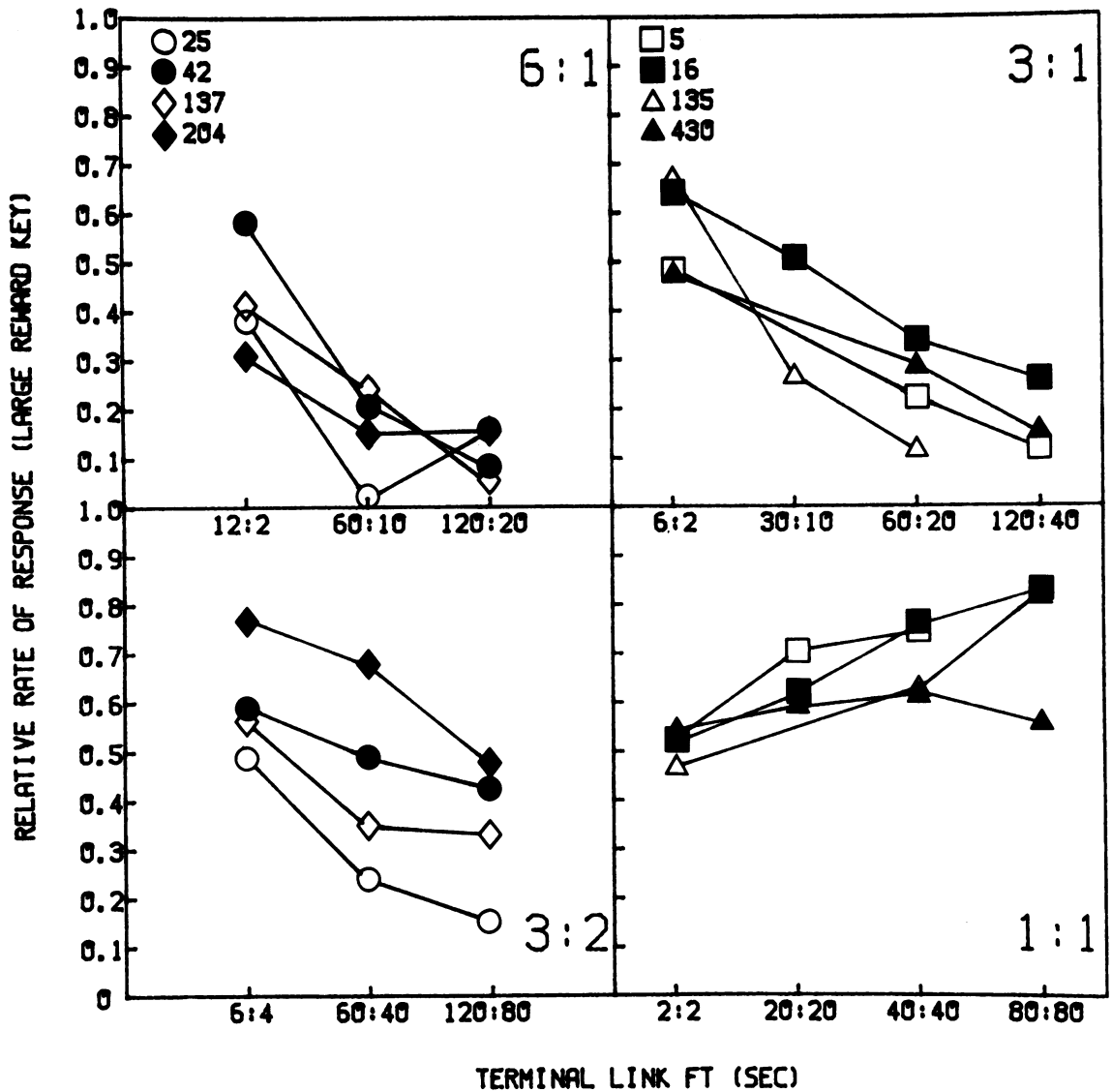
Fig. 1. Relative rate of response for the larger reward key as a function of the terminal-link FT schedules for each bird in each condition.

ward in the present experiment was relatively larger than in previous studies.

Although the Stubbs and Pliskoff procedure may have helped to solve one problem, it brings with it interpretational difficulties of its own. Specifically, the interdependent initial-link procedure penalizes extreme relative rates of response. Because reinforcement is available on only one key at a time, rate of reinforcement may decline as the subject spends most of its time responding on one key while reinforcement is programmed on the other. This is even more likely at low response rates, which, in the present experiment, are correlated with extremes of preference. The fact that relative rates of response at long terminal-link values were closer to indifference than previously reported may therefore be as much due to the fact that the procedure decreases overall reinforcement rate as that it equates the rate on the two keys.

In contrast to the results of Gentry and Marr (1980), the present results show a systematic change in relative responding at all delay

ratios as the length of the terminal links increased. Gentry and Marr reported no regular increase in preference with terminal-link duration when those durations were equated through the use of blackouts. There were, however, rather large unsystematic changes in their relative response-rate data, indicating other unexplained factors were in effect. The use of a blackout in the present study may have produced less extreme preference, but the results of this experiment, along with those of Mac-Ewen (1972), Navarick and Fantino (1976), and Green and Snyderman (1980), indicate there is an effect of absolute terminal-link duration on choice independent of the delay ratio.

An incongruity arises in the data for 1:1 condition when the delay values are 2 sec vs. 2 sec. All four subjects are nearly indifferent at this point, even though one key provides three times the reinforcement of the other. Neither of two apparent explanations for this indifference is wholly satisfactory. First, it may represent key bias. This seems unlikely, as it would require half the birds to be biased towards the left key, half to the right, and always towards the key with the smaller amount of reward. A second explanation has to do with the aforementioned characteristic of the Stubbs and Pliskoff (1969) procedure. Because each terminal link must be entered equally often, any significant preference will tend to decrease overall reinforcement rate, thereby driving preference back towards indifference. The problem here is that this effect should be pronounced only when preferences are extreme, and probably would not have affected any slight preferences that might have existed in the 2-sec vs. 2-sec condition. In short, there seems to be no ready explanation for this result, though it is interesting to note that data from an unpublished experiment by Green (1969), cited in Killeen (1982b), shows the same effect with 1-sec terminal links providing 3- and 9-sec access to grain.

The original impetus behind Green and Snyderman's (1980) study was to provide a test between two models of delay and amount of reward on choice: Rachlin and Green's (1972) and Navarick and Fantino's (1976). The simple matching model of Rachlin and Green was quickly discarded, as it failed to predict any change in preference with increasing absolute delay at a constant delay ratio. The Navarick

and Fantino model, which is a more general form of Fantino's (1969) model of concurrent-chain performance, had similar problems. In its most simple form the model may be represented as follows:

$$\frac{B_1}{B_1 + B_2} = \frac{VI + D_2 a - D_1}{2VI}, \qquad (1)$$

where B_1 and B_2 are responses to the larger, delayed and smaller, more immediate alternatives, respectively. VI is the length of each initial-link schedule (here the two are assumed to be equal), D_1 is the length of the longer terminal link, D_2 is the shorter terminal link, and a is the ratio of the larger amount of reward to the smaller. The model has the advantage of accounting for changes in the initial-link schedules, as well as changes in absolute delay, but fails because it assumes that delay and amount combine in a simple multiplicative fashion. Equation 1 thus predicts that in the 3:1 condition, with the amount ratio equal and opposite to the delay ratio, preference should remain at indifference at all delay values. This prediction is counter to the data from both the present experiment and Green and Snyderman's (1980).

Green and Snyderman provided an alternative formulation that was better able to account for their data. Their model is identical to Equation 1, with the addition of one free parameter:

$$\frac{B_1}{B_1 + B_2} = \frac{VI + D_2 a^x - D_1}{2VI}, \qquad (2)$$

where B_1, B_2, VI, D_1, D_2, and a are as in Equation 1. x is a parameter whose value will vary with the relative potency of amount, as opposed to delay, of reward in determining preference. (Logue, Rodriguez, Pena, and Mauro [Note 2] have also suggested the use of exponents in modeling the effects of delay and amount of reward, but their model is apparently not applicable to concurrent chains.) When $x = 1$, delay and amount are of equal importance and the model reduces to Equation 1. Data from previous delay-amount experiments suggest that in most instances x will be less than one, indicating that delay is the more critical variable. Green and Snyderman found that a value of $x = .67$ provided a fairly good fit to their data. Nevertheless, the next figure

demonstrates that Equation 2 is a fundamentally inaccurate model of delay-amount behavior.

Figure 2 is a summary graph presenting relative response rate averaged across subjects for each delay ratio. Examination of the figure reveals that neither of the models considered thus far offers an adequate account of the data. This graph shows that relative response rate is a curvilinear function of delay duration as delay ratio is held constant. Equations 1 and 2 both predict linear functions with a floor and ceiling at absolute preference.

One possible explanation for the trend in Figure 2 is that it is merely procedural artifact, a function of the penalty imposed on extreme preference by the Stubbs and Pliskoff procedure. This same curvilinearity is evident, however, in the data of Green and Snyderman (1980), as well as those of Green (1969, cited in Killeen, 1982b), and Ito and Asaki (1982), if they are plotted as in Figure 2. Although the procedural details of the Green study are not given in Killeen, neither Green and Snyderman nor Ito and Asaki used a single-tape procedure. There thus seems to be a strong argument against models that predict linear data.

A model recently proposed by Ito and Asaki (1982) does not predict linearity but suffers from other problems. These researchers ran a study essentially identical to the 1:1 delay-ratio condition of the present experiment but with rats as subjects. Ito and Asaki also found a curvilinear increase in preference for the larger reward as absolute delay increased. The general form of their model, another modification of Equation 1, is:

$$\frac{B_1}{B_1 + B_2} = \frac{VI + kD_2{}^n - D_1}{2VI} \qquad (3)$$

where B_1, B_2, D_1, D_2, and VI are as in Equation 1. k and n are free parameters that are fit to the data.

The danger in ex post facto fits, as in the Green and Snyderman (1980) and Ito and Asaki (1982) experiments, is that what may work to fit one particular set of data may be inappropriate as a general account of behavior. For example, by using a value of $n = .68$, Ito and Asaki were able to predict the increase in

preference for the large reward with increasing delay revealed both in their experiment and in the 1:1 delay-ratio condition of the present study. However, with n less than 1 in Equation 3, the prediction is that preference for the large reward will eventually go to 0 (given that all negative values of relative rate are interpreted as 0) as the values of D_1 and D_2 increase. This leads to the rather counter-intuitive prediction that with equal delays and different amounts of reward in the terminal links, organisms will show exclusive preference for the smaller reward at very long delays. A value of n greater than 1 may thus be necessary in order to account for conditions in which preference for the large reward increases with delay. Unfortunately, such an exponent seems inadequate for the three conditions in the present experiment (6:1, 3:1, 3:2) in which preference decreases. In Equation 3, when n is greater than 1, preference for the large reward will eventually go to 1 (given that all values of relative rate greater than 1 are interpreted as 1) as the delays increase. It is unlikely that subjects in the 6:1 delay ratio would have reversed their preference if the delays had been increased past 120 sec:20 sec. Therefore it seems that the value of n will have to vary with the particular delay ratio used, though there is no apparent psychological reason for it doing so.

Killeen (1982b) has developed a model of concurrent-chain behavior that has the great advantage of being generated from first principles rather than merely fit to the data. Schedule strength is said to be determined by the additive interaction of the response-directing effects of primary and conditioned reinforcement, multiplied by the motivating effects of the overall rate of reward. The model, which is an extension of Killeen's (1982a) incentive theory, has done extremely well in predicting the results of a number of concurrent-chain experiments. Originally set up to account for studies in which the amount of reinforcement does not vary between the two terminal links, Killeen has applied the model to the delay-amount situation. He assumed that increasing the amount of reinforcement attenuates the exponential decay of primary reinforcement with time. Specifically:

$$\frac{B_1}{B_1 + B_2} = \frac{p_1(e^{-(q/A_1)D_1} + 1/D_1)/(VI + T_1)}{p_1(e^{-(q/A_1)D_1} + 1/D_1)/(VI + T_1)) + (p_2(e^{-(q/A_2)D_2} + 1/D_2)/(VI + T_2)}, \qquad (4)$$
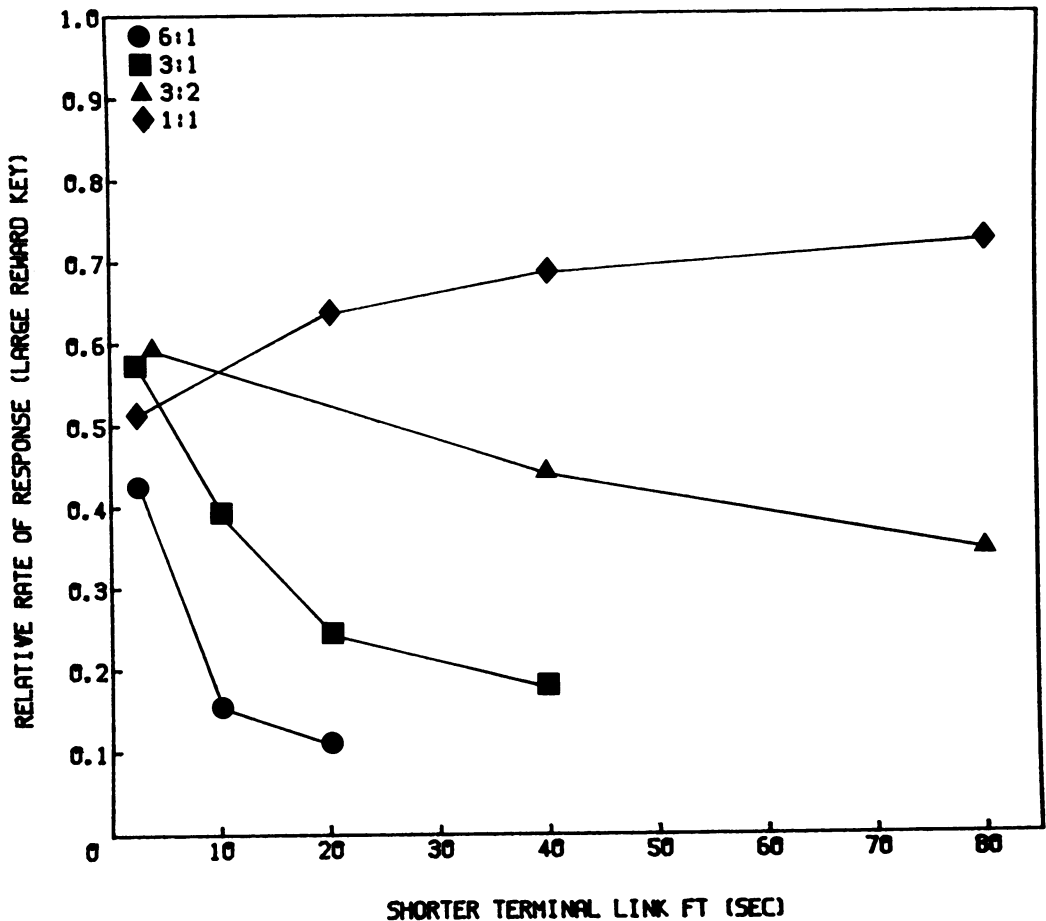
Fig. 2. Relative rate of response for the larger reward key as a function of the shorter terminal-link duration for each delay ratio, averaged across subjects.

where B_1, B_2, D_1, D_2, and VI are as in Equation 1. A_1 and A_2 are the amounts of reward associated with delays D_1 and D_2, and T_1 and T_2 are the length of the two terminal links. (They will be equal to D_1 and D_2 if blackouts following reinforcement do not affect behavior.) q is a free parameter representing temporal decay, and p_1/p_2 is key bias.

The model's fit to the Green and Snyderman data, although generally good, was no better than that using Equation 2 with only one parameter. (Of course, Equation 2 has the problem of predicting linearity.) With regard to the present data, there appears to be no combination of q and p_1/p_2 values that will predict both an increase in the 1:1 data and a decrease in the 3:2 data out to an 80-sec shorter delay. This is the case whether or not the length of the blackouts is included in T_1 and

T_2. It is also the case even if amount of reinforcement is assumed to affect conditioned (A_i/D_i) as well as primary $(e^{-(q/A_i)D_i})$ reinforcement.

Given the extraordinary success of Killeen's model in predicting standard concurrent-chain data, it would seem to be the best account of such behavior currently available. Its difficulties with the data from the present experiment most likely stem from Killeen's hypothesis about how delay and amount combine in their effects upon choice. Although intuitively sensible, the assumption has little empirical basis. The same may be said about every other model in this area, where relevant data are conspicuously absent. In particular, there is insufficient information to determine whether delay and amount are independent in their effects upon behavior and therefore combine additively, or

whether there is some interaction between them. It is noteworthy that Equation 4 is the only model that predicts an interaction, though apparently not the appropriate one. The failure of the models considered to account for the data of the present experiment, as well as those of other studies of delay and amount of reward in concurrent chains, indicates that it is time to gather more data on delay and amount of reinforcement and worry less about theory.

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