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RESISTANCE TO CHANGE PRODUCED BY ACCESS TO FIXED-DELAY VERSUS VARIABLE-DELAY TERMINAL LINKS

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Pigeons' responding was reinforced on a multiple schedule consisting of two two-link chain schedules presented in regular alternation. Responding in initial links (always variable-interval 60-s) produced a key-color change and access to a terminal link. The terminal link for one chain provided food after a fixed delay (fixed-interval or fixed-time); the terminal link for the other provided food after a variable delay (variable-interval or variable-time). The average duration of the terminal-link schedules was varied across conditions, but in every condition the arithmetic mean of the variable-delay terminal-link schedule was equal to the duration of the fixed delay. Response rates were higher in the initial links of the chains with the variable-delay terminal links. Response-decreasing operations (satiation, extinction) were used after performances reached asymptote. Response rates maintained by access to variable-delay terminal links tended to be more resistant to change than were rates maintained by access to fixed-delay terminal links. These results are consistent with the preference for variable- over fixed-interval terminal links observed with concurrent-chains schedules, suggesting (1) that immediacy of reinforcement influences the conditioned reinforcing potency of access to a terminal link and (2) that choice in concurrent chains and resistance of responding to change may be manifestations of the same effect of reinforcement.

Key words: response strength, conditioned reinforcer value, resistance to change, immediacy of reinforcement, chain schedules, aperiodicity of reinforcement, satiation, extinction, key peck, pigeon

In a chain schedule of reinforcement, responding in one stimulus setting, or initial link, produces a transition to a second stimulus setting, or terminal link, in which primary reinforcement (such as food delivery) occurs. The transition from initial to terminal link is considered to be conditioned reinforcement of the response that produces the transition (Kelleher & Gollub, 1962), and the reinforcing effectiveness of the transition varies in degree depending upon such things as the temporal distribution of primary reinforcements scheduled in the terminal link. For example, other things being equal, a transition followed by a short delay to primary reinforcement is more reinforcing than is a transition followed by a long delay (Chung & Herrnstein, 1967; Davison, 1969; Hursh & Fantino, 1973). Two kinds of measures have been used to assess the conditioned reinforcing strength of a transition: (a) the relative rates of responding in the initial links of chains (based on the view that reinforcement enhances the emission rate of a response) and (b) the resistance of response rates in the initial links of chains to change when operations are introduced that tend to decrease response rate (Nevin, 1979). The present study concerns an apparent discrepancy between the results of these two approaches.

The use of the concurrent-chains procedure is based on the first approach. Typically, a pigeon is confronted with two lighted response keys, each corresponding to the initial link of a different chain schedule. A key peck during the initial link occasionally will produce a transition to a terminal link correlated with that key. The color of that key changes, and the other key darkens. Food presentations occur in the terminal link according to a schedule correlated with that key. The independent variable usually involves some difference in the conditions arranged in the terminal links. The schedules arranged in the two initial links usually have been the same—identical variable-interval (VI) schedules—so that any difference between response rates in the initial links would be attributable to different reinforcing strengths of the terminal links rather than to differing characteristics of the initial links. Consequently, differences in response

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rates in the initial links can be used to rank order the conditioned reinforcement potency of transitions to various terminal-link schedules.

The second approach (e.g., Nevin, 1979) views reinforcement as affecting the resistance of asymptotic responding to change when conditions are altered. In a resistance-to-change paradigm, two chain schedules are presented to the organism in regular alternation, comprising a multiple chain schedule of reinforcement. Each chain schedule is composed of an initial and a terminal link, again correlated with distinctive key colors. As in the concurrent-chains procedure, the initial links of the two chains are identical VI schedules, and the independent variable usually involves some difference between conditions arranged in the terminal links. After initial-link response rates have become stable, a response-decreasing operation is introduced, such as extinction, satiation, or punishment. The measure of interest is the degree of decrease in response rate during a given initial link *relative to* its predisruption (baseline) rate. Inasmuch as the schedules in the two initial links are the same, the assumption is that a systematic difference between the relative decreases in response rate is due to a difference between the reinforcing strengths of the terminal links.

For most comparisons of terminal-link schedules, resistances of initial-link response rates to change have been consistent with the ordering of initial-link response rates in concurrent-chains schedules (Nevin, 1974, 1979; Nevin, Mandell, & Yarensky, 1981). An exception, however, has been reported by Mandell (1980, Experiment 3) in comparing the reinforcing effectiveness generated by fixed-interval (FI) versus VI schedules in the terminal links of chain schedules. To appreciate the problem, consider first the results obtained from the concurrent-chains procedure where one terminal link arranges an FI schedule and the other arranges a VI schedule whose arithmetic average delay to primary reinforcement is the same as the FI (e.g., VI 30 s vs. FI 30 s). With concurrent-chains schedules, a most reliable and robust finding is that relative rates of responding are higher in the initial link correlated with the VI than with the FI terminal link (Fantino, 1977; Herrnstein, 1964; Killeen, 1968; MacEwen, 1972). Apparently, the occasional short delays arranged by the VI contribute disproportionately to the conditioned reinforcing potency of the terminal link.

Given the usual consistency between the results of the concurrent-chains and the resistance-to-change procedures, one might expect that an FI terminal link would produce a *less* resistant initial-link response rate than would a VI terminal link that provided the same arithmetic average delay. It was surprising, therefore, that Mandell (1980) reported no differential resistance to change under these conditions. Mandell offered two interpretations of this apparent inconsistency. First, relative response rates in concurrent-chains schedules and resistances of initial-link response rates to change might be influenced by different aspects of terminal-link schedules. For example, resistance to change may be determined by the total access to reinforcement per terminal-link time, whereas relative responding in concurrent-chains schedules may be more influenced by the local densities of reinforcement that immediately follow the transitions from initial to terminal links. The second possibility is that resistance to change and relative responding may be influenced by the same properties of terminal-link schedules, but the resistance-to-change measure may be less sensitive than the relative-response measure to differences in the reinforcing effectiveness of transitions to terminal links.

There is, in fact, reason to suspect that the resistance-to-change measure may be insufficiently sensitive. In reviewing the resistance-to-change literature (Nevin, 1974, 1979; Nevin et al., 1981), we found no observations of differential resistance in initial links of multiple chain schedules when the terminal links differed by a ratio of less than 3:1. The question, then, is how different Mandell's VI terminal link was relative to its corresponding FI.

When only one primary reinforcement is scheduled per terminal link, the ordering of relative response rates in the initial links of concurrent chains usually corresponds reasonably well with the ordering of the average immediacies of primary reinforcement in the terminal links (Killeen, 1968; MacEwen, 1972; Mazur, 1984; McDiarmid & Rilling, 1965). The immediacy of primary reinforcement is the reciprocal of its delay, and so the average immediacy is the mean of the reciprocals of all the delays arranged by the VI. The reciprocal transformation gives disproportionate weight to the shorter intervals. (The question of whether or not a simple reciprocal transformation provides the most general account is not critical to the present discussion [cf. Duncan & Fantino, 1970; Fantino & Davison, 1983; Moore, 1984].) In Mandell's study, the mean immediacy of the terminal-link VI was only 1.5 times higher than that of the comparable terminal-link FI. The reason was that the interval values in Mandell's schedules were derived from an arithmetic progression with few short intervals. Perhaps reliable differences in resistance to change would be revealed if the VI schedules were derived from constant-probability progressions (e.g., Fleshler & Hoffman, 1962) or some other type of progression that arranged a higher proportion of shorter intervals.

The size of the VI schedules used in the initial links of Mandell's Experiment 3 also might have reduced the sensitivity of the resistance-to-change measure. These schedules were quite short (VI 20 s), and, given the low response rates reported in the initial links, many of the transitions from initial to terminal link must have been produced with only a single response in the initial link. Furthermore, this must have happened most often in the initial link that led to the FI terminal link. Thus, although the initial links in Mandell's study were nominally identical VI schedules, they might have differed functionally, with the more "favorable" initial-link schedule correlated with the FI terminal link. The possibility of this confound should be reduced by using longer VI schedules in the initial links.

Based on the considerations outlined above, the present study was designed as a partial replication of Mandell's (1980) Experiment 3, with two major modifications. First, the average duration of the initial-link VI schedules was increased from 20 s to 60 s. Second, all VI schedules used in the present study were derived from a constant-probability progression of intervals, so that the ratio of the VI-to-FI mean immediacies was 3.9:1.0. The purpose was to see if VI versus FI terminal links would produce different initial-link resistances to change under these conditions.

METHOD

Subjects

The subjects were 5 adult male pigeons (Palmetto Pigeon Plant). All were maintained at about 80% of their free-feeding weights, except during resistance-to-satiation tests, during which weights increased. The birds were individually housed and were given continuous access to water and grit in their home cages. All subjects had extensive histories of reinforcement on operant conditioning schedules.

Apparatus

A hand-built, two-key operant conditioning chamber was used. The chamber was 50 cm long, 40 cm wide, and 38 cm high. The two translucent response keys were mounted 24 cm above the floor and 20 cm apart, center to center, and could be transilluminated with red, green, or white light. When lighted, a sufficiently forceful peck (minimum pressure 0.2 N) produced a brief click from a relay mounted behind the front wall of the chamber. An overhead houselight located on the ceiling near the front wall provided low-level illumination. Centered below the keys, 10 cm above the floor, was a rectangular opening that gave access to mixed grain when the food hopper was raised. At those times, the feeder opening was illuminated and the keylights and houselight were darkened. An externally mounted fan provided masking noise and ventilation.

Procedure

The experiment was a partial replication of Mandell's (1980) Experiment 3 with the following modifications: (1) Different schedule values were used in initial and terminal links; (2) all VI schedules were based on constant-probability, rather than arithmetic, progressions of interval values; (3) the resistance-to-satiation tests were somewhat different; and (4) additional control conditions were added in which fixed-time and variable-time schedules were programmed in terminal links.

Because of the pigeons' prior experience, no particular pretraining was needed. All subjects pecked lighted response keys on a two-chain multiple schedule. Each chain consisted of an initial and a terminal link, and the two chains were performed on different keys. The chain with the FI terminal link (FI chain) was performed on the left key, and the chain with the VI terminal link (VI chain) was performed on the right key. The two chains were presented in strict alternation. (As is detailed

Table 1

For each pair of terminal-link schedules, the arithmetic mean duration and harmonic mean duration for the VI terminal-link schedule, together with the VI-to-FI immediacy ratio. Also presented are the key positions correlated with each condition.

Terminal-link condition	Arithmetic mean for VI	Harmonic mean[a] for VI	Immediacy[b] ratio	Key position
Condition 1 FI 60/VI 60	60 s	15.5 s	3.9	FI chain/left VI chain/right
Condition 2 FI 120/VI 120	119.4 s	29.6 s	4.1	FI chain/left VI chain/right
Condition 3 FI 30/VI 30	30 s	7.4 s	4.1	FI chain/left VI chain/right
Condition 4 FI 60/VI 60	60 s	15.5 s	3.9	VI chain/left FI chain/right
Control FT 60/VT 60	60 s	15.5 s	3.9	VT chain/left FT chain/right

[a] Harmonic mean equals $\frac{1}{\frac{1}{N}\sum\frac{1}{t_i}}$ where N is the number of intervals in the progression and t_i is the duration of the ith interval.

[b] Immediacy ratio equals $\left[\left(\frac{1}{\text{harmonic mean for VI}}\right) \div \left(\frac{1}{\text{FI duration}}\right)\right]$.

below, for the final condition the chains correlated with the left and right keys were reversed.) Initial links were correlated with green (left) and red (right) keylights, and terminal links were correlated with white keylights. Across all experimental conditions, responding during an initial link produced access to the corresponding terminal link according to one of two independent VI 60-s schedules that differed only in the sequence of their intervals. The schedules were arranged in the following sequence in a continuously repeating series: 90, 59, 2, 125, 24, 51, 157, 12, 15, 45, 78, 19, 39, 240, 8, 28, 67, 5, 33, and 105 s for one schedule, and 39, 78, 33, 59, 12, 157, 19, 90, 67, 5, 125, 51, 2, 105, 15, 240, 45, 28, 8, and 24 s for the other. The particular 60-s initial-link schedule correlated with each key was varied unsystematically. Primary reinforcement in the terminal links was 3-s access to grain.

Subjects were exposed to four experimental conditions and to two control conditions. (The rationale for and the results of the control conditions will be presented in the Discussion.)

The average durations of the terminal-link schedules varied across experimental conditions, but in every condition the arithmetic mean of the VI terminal-link schedule was equal to the FI duration. Thus, the FI and VI schedules in the terminal links were changed in tandem over conditions in the following order: 60, 120, 30, and 60 s. During the final experimental condition (replication of the 60-s terminal links), the position of the schedules was reversed so that now pecking on the left (green key) initial link produced the VI terminal link, and pecking on the right (red key) initial link produced the FI terminal link. In all cases the VI terminal link consisted of 20 intervals from a constant-probability progression (Fleshler & Hoffman, 1962).

For the control conditions, the procedure was identical to the final, 60-s experimental condition, except that the schedules in the terminal links no longer required a response to produce food. That is, the terminal-link schedules were variable-time (VT) and fixed-time (FT) 60-s schedules. The experimental and control conditions are summarized in Table 1.

Each training session continued until a total of 40 chains had been completed. Each chain ended after the presentation of grain; the end of one terminal link was separated from the beginning of the next initial link by a 30-s intertrial interval, during which the keylights were dark and the houselights were turned off. The chamber was dark before the start of each session and after the completion of the final chain.

Each condition consisted of at least 25 pre-satiation training sessions, followed by a test for resistance to satiation, then at least 8 preextinction training sessions, and finally a test for resistance to extinction, during which food presentations were discontinued. In one of the control conditions, subjects were exposed to at least eight additional training sessions, followed by a test for resistance to extinction during which both food presentations and terminal-link keylight presentations were discontinued.

Resistance-to-satiation tests. Resistance-to-satiation tests consisted of feeding each bird in its home cage 1 hr before testing and increasing the number of chain presentations from 40 to 80 per daily session. (An exception occurred in Conditions 3 and 4 (30- and 60-s delays in terminal links); Bird 1279 was not fed before resistance-to-satiation testing. This subject's responding was more easily decreased than was the responding of the other birds.) In Mandell's procedure, birds were fed before testing and were run continuously until 1 hr had elapsed with no responses emitted. It was hoped that the present procedure would produce more gradual changes in response rates over sessions; it was not expected to bias the results otherwise. Data were recorded in successive 20-chain blocks, which provided for a finer within-session analysis. Resistance-to-satiation testing continued daily until 1 hr had elapsed without a response. If this criterion had not been met during a daily testing session, the session ended automatically after 80 chains had been completed.

Resistance-to-extinction tests. Daily sessions were conducted as in training except that food reinforcement was withheld; completion of each link was response-dependent as in training, but completion of the terminal links produced only a 3-s darkening of the keys, followed (as usual) by the 30-s intertrial interval and the next chain. Resistance-to-extinction tests continued until 1 hr had elapsed without a response, when testing ended automatically. If this criterion had not been met during a session, the session ended after the 40th chain had been completed. Data were recorded separately for successive 10-chain blocks. Pigeons were maintained at 80% of their free-feeding weights by feedings in the home cages; they were never fed until at least 1 hr had elapsed after the end of a daily testing session.

As noted above, a second kind of resistance-to-extinction test was added in the control series: Responding in the initial links produced neither the primary reinforcer nor the conditioned reinforcer. That is, the terminal-link keylight presentations were withheld so that an initial-link response that would have produced a terminal link instead produced only a 3-s darkening of the keys followed (as usual) by a 30-s intertrial interval.

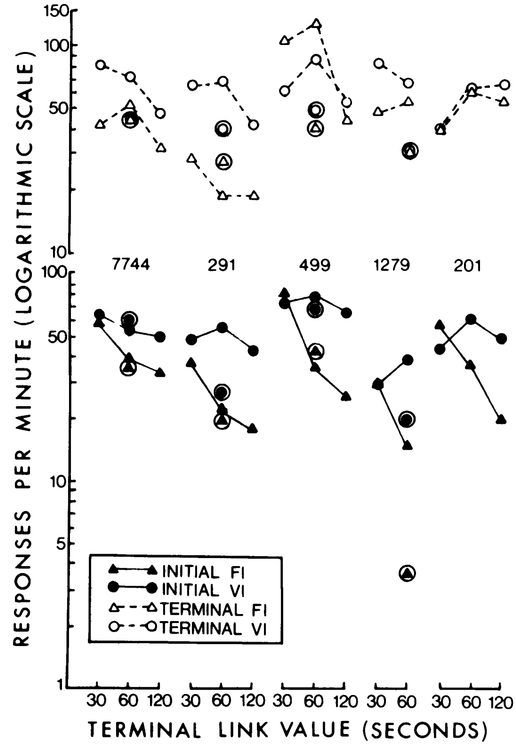

Fig. 1. Responses per minute, on a logarithmic scale, in initial and terminal links of a multiple chain schedule, plotted as a function of terminal-link schedule duration (seconds). Response rates from the 60-s replication condition (Condition 4) are plotted separately and circled. Each group of connected points represents the data from a single subject. Subjects are identified by the numbers above or below each group of points. The schedules in the initial links were identical VI schedules that gave access either to an FI terminal link (triangles) or a VI terminal link (circles).

RESULTS

Before considering the resistance-to-change data, it seemed important to examine the relation between response rate and the duration of the terminal-link schedules to see if well established functional relations were replicated in the present study. The response-rate data to be presented are means derived from daily totals summed over the last five sessions

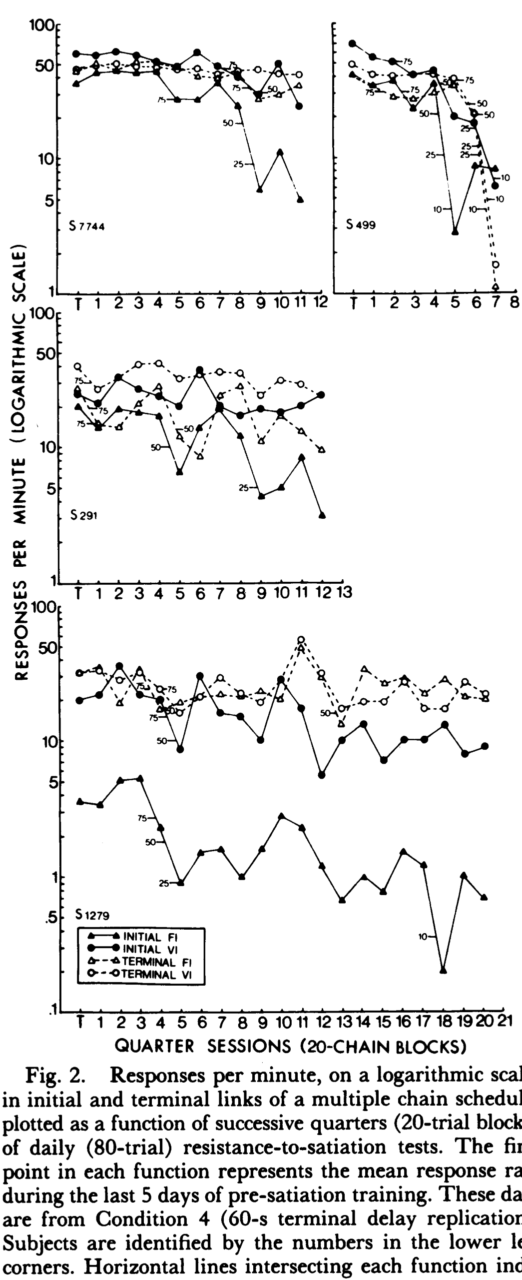

Fig. 2. Responses per minute, on a logarithmic scale, in initial and terminal links of a multiple chain schedule, plotted as a function of successive quarters (20-trial blocks) of daily (80-trial) resistance-to-satiation tests. The first point in each function represents the mean response rate during the last 5 days of pre-satiation training. These data are from Condition 4 (60-s terminal delay replication). Subjects are identified by the numbers in the lower left corners. Horizontal lines intersecting each function indicate proportions of baseline responding (see text).

of each pre-satiation (baseline) condition. There were four different response rates for each condition: initial link leading to the VI, initial link leading to the FI, terminal-link VI, and terminal-link FI.

Figure 1 shows, for each bird, each of the mean response rates plotted as a function of the schedule duration in the terminal link (i.e., arithmetic mean delay to reinforcement). Both axes are scaled logarithmically. The findings are similar to well established relations in several respects: (a) In most cases, response rate was lower in an initial link of a chain than in its corresponding terminal link. (b) In most cases, the rate of responding during an initial link was lower when it led to an FI than when it led to the corresponding VI terminal link. (c) Increasing the duration of the terminal-link schedule usually caused the rate of responding in the initial link of the chain to decrease (although, as in Mandell's [1980] study, there were exceptions).

Because response rate is plotted on a logarithmic scale, parallel functions would indicate that the two initial-link response rates decreased to the same proportion of their initial rates at each of the average terminal-link durations. That is, parallel functions would indicate equal resistance to change—if one viewed increasing the terminal-link schedule as a change-inducing operation on response rate in the initial links. However, the functions tended to diverge, being steeper when the terminal-link schedule was an FI (solid triangles) than when it was a VI (solid circles). By this score, then, responding that produced the VI terminal link was more resistant to change than was responding that produced the FI terminal link. As Mandell (1980) points out, this finding is consistent with results obtained using relative response rates in initial links of concurrent-chains schedules to scale the reinforcing effectiveness of transitions to FI and VI terminal links.

Next to be considered are the effects of satiation and extinction operations on the resistances of the performances to change. Figure 2 shows response-rate data from resistance-to-satiation tests from Condition 4, the 60-s terminal-link replication. Each panel shows data from a different bird, identified by the number in the lower left corner. Mean response rates (initial and terminal links) are plotted on a logarithmic scale as a function of successive quarters (20-chain blocks) of daily (80-chain) resistance-to-satiation tests for initial and terminal links of each chain. The leftmost point in each function represents the baseline response rate—that is, the mean rate of responding during the 5 sessions immediately preceding the satiation test.

The primary question was whether re-

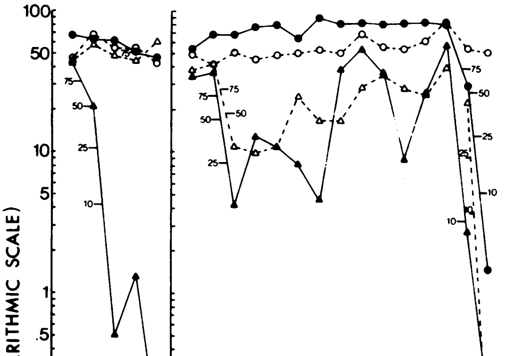

Fig. 3. Responses per minute, on a logarithmic scale, in initial and terminal links of a multiple chain schedule, plotted as a function of successive quarters (10-trial blocks) of daily (40-trial) extinction tests. The first point in each function represents the mean response rate during the last 5 days of preextinction training. These data are from Condition 4 (60-s terminal delay replication). Subjects are identified by the numbers in the lower left corners. Horizontal lines intersecting each function indicate proportions of baseline responding (see text).

sponse rates in the initial links were differentially resistant to the effects of satiation, depending on whether an FI or a VI was scheduled in the terminal link. Again, because response rates are plotted on a logarithmic scale, the slope of the response-rate function indicates the amount of change relative to baseline levels. In most cases, the initial-link response-rate functions were flatter when the terminal-link schedule was a VI (solid circles) than when it was an FI (solid triangles). In other words, the VI terminal link usually engendered the more resistant initial-link performance.

Although not directly related to the main concern of the present study, it is worth noting that response rate in a terminal link tended to be more resistant to the effects of satiation than was the response rate in the corresponding initial link (compare open with solid circles and open with solid triangles).

In Figure 3 the resistance-to-extinction data from the same condition are presented in a similar manner, except that the successive quarters of sessions here represent 10-chain blocks of daily 40-chain resistance-to-extinction sessions (vs. 20-chain blocks). Recall that extinction consisted of replacing the feeder presentation at the end of a terminal link with a brief darkening of the keylight. As would be expected, response rates declined as extinction continued. The main question was whether the response rates in the initial links would decline at the same rate or at different rates. Visual scanning indicates that the results of the extinction procedure appear to be consonant with the results of the resistance-to-satiation procedure: Initial-link response rate tended to be more resistant to the effects of extinction when the terminal link was a VI than when it was an FI schedule. (Again, although somewhat less consistent than before, response rates in the terminal links usually were more resistant to the effects of extinction than were the response rates in the corresponding initial links.) Although there were exceptions to these trends, most of the deviations appeared to be unsystematic, except that differences in resistances to change were less frequently observed for Birds 291 and 201 than they were for the other 3 birds. Clear differences were invariably observed for Bird 7744. As will be shown, the tendencies reported for this one condition (the replication of the 60-s terminal links with the key positions reversed) were consistent with the tendencies observed in the other conditions.

Although a visual-scan analysis has some appeal, it is imprecise and inefficient for summarizing the results of the various conditions. Consequently, the following summary statistics were developed. Each horizontal line that intersects a function in Figures 2 and 3 represents a particular proportion of the mean response rate during the baseline. For example, when a function intersects a horizontal

Table 2

Comparison of resistance to change of initial-link responding in FI and VI chains. Entries show the number of instances (and the proportion of instances) of each of four possible outcomes summed over birds and terminal-link durations. Rows indicate the four criterion proportions of average baseline rate at which relative resistance to change was assessed. Columns represent the four possible outcomes. Numbers in lower margins indicate the proportion of all observations (for each test) corresponding to each outcome. Numbers in right margins indicate, at each test criterion, the proportion of cases in which VI-chain responding was found to be more resistant when "no differential strength" and "differential strength untestable" cases were omitted. Numbers in the lower right corners (set off in parentheses) indicate the overall proportion of VI-stronger cases when these other cases were omitted.

Test criterion	FI chain stronger	VI chain stronger	No diff. strength	Diff. strength untestable	Proportion VI stronger
Resistance-to-satiation tests					
.75	3 = .17	10 = .56	4 = .22	1 = .06	.77
.50	1 = .06	8 = .44	8 = .44	1 = .06	.89
.25	4 = .22	10 = .56	2 = .11	2 = .11	.71
.10	5 = .28	6 = .33	0 = .00	7 = .39	.55
	13 = .18	34 = .47	14 = .19	11 = .15	(.73)
Resistance-to-extinction tests					
.75	0 = .0	10 = .56	8 = .44	0 = .0	1.00
.50	1 = .06	13 = .72	4 = .22	0 = .0	.93
.25	0 = .0	14 = .78	4 = .22	0 = .0	1.00
.10	1 = .06	10 = .56	5 = .28	2 = .11	.91
	2 = .03	47 = .65	21 = .29	2 = .03	(.96)

line marked "75," the response rate in that link has decreased to .75 of its baseline level. In this manner, it was possible to determine the number of quarter-sessions (and, by linear interpolation, fractions of quarter-sessions) taken for each response rate function to reach each of several criterion proportions (.75, .50, .25, and .10) of its baseline level.

Frequently, the response rate in a given link failed to decrease to one or more of the four criterion proportions of the mean baseline rate for that link before performance in another link declined to such an extent (1 hr without a response) that the session and test condition ended. When that happened, a conservative score was inferred for the response rate in the link that was still "going strong"—namely, the number of quarter-sessions that had elapsed when the session ended.

The number of quarter-sessions taken to reach the various proportions of baseline response rate was used to determine which of two response rates was the more resistant—for example, the rate in the initial link of the VI chain or the rate in the initial link of the FI chain. For a given comparison, the resistances to change were regarded as "nondifferential" (a tie) if equal numbers of quarter-sessions (±0.2 quarter-sessions) were required for the two performances to decrease to the particular proportion. If the requisite number of quarter-sessions differed by more than 0.2 quarter-sessions, the performance that took more session time to reach the given proportion was scored as the more resistant to change, or stronger, at that criterion level. (The 0.2 criterion was chosen because it appeared to be a conservative indicator of a difference in slope between the two functions. Use of a more conservative criterion (0.4) resulted in a larger number of nondifferential cases but did not otherwise affect the trends reported.) These statistics were collected from the behavior of all subjects in all conditions; the results of these comparisons appear in Tables 2 through 5.

Table 2 shows the comparison of greatest interest: the resistances of response rates in the initial links to effects of satiation and extinction as a function of whether the schedule in the terminal link was an FI or an equal arithmetic-mean VI. Entries are based on frequencies summed over all subjects and conditions. Rows indicate the four criterion proportions of average baseline rate, and columns represent the four possible outcomes: FI chain responding stronger, VI chain responding

Table 3

Individual performance comparisons in initial links. The results of comparisons of performances in initial links of FI and VI chains, for resistance-to-satiation and resistance-to-extinction tests. Columns indicate the terminal-link durations (conditions). Each group of columns indicates one of the four criterion proportions at which differential resistance to change was tested. "VI" indicates that the VI performance was recorded as stronger, "FI" indicates that the FI performance was stronger, "T" indicates that the performances were recorded as tied, and "U" indicates that the differential strengths were untestable.

	.75 Criterion				.50 Criterion				.25 Criterion				.10 Criterion			
	Condition				Condition				Condition				Condition			
Subject	60 (a) 1	120 2	30 3	60 (b) 4	60 (a) 1	120 2	30 3	60 (b) 4	60 (a) 1	120 2	30 3	60 (b) 4	60 (a) 1	120 2	30 3	60 (b) 4
								Satiation tests								
7744	VI	VI	VI	VI	VI	VI	VI	VI	VI	VI	VI	VI	U	VI	VI	U
291	FI	T	VI	VI	FI	T	T	VI	FI	FI	FI	VI	FI	FI	FI	U
499	T	FI	T	FI	T	T	T	T	U	VI	T	VI	U	U	T	VI
1279	T	*	VI	VI	T	*	T	VI	T	*	FI	VI	FI	*	FI	VI
201	U	VI	VI	**	U	VI	VI	**	U	VI	VI	**	U	VI	U	**
								Extinction tests								
7744	VI	T	VI	VI	VI	VI	VI	VI	VI	VI	VI	VI	VI	T	VI	VI
291	T	T	T	VI	VI	VI	T	VI	VI	VI	T	VI	U	VI	T	VI
499	VI	T	VI	VI	VI	T	VI	VI	VI	T	VI	VI	VI	T	FI	VI
1279	VI	*	T	VI	FI	*	VI	VI	VI	*	VI	VI	VI	*	VI	VI
201	T	VI	T	**	T	VI	T	**	T	VI	T	**	U	VI	T	**

* This subject failed to maintain a stable baseline performance during Condition 2 (120-s terminal-link duration) and was not tested in this condition.

** This subject died during initial training for Condition 4 (replication of 60-s terminal-link duration).

stronger, no differential strength across chains detected, and no opportunity to test relative strength. The latter category was needed when *both* comparison performances had not yet decreased to the particular proportion before the end of testing. The cells in Table 2 contain the frequencies (and proportions) of each type of outcome. The lower margins show the frequencies (and proportions) of each type of outcome summed over criterion proportions. About 25% of all cases (19% of satiation-test comparisons and 29% of extinction-test comparisons) were recorded as ties. However, in the majority of cases where differential resistances were observed, initial-link responding in the VI chain was more resistant than was initial-link responding in the FI chain (see proportions in right-hand columns).

Table 3 shows individual comparisons of initial-link response strength in FI and VI chains. For all subjects, the resistance-to-extinction tests showed initial-link response rates to be more often more resistant to change in the VI chain than in the corresponding FI chain. There was greater between-bird variability in the results of the resistance-to-satiation tests. For Birds 7744 and 201, initial-link response rates were more often more resistant to satiation in the VI chain than in the FI chain; for Birds 499 and 1279, initial-link response rates were about equally resistant to satiation in the VI and FI chain. For Bird 291, initial-link response rates were more often more resistant to satiation in the FI chain than in the VI chain. (This anomalous result for Bird 291 was observed only when the FI chain was correlated with the left key [cf. results from Condition 4 where the schedule-key positions were reversed].)

The final two tables show effects that are secondary to the main purposes of the experiment, but that bear on the interpretation of resistance-to-change effects in chain schedules generally. In chain schedules, initial-link response rate has proven to be less resistant to change than is the terminal-link response rate under a variety of conditions (e.g., Ferster & Skinner, 1957; Fischer & Fantino, 1968; Nevin et al., 1981). As Nevin (1979) has pointed out, these findings make sense if one

Table 4

Comparison of resistance to change of initial-link responding to terminal-link responding in FI and VI chains. Entries show the number of instances (and the proportion of instances) of each of four possible outcomes summed over birds and terminal-link durations. Rows indicate the four criterion proportions of average baseline rate at which relative resistance to change was tested. Columns represent the four possible outcomes. Numbers in lower margins indicate the proportion of all observations (for each test) corresponding to each outcome. Numbers in right margins indicate, at each test criterion, the proportion of cases in which terminal-link responding was found to be more resistant when "no differential strength" and "differential strength untestable" cases were omitted. Numbers in the lower right margins (set off in parentheses) indicate the overall proportion of terminal-link stronger cases when these other cases were omitted.

FI chain

Test criterion	Initial stronger	Terminal stronger	No diff. strength	Diff. strength untestable	Proportion terminal stronger
		Resistance-to-satiation tests			
.75	5 = .28	8 = .44	4 = .22	1 = .06	.61
.50	4 = .22	12 = .67	1 = .06	1 = .06	.75
.25	3 = .17	12 = .67	2 = .11	1 = .06	.80
.10	2 = .11	6 = .33	3 = .17	7 = .39	.75
	14 = .19	38 = .53	10 = .14	10 = .14	(.73)
		Resistance-to-extinction tests			
.75	3 = .17	11 = .61	4 = .22	0 = .0	.79
.50	3 = .17	11 = .61	4 = .22	0 = .0	.79
.25	2 = .11	13 = .72	3 = .17	0 = .0	.87
.10	2 = .11	11 = .61	3 = .17	2 = .11	.85
	10 = .14	46 = .64	14 = .19	2 = .03	(.82)

VI chain

Test criterion	Initial stronger	Terminal stronger	No diff. strength	Diff. strength untestable	Proportion terminal stronger
		Resistance-to-satiation tests			
.75	4 = .22	9 = .50	4 = .22	1 = .06	.69
.50	1 = .06	10 = .56	1 = .06	6 = .33	.91
.25	0 = .0	5 = .28	3 = .17	10 = .56	1.00
.10	0 = .0	4 = .22	4 = .22	11 = .61	1.00
	5 = .07	28 = .39	12 = .17	28 = .39	(.89)
		Resistance-to-extinction tests			
.75	3 = .17	12 = .67	3 = .17	0 = .0	.80
.50	2 = .11	11 = .61	3 = .17	2 = .11	.85
.25	3 = .17	8 = .44	3 = .17	4 = .22	.73
.10	1 = .06	6 = .33	3 = .17	8 = .44	.86
	9 = .13	37 = .51	12 = .17	14 = .19	(.80)

considers the transition to the terminal link to be conditioned reinforcement for initial-link responding. The effectiveness of the transition as conditioned reinforcement presumably would be less than that of the primary reinforcement on which it is based. Table 4 shows the results of comparisons of the resistances to change of responding in initial versus terminal links of FI chains (Table 4a, top) and of VI chains (4b, bottom); the data were collected from all birds over all conditions. For both chains, in both satiation and extinction tests, there were a number of cases where no differential strength was detected. However,

Table 5

Comparison of resistance to change of terminal-link responding in FI and VI chains. Entries show the number of instances (and the proportion of instances) of each of four possible outcomes summed over birds and terminal-link durations. Rows indicate the four criterion proportions of average baseline rate at which relative resistance to change was tested. Columns represent the four outcomes. Numbers in lower margins indicate the proportion of all observations (for each test) corresponding to each outcome. Numbers in the right margins indicate, at each test criterion, the proportion of cases in which VI terminal-link responding was found to be more resistant than FI terminal-link responding when "no differential strength" and "differential strength untestable" cases were omitted. Numbers in the lower right corners (set off in parentheses) indicate the overall proportion of VI-stronger cases when these other cases were omitted.

Test criterion	FI chain stronger	VI chain stronger	No diff. strength	Diff. strength untestable	Proportion VI stronger
		Resistance-to-satiation tests			
.75	4 = .22	11 = .61	3 = .17	0 = .0	.73
.50	3 = .17	7 = .39	2 = .11	6 = .33	.70
.25	2 = .11	3 = .17	3 = .17	10 = .56	.60
.10	1 = .06	2 = .11	4 = .22	11 = .61	.67
	10 = .14	23 = .31	12 = .17	27 = .38	(.70)
		Resistance-to-extinction tests			
.75	1 = .06	13 = .72	2 = .11	2 = .11	.93
.50	1 = .06	10 = .56	2 = .11	5 = .28	.91
.25	1 = .06	9 = .50	2 = .11	6 = .33	.90
.10	0 = .0	6 = .33	3 = .17	9 = .50	1.00
	3 = .04	38 = .53	9 = .13	22 = .31	(.93)

in the majority of cases where differential strengths were detected, terminal-link performances were more resistant to change than were the corresponding initial-link performances. The present results are thus consonant with those from a substantial number of prior investigations.

Table 5 shows the results of a final comparison: the resistances of response rates in the terminal links of the chains (VI vs. FI). In the majority of cases where differential strengths were detected, terminal-link response rates were more resistant in the VI terminal link than in the corresponding FI terminal link in both the satiation tests and in the extinction tests.

DISCUSSION

The present results indicate that there may not be a contradiction between preference (concurrent-chains) and resistance-to-change assessments of the relative reinforcement effectiveness of FI versus equal arithmetic-mean VI terminal-link schedules. As in concurrent-chains studies, where transitions to VI terminal links are found to be more effective as conditioned reinforcement than are transitions to equal arithmetic-mean FI terminal links, so here, when differences were observed, the transition to the terminal-link VI was more often more effective than was the transition to the corresponding FI in making initial-link response rates resistant to change.

The present results seem different from those reported by Mandell (1980). In her study, equal arithmetic-mean FI and VI terminal-link schedules produced initial-link response rates that were *equally* resistant to the effects of extinction and satiation. A likely basis for these different outcomes was the type of VI schedules used in the terminal links. As noted in the introduction, the distribution of intervals comprising the VI in Mandell's study (an arithmetic series) yielded a mean immediacy that was about 1.5 times greater than that yielded by the equal arithmetic-mean FI. In contrast, the distribution of intervals comprising the VIs used here (a constant-probability series) yielded a mean immediacy that was 3.9 times higher than that yielded by the corresponding FI. Thus, if the conditioned reinforcing potency of the terminal links is correlated with the mean immediacy, the VI and FI schedules used by Mandell were not nearly as different from each other as were those used here. Although the present findings do not exclude the possibility of additional control by arithmetic rate of reinforcement, the more parsimonious conclusion is that the resistance-to-change measure was insufficiently sensitive to detect the differential strength produced by the comparison terminal links of the Mandell study. That there were many cases of no differential resistance in the present study further supports the view that the resistance-to-change measure is relatively insensitive to differences in reinforcing effectiveness.

So far, we have implied that different resistances to change of initial-link response rates mean that the two terminal links differ in potency as conditioned reinforcers *during baseline.* Although this is the conventional interpretation, there is an ambiguity that applies to our own and to previous work. If two initial-link response rates decrease to different proportions of their initial rates, does this mean that one terminal link was a more potent conditioned reinforcer than the other *prior to* the introduction of the change-inducing operation? Or could it mean that the change-inducing operation is *producing* differences in the conditioned reinforcing strength *during* the test? If the latter, perhaps the two initial-link response rates during the change-inducing operation are best regarded as tracking the changes in the conditioned reinforcing potency of the terminal links. (This is an instance of a more general point—that the change-inducing operation must be assumed to be orthogonal to the variable whose effect on strength is being assessed in order to interpret different resistances as measuring different initial strengths.)

There are several ways that the conditioned reinforcing potency could decline differentially. For example, in the present study extinction and satiation would tend to engender pausing during the terminal links. If such pausing were more prevalent during the FI than during the VI terminal link, the pigeon likely would be exposed more to the FI terminal-link stimulus than to the VI terminal-link stimulus. This differential exposure could cause the conditioned reinforcing potency to drop more rapidly for the FI than for the VI terminal link.

Even without differential pausing, the extinction operation might have led to a differential relative loss of conditioned reinforcing potency. Recall that the extinction procedure consisted of scheduling the terminal-link stimulus as usual but replacing the food at the end of the terminal link with a blackout. Perhaps the conditioned reinforcing function of the terminal link extinguishes more rapidly when the primary reinforcer has occurred at a constant point in time than when it has occurred at different points in time (cf. Table 5). Although this interpretation seems less plausible as an account of the effects of satiation, it could apply if satiation were regarded as an instance of extinction—that is, if it were the result of contact with an event no longer effective as a reinforcer.

Two additional tests were included in the present study to address the interpretation that differential resistances are due to tracking differentially declining conditioned reinforcement. In the first, the resistances to the effects of satiation and extinction were determined as before except that the schedules in the terminal links no longer required a response to produce food (i.e., the terminal links were FT and VT schedules). The response requirements in the initial links were retained. The point here was to ensure that the durations of the terminal links would be as scheduled regardless of pausing during the terminal links. The second test consisted of programming extinction in a different way. Terminal-link keylight presentations, as well as food, were withheld. That is, initial-link responding produced only a 3-s blackout followed (as usual) by a 30-s intertrial interval. Unfortunately, although this latter kind of extinction test might be the cleanest conceptually, it led to such a rapid decline of responding that the results were less helpful than we had hoped.

