DOES CONTINGENT REINFORCEMENT STRENGTHEN OPERANT BEHAVIOR?

JOHN A. NEVIN, LAURENCE D. SMITH, AND JEAN ROBERTS

UNIVERSITY OF NEW HAMPSHIRE, UNIVERSITY OF MAINE, AND
BUCKNELL UNIVERSITY

In Experiment 1, pigeons were trained to peck keys with equal food-reinforcement schedules in components that ended with either noncontingent or contingent transitions to a third component with a five-fold richer schedule. Response rates were higher in the initial component with contingent transitions, but resistance to prefeeding or extinction was not consistently greater. Experiment 2 also included noncontingent or contingent transitions to a signaled period of nonreinforcement. There was no effect of the contingency on transitions to nonreinforcement, but the difference in response rates maintained by contingent versus noncontingent transitions to the richer schedule was replicated. In addition, response rates were higher in components that preceded nonreinforcement than in components that preceded the richer schedule. However, resistance to extinction was greater for noncontingent transitions to the richer schedule than to nonreinforcement, implicating stimulus–reinforcer relations in the determination of resistance to change. Resistance to change was also somewhat greater for noncontingent than for contingent transitions to the richer schedule. The latter result, together with the results of Experiment 1 and related research, suggests that response-contingent reinforcement does not increase resistance to change.

Key words: response–reinforcer contingencies, stimulus–reinforcer contingencies, response rate, resistance to change, timeout, prefeeding, extinction, key peck, pigeons

The term "reinforcement" designates the increase in rate of response when a certain consequence (presentation of a "reinforcer") is contingent upon that response. Although this standard usage is intended to avoid surplus meaning, the notion of reinforcement carries connotations of "strengthening" from everyday language, and the concept of "strength of response" is deeply embedded in the study of behavior (e.g., Morse, 1966; Skinner, 1938; K. Smith, 1974; Staddon, 1975).

As Nevin (1974) pointed out, response rate is not always a useful measure of response strength because it is readily shaped by the contingencies of reinforcement, and the outcome of that shaping process may be unrelated to other aspects of behavior. For example, Blackman (1968) employed pacing schedules to establish high or low response rates with equal rates of reinforcement, and found that

high rates were relatively more suppressed by signaled shocks than were low rates. He also found that when pacing schedules were employed to establish equal response rates with different rates of reinforcement, performances maintained by low rates of reinforcement were more easily suppressed than were performances maintained by high rates of reinforcement.

The possibility of dissociating response rate and resistance to change in this way, coupled with the theoretical notion that response strength may be measured by the persistence of responding in the face of an impediment (K. Smith, 1974; Thorndike, 1913), has led us to identify the strengthening aspect of reinforcement with the resistance to change of steady-state performance when the maintaining conditions are altered. We have shown repeatedly that response rate is more resistant to change, relative to its baseline, in the presence of a cue correlated with relatively frequent, large, or immediate reinforcers than it is in the presence of a cue correlated with relatively infrequent, small, or delayed reinforcers (Nevin, 1974; Nevin, Mandell, & Atak, 1983; Nevin, Mandell, & Yarensky, 1981). Many supporting findings have been reviewed by Nevin (1979). Given the high degree of consistency in these

findings, we have gone on to use differences in resistance to change to evaluate the effects of other variables such as Pavlovian contingencies (Nevin, 1984), cue compounding (L. Smith, 1979), and signaled reinforcement (Roberts, Tarpy, & Lea, 1984; Tarpy & Roberts, 1985).

Although response rate and resistance to change can be dissociated experimentally, they may sometimes depend on the same variables. For example, increasing the rate, magnitude, or immediacy of reinforcement usually increases both response rate and (as noted above) resistance to change. The same may hold for the fundamental contingency between a response and delivery of a reinforcer. Response-contingent reinforcers routinely establish higher response rates than do noncontingent reinforcers presented at the same rate (e.g., fixed-interval vs. fixed-time: Appel & Hiss, 1962; variable-interval (VI) vs. variable-time (VT): Halliday & Boakes, 1971). But does contingent reinforcement also increase resistance to change? There is little consistent evidence bearing on this question. An obvious experiment would involve training on multiple VI VT schedules and then comparing resistance to prefeeding, alternative reinforcement, extinction, or any other variable that could be applied equally to both schedule components. We have attempted this sort of experiment several times, but have been frustrated by excessive variability and failures to recover response rate in the VT component (e.g., Nevin, 1981). Here, we present a new method for addressing the question.

Our method employs a common or "background" VI schedule across several components, accompanied by different stimuli, to maintain stable baselines on which other variables may be superimposed (cf. Blough, 1975). For example, Nevin (1984) maintained pecking with a common VI 2-min schedule in three initial components that were followed by noncontingent transitions to different signaled reinforcement rates. One was followed by a higher rate of reinforcement, a second by the same rate of reinforcement, and the third by nonreinforcement. Responding was more resistant to prefeeding or extinction in the VI 2-min component that preceded the higher rate of reinforcement than in the VI 2-min component that preceded nonreinforcement, demonstrating that differential stimulus–reinfor-

cer relations in a stimulus sequence affected resistance to change.

The present experiments extend the method to compare response-contingent with noncontingent transitions to higher rates of reinforcement or to nonreinforcement, and also provide a systematic replication of Nevin's (1984) result. In the first experiment, two initial components with identical VI schedules of food reinforcement were followed by a signaled period with a second, richer schedule. In one case, the transition was response contingent (C) and in the other it was noncontingent (NC). We examined response rates, resistance to prefeeding, and resistance to extinction. In the second experiment, the procedure was expanded to include four initial components: two as above, followed by contingent or noncontingent transitions to a richer schedule (C-R and NC-R), and two otherwise identical components followed by contingent or noncontingent transitions to a signaled period of nonreinforcement (C-X and NC-X). Both response rates and resistance to extinction were examined. These experiments permit separate evaluation of the effects of the response contingency (C vs. NC) and the following rate of reinforcement (R vs. X) with respect to both response rate and resistance to change.

EXPERIMENT 1

METHOD

Subjects

Four White Carneau pigeons, with histories of autoshaped pecking on a white key, were maintained at 80% of their free-feeding weights (± 15 g).

Apparatus

The experiment was conducted in a two-key Lehigh Valley pigeon chamber equipped with a houselight centered above the keys and a grain feeder centered below them. A blower provided ventilation and masking noise. The experiment was controlled by electromechanical equipment in an adjacent room.

Procedure

After brief training in which each key peck produced food, several experimental phases were arranged in sequence:
Noncontingent schedule transitions (NC).

The left key was lighted red for periods of variable duration averaging 40 s. At the end of each red-key period, the right key was lighted green for fixed 30-s periods, followed by another red-key period. Pecks on the left (red) key produced food according to a VI 180-s schedule, and pecks on the right (green) key produced food according to a VI 36-s schedule. The keys were darkened during food presentations, which lasted 3 s. The houselight was on throughout each session, which always began with a red-key component and ended after the 45th green-key component. Thirty-five sessions were conducted, 6 days per week.

Contingent schