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Functional equivalence of fixed-interval and fixed-delay schedules: Independence from initial-link duration

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Pigeons were trained on concurrent-chain schedules with one response-dependent fixed-interval 30-sec terminal link and one response-independent fixed-delay 30-sec terminal link. The equal, concurrent, initial links were varied across conditions. Measures of the differential effects of the terminal links and of the left/right key bias were calculated at each initial-link duration, using equations derived from the generalized matching law. Two subjects displayed idiosyncratic preferences for one or the other terminal link; however, consistent with previous research, no systematic preference for the fixed-interval or the fixed-delay schedule was found at any initial-link duration.

In the initial links of a concurrent-chain schedule, concurrent variable-interval variable-interval (VI VI) schedules are arranged. Completion of one initial link leads to the exclusive presentation of a further schedule that typically terminates in a single food reinforcer. The initial links are then reinstated (e.g., Fantino, 1969). When equal initial-link schedules are arranged and each leads to a different terminal-link consequence (e.g., fixed-delay [FD] vs. fixed-interval [FI] schedules), preferences for one terminal link over the other are measured by comparing the number of responses occurring on each initial-link alternative.

Neuringer (1969) used a concurrent-chain procedure to measure subjects' preference for response-independent FD schedules versus response-dependent FI schedules of reinforcement. In Experiment 1, he arranged concurrent VI 90-sec VI 90-sec initial links and a number of FD x versus FI x terminal links, where x ranged from 2 to 45 sec. He found a small preference for the FI schedule. However, when a houselight was included during the sessions, the subjects showed no preference for either alternative. Neuringer concluded that the small preference for the FI schedule shown in his Experiment 1 was due to the FD terminal-link blackouts per se, and that pigeons demonstrate little or no preference for a response-independent delayed reinforcer or a temporally equal FI schedule.

Other concurrent-chain experiments have shown that animals have no preference for response-dependent or response-independent schedules of reinforcement when these schedules are equal in terms of the temporal delay to the reinforcer (e.g., Chung & Herrnstein, 1967; Moore & Fantino, 1975; Shimp, 1969). However, although all of these studies varied the terminal links in the concurrent-chain procedure, none varied the duration of the concurrent initial links.

Many experiments have shown that initial-link response ratios in a concurrent chain are also a function of the initial-link duration. For example, Fantino (1969) obtained a mean relative response rate of .95 with concurrent VI 40-sec VI 40-sec initial links leading to VI 30-sec versus VI 90-sec terminal links, but when the initial-link duration was increased to VI 600-sec VI 600-sec, the mean relative response rate dropped to .60. Alsop and Davison (1986) arranged a mixed schedule and a multiple schedule as the terminal links in a concurrent chain. With concurrent VI 4-sec VI 4-sec initial links, their subjects preferred the alternative leading to the multiple schedule. However, as the initial links were increased to concurrent VI 30-sec VI 30-sec, relative response rates fell to .50. When the initial links were increased to concurrent VI 72-sec VI 72-sec, large preferences for the alternative leading to the mixed schedule were demonstrated.

The initial links arranged by Shimp (1969) and by Moore and Fantino (1975) were concurrent VI 60-sec VI 60-sec, whereas those arranged by Neuringer (1969) were concurrent VI 90-sec VI 90-sec. It is possible that any small preference for response-dependent or response-independent terminal links in these experiments was masked by the duration of their initial links.