The results of the tests are presented in Figure 4. The left-most point in each function represents the mean rate of responding, based on the last five sessions of each of the three resistance-to-change tests. The results of the satiation and the first extinction test (EXT I, food replaced by blackout at the end of the terminal link) were comparable to those obtained with the response-dependent schedules in the terminal links, suggesting that pause-induced extensions of the terminal links were not responsible for the differential resistances reported earlier. The results of the second extinction test (EXT II, no presentation of ter-

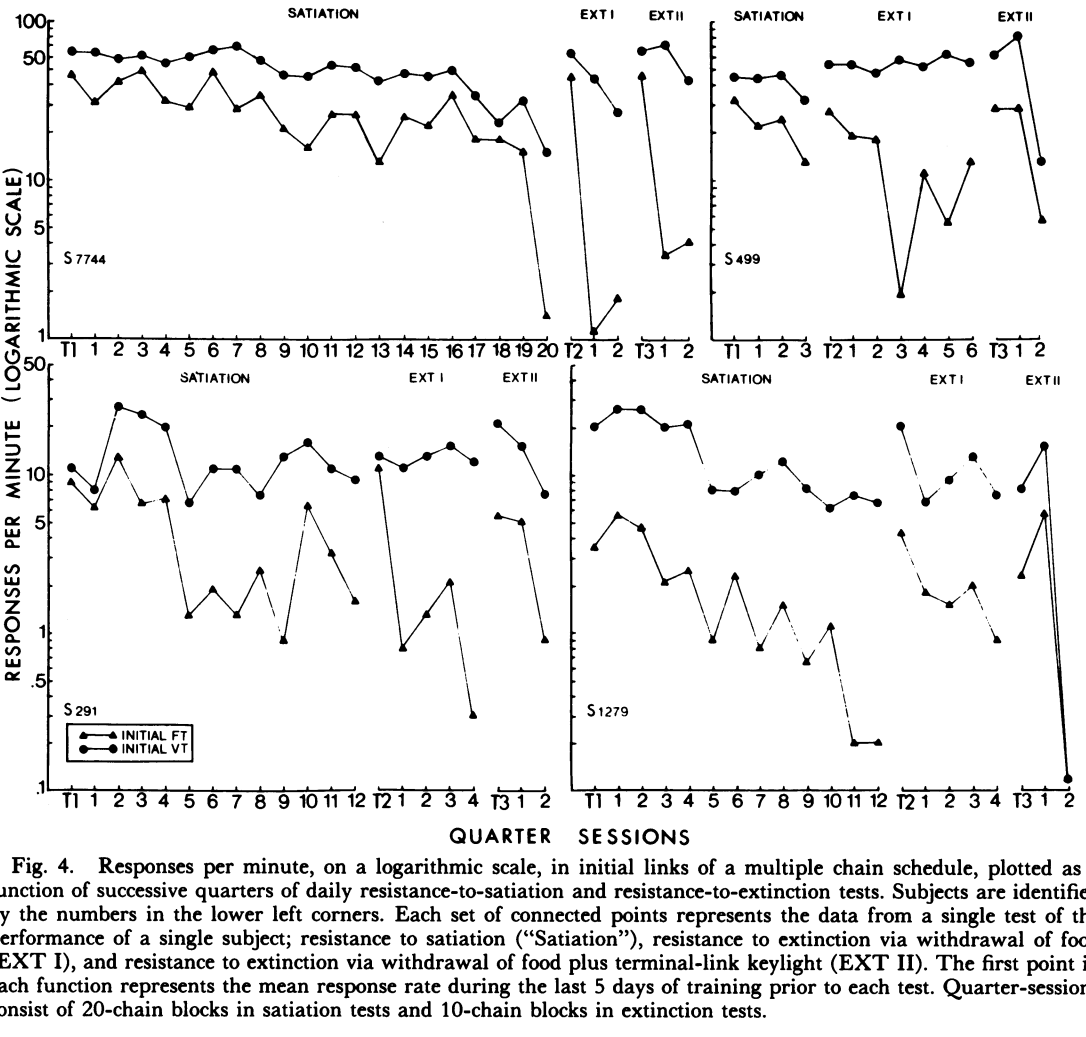

Fig. 4. Responses per minute, on a logarithmic scale, in initial links of a multiple chain schedule, plotted as a function of successive quarters of daily resistance-to-satiation and resistance-to-extinction tests. Subjects are identified by the numbers in the lower left corners. Each set of connected points represents the data from a single test of the performance of a single subject; resistance to satiation ("Satiation"), resistance to extinction via withdrawal of food (EXT I), and resistance to extinction via withdrawal of food plus terminal-link keylight (EXT II). The first point in each function represents the mean response rate during the last 5 days of training prior to each test. Quarter-sessions consist of 20-chain blocks in satiation tests and 10-chain blocks in extinction tests.

minal links) were not as clear because extinction was so rapid. However, in the one clear case (Bird 7744), the response that previously had been reinforced by onset of the VT terminal link was more resistant than was the response that had been reinforced by onset of the FT terminal link. Thus, these results, along with the consistencies between the results of the extinction and satiation tests, provide some support for the interpretation that different resistances were engendered by the VI versus FI terminal links prior to introduction of the change-inducing operations.

Assuming that this last interpretation is correct, the rank ordering of conditioned reinforcing potencies of terminal links appears to be the same whether the ordering is based on the ability of the terminal link to make its initial-link performance resistant to change or whether it is based on preference measures in concurrent chains. This correspondence suggests that a transition to an FI terminal link is generally less effective as conditioned reinforcement than is a transition to an equal arithmetic-mean VI terminal link.

Nevin (1979) has indicated how differential resistances to change could be derived from Herrnstein's (1970) quantitative model of the effects of reinforcement on response rate. This model applies to situations where more than one source of reinforcement is scheduled (i.e., concurrent schedules) and where only one source of reinforcement is explicitly scheduled at any one time. In the latter case, the model assumes that there are unscheduled sources of reinforcement concurrently available (e.g., those derived from preening) that act to reduce the rate of the measured operant. Within this framework, change-inducing operations could be interpreted as increasing the unscheduled background reinforcement—equivalently for the two initial links of the multiple chains. If so, the rate of a less potently reinforced initial-link operant would decline relatively more than would the rate of a more highly reinforced initial-link operant. Thus, the correspondence between the results of the different procedures is consistent with the view that the resistance of responding to change and choice in concurrent schedules might be manifestations of the same effect of reinforcement.

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