In the present concurrent-chain experiment, we investigated preference between a response-dependent FI 30-sec terminal link and a response-independent FD 30-sec terminal link when the initial links were varied from concurrent VI 10-sec VI 10-sec to concurrent VI 180-sec VI 180-sec. At each initial-link duration, at least two conditions were employed: in one, the left-key initial link led to the FI terminal link and the right-key initial link led

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to the FD terminal link; in the other, these terminal-link contingencies were reversed. The results were analyzed using the concatenated form of the generalized matching law (e.g., Killeen, 1972; Schneider, 1973). This can be written as

$$\log\left(\frac{B_1}{B_2}\right) = a_r\log\left(\frac{R_1}{R_2}\right) + a_x\log\left(\frac{X_1}{X_2}\right) + \log c, \quad (1)$$

where B denotes responses, R denotes obtained reinforcers, X denotes some other variable affecting choice, such as magnitude or immediacy of reinforcement, and the subscripts 1 and 2 denote the two concurrent alternatives. The parameter c is called *bias* and measures any constant preference for one or the other alternative not associated with the independent variables R and X and not under the control of the experimenter. The parameters a_r and a_x measure the sensitivity of the subject to changes in the obtained reinforcer ratio and to changes in the independent variable X, respectively.

Equation 1, applied to the concurrent-chain procedure used in the present experiment, when the left key leads to the FI terminal link and the right key leads to the FD terminal link, becomes

$$\log\left(\frac{B_w}{B_x}\right) = a_r\log\left(\frac{R_w}{R_x}\right) + a_{tl}\log\left(\frac{\text{FI}}{\text{FD}}\right) + \log c, \quad (2)$$

where B, R, a, c are as above, FI and FD nominally denote some unidimensional preference scale values, the parameter a_{tl} denotes sensitivity to these values, and w and x denote the left and right keys, respectively.

Similarly, when the terminal links are reversed (i.e., the left key and right key lead to the FD and FI terminal links, respectively), but all other experimental variables are held constant, we can write

$$\log\left(\frac{B_y}{B_z}\right) = a_r\log\left(\frac{R_y}{R_z}\right) + a_{tl}\log\left(\frac{\text{FD}}{\text{FI}}\right) + \log c, \quad (3)$$

where B, R, a_r, a_{tl}, c, FI, and FD are as above, and y and z denote the left and right keys, respectively.

The equal initial links in the present experiment were nonindependently scheduled (see Method). This ensured that R_w was approximately equal to R_x, and that R_y was approximately equal to R_z, so that the log reinforcer ratios in Equations 2 and 3 are close to zero and can be discounted. A measure of preference for one terminal link over the other can be obtained for a particular initial-link duration by subtracting Equation 3 from Equation 2, giving

$$½\log\left(\frac{B_wB_z}{B_xB_y}\right) = a_{tl}\log\left(\frac{\text{FI}}{\text{FD}}\right). \quad (4)$$

Similarly, a measure of bias between the left and right alternatives not under the control of the experimenter, irrespective of the terminal-link schedules, is obtained when Equations 2 and 3 are added, giving

$$½\log\left(\frac{B_wB_y}{B_xB_z}\right) = \log c. \quad (5)$$

This analysis is analogous to Davison and Tustin's (1978) application of the generalized matching law to signal-detection theory, which uses subtraction and addition of generalized matching law equations to derive measures of discriminability and bias.

If initial-link duration affects preference for FI versus FD terminal links, measures of the terminal-link effects (Equation 4) should show a preference for one schedule type over the other at short initial-link durations, but subjects' behavior should tend toward indifference as the duration of the initial links is increased, as demonstrated by Fantino (1969).

METHOD

Subjects

Six homing pigeons, numbered 61 to 66, were maintained at 85% ± 15 g of their free-feeding body weights. All subjects had histories of responding on free-operant procedures, but no prior training on concurrent-chain schedules. Water and grit were freely available in their home cages at all times.

Apparatus

A PDP-8e computer, situated far from the experimental chamber, controlled all experimental events and recorded data, using SUPERSKED software. The chamber, which was 33 cm high, 33 cm wide, and 31 cm deep, contained three response keys, 2 cm in diameter, 11 cm apart, and 25 cm above the grid floor. The left and right keys could be transilluminated white, red, or green. The center key was dark throughout the experiment. When lit, the keys were operated by pecks exceeding about 0.1 N, each of which produced a feedback-relay click. Pecks on darkened keys were ineffective and were not counted.

The food magazine was situated beneath the center key, 12 cm from the grid floor. During reinforcement, a nominal 3 sec access to wheat, the hopper was illuminated and the keylights were extinguished. There were no other sources of illumination in the chamber.

Procedure

Because the pigeons were experienced with free-operant procedures, no shaping was necessary. After 40 days of training on the concurrent-chain schedule with a variety of equal and unequal FI terminal links, Condition 1 began (Table 1).

The general procedure used in the experiment is diagrammed in Figure 1. During the concurrent initial links, both side keys were transilluminated white and each was associated with a nonindependent VI

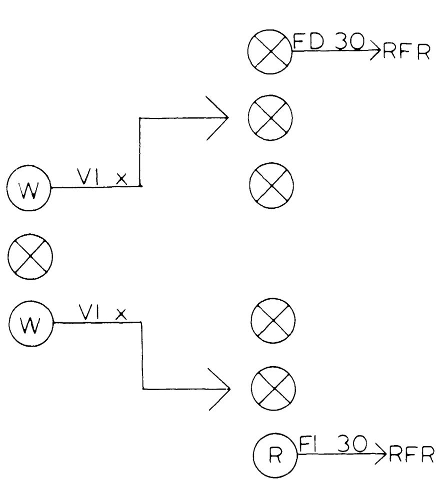

Figure 1. A diagram of the general experimental procedure (see text). W = white; VI = variable-interval schedule; FD 30 = fixed-delay 30-sec schedule; FI 30 = fixed-interval 30-sec schedule; RFR = reinforcement.

schedule. These two equal VI schedules were arranged using a single VI timer. When an interval had been timed, the timer was stopped and entry into a terminal link was probabilistically assigned ($p = .5$) to either the left or right key, in the manner of Stubbs and Pliskoff (1969). This procedure ensured that the number of entries into the terminal links obtained from each initial link was approximately equal. The initial-link VI schedules were selected randomly, without replacement, from the first 12 terms of arithmetic progressions, with the shortest interval $\frac{1}{12}$ of the mean interval.

When a response on a key produced an FI terminal link, that key changed color (to red or green), the other key was extinguished, and a reinforcer could be obtained on completion of an FI 30-sec schedule. When a response on a key produced an FD terminal link, both side keys were extinguished and a reinforcer was delivered following 30 sec of blackout. Following reinforcement, the initial-link timer was restarted and the initial-link schedules were again available.

The sequence of experimental conditions, the number of sessions of training in each, the VI schedules during the initial links, and the arranged terminal-link schedules are shown in Table 1. In Condition 1 and Conditions 17-20, both initial links led to FI 30-sec terminal links, but the initial-link schedules or the color (red or green) associated with the terminal links differed across these conditions (see Table 1). Condition 20 was a replication of Condition 1. Across Conditions 2 to 8, the initial-link VI schedules ranged from concurrent VI 10-sec VI 10-sec to concurrent VI 180-sec VI 180-sec. The left-key initial link led to an FI 30-sec schedule on a red key. The right-key initial link led to an FD 30-sec in blackout. Across Conditions 9 to 16, the same initial-link values as in Conditions 2 to 8 were arranged, but the consequences for responding on the two keys were reversed (see Table 1). Condition 15 was a replication of Condition 11.

Sessions began in blackout, and ended in blackout either after 42 min had elapsed or after 40 reinforcers had been obtained. At the end of each daily session, the following data were recorded: the number of responses emitted to each key, the number of entries into each terminal link (and therefore the number of reinforcers), and the number of responses emitted and time spent in the FI terminal link (when both terminal links were FI schedules, only the number of responses in each was recorded). Following each experimental session, the pigeon was returned to its home cage and was fed the amount of mixed grain necessary to maintain its designated body weight.

Table 1
Sequence of Experimental Conditions, Value of Each Initial-Link VI Schedule (in Seconds), Type of Terminal-Link Schedules and Key Colors, and Number of Sessions of Training in Each Condition

Condition	Initial Links	Terminal Links Left	Terminal Links Right	Sessions
1	30	FI (red)	FI (green)	30
2	30	FI (red)	FD	19
3	15	FI (red)	FD	26
4	90	FI (red)	FD	31
5	10	FI (red)	FD	31
6	180	FI (red)	FD	30
7	20	FI (red)	FD	37
8	60	FI (red)	FD	30
9	60	FD	FI (red)	35
10	30	FD	FI (red)	22
11	90	FD	FI (red)	18
12	10	FD	FI (red)	30
13	180	FD	FI (red)	28
14	20	FD	FI (red)	32
15	90	FD	FI (red)	27
16	15	FD	FI (red)	36
17	30	FI (green)	FI (red)	57
18	180	FI (green)	FI (red)	30
19	180	FI (red)	FI (green)	34
20	30	FI (red)	FI (green)	35

Note—The arranged duration of the terminal-link schedules was always 30 sec.

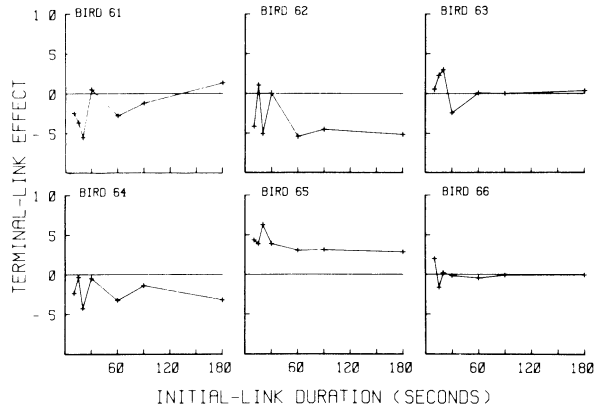

Figure 2. Measures of the log terminal-link effect (Equation 4) for each subject, plotted as a function of the initial-link durations arranged in Conditions 2-16. Numbers greater than zero indicate preference for the fixed-interval terminal link; numbers less than zero indicate preference for the fixed-delay terminal link.

Each experimental condition remained in effect until all birds had reached a defined stability criterion five (not necessarily consecutive) times. The criterion was that the median relative initial-link response number over five sessions did not differ by more than .05 from the median of the preceding five sessions. The data summed across the last five sessions of training in each condition were used in the analyses. Bird 62 died during Condition 17, and was not replaced.

RESULTS

Measures of the terminal-link effect (Equation 4) were calculated for each subject at each initial-link duration. These data are shown in Figure 2. Because there were no systematic differences between the data from Condition 11 and those from its replication, Condition 15, mean data across the two conditions were used in the analysis. Across subjects, there was no systematic preference for one terminal-link type over the other. Bird 65 showed a small consistent preference for the initial-link alternative leading to the FI terminal link, Bird 64 (and, arguably, Bird 62) preferred the initial link leading to the FD terminal link, and the remaining 3 subjects appeared to have no preference (see Figure 2). Furthermore, there was no effect of initial-link duration. Nonparametric trend tests (Ferguson, 1965) on the data from all subjects showed no significant change in the terminal-link effect as the initial-link duration increased. Similarly, there was no significant change when the absolute values of the terminal-link effect were tested (i.e., the estimates were tested for a trend toward, or away from, zero, irrespective of the direction of the preferences).

Measures of left/right key bias (Equation 5) are shown in Figure 3 for each subject at each initial-link duration. A nonparametric trend test revealed no significant change with increasing initial-link duration for the measures of bias or for the absolute values of these measures (i.e., no trend toward, or away from, zero, irrespective of the

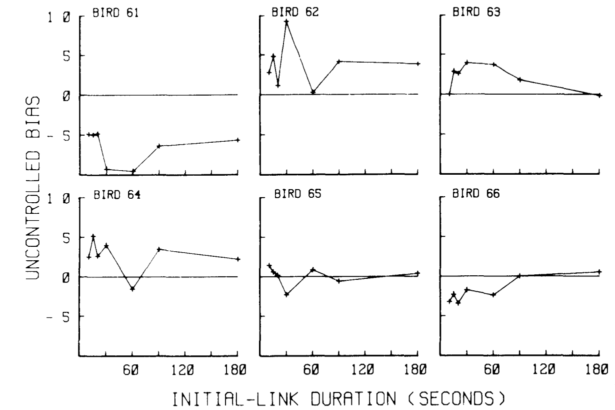

Figure 3. Measures of the log left/right key bias (Equation 5) for each subject, plotted as a function of the initial-link durations arranged in Conditions 2-16. Numbers greater than zero indicate preference for the left key; numbers less than zero indicate preference for the right key.

direction of the bias). Birds 62, 63, and 64 displayed a large bias toward the left key, Bird 61 displayed a large bias toward the right key, and Birds 65 and 66 showed relatively little key bias.

Effects of key color were analyzed using the data from Condition 1 and Conditions 17-20. There were no systematic differences between Condition 1 and its replication, Condition 20, so mean data across the two conditions were calculated for each subject. Measures of the effects of key color were calculated from an equation equivalent to Equation 4. Bird 61 showed no preference for either color, Bird 64 showed a small preference for the red key, and the remaining subjects displayed a small preference for the green key. Measures of left/right key bias, calculated using Equation 5, matched the results obtained from Conditions 2-16. There were no systematic differences in the measures of key-color effect or left/right bias obtained at the two different initial-link durations (concurrent VI 30-sec VI 30-sec and concurrent VI 180-sec VI 180-sec).

DISCUSSION

The failure of subjects to demonstrate a preference for response-independent or response-dependent terminal links in previous studies (e.g., Moore & Fantino, 1975; Neuringer, 1969; Shimp, 1969) is not simply a function of the initial links used in those studies. In the present experiment, no systematic preference for either terminal link was found as the initial-link duration was decreased.

Although only 2 of the subjects in the present study showed idiosyncratic preferences (Bird 65 for the FI terminal link, Bird 64 for the FD terminal link), such preferences seem to be common in this type of research. Three of the 4 subjects used by Brinker and Treadway (1975) showed no preference for response-dependent or response-independent schedules, but 1 subject preferred VI 30-sec schedules to variable-time (VT) 30-sec schedules. Similarly, Killeen (1968) found that 4 of his subjects showed no preference for a VI 30-sec schedule or a VI 30-sec schedule with an added drl (differential reinforcement of low rates of responding) 1.5-sec contingency, whereas 1 subject did prefer the VI 30-sec schedule with the added drl contingency. The data from Neuringer's (1969) Experiment 3 cannot be checked for idiosyncratic preferences, because he reported only the group mean.

The large left/right bias displayed by some subjects is not atypical of research results in this area. The left/right biases reported by Brinker and Treadway (1975) for their subjects covered a range similar to, and on average greater than, the range obtained in the present experiment. Also, given that (1) the size and direction of left/right bias varied across subjects, (2) the biases were independent of the initial-link duration, and (3) the size and direction of the bias were unrelated to measures of terminal-link effects, the results of the left/right bias analysis do not present difficulties for interpreting the effects of the FI versus FD terminal links on initial-link preference.

The results of the present experiment suggest that the "functional equivalence" (Neuringer, 1969) between response-dependent FI schedules and response-independent FD schedules is not merely an isolated point along a range of preferences (e.g., Alsop & Davison, 1986; Fantino, 1969), but is reliable across initial-link durations. Furthermore, any idiosyncratic preferences that subjects may display between these terminal links, and any unaccounted-for left/right biases, are also unaffected by changes in the initial-link duration.

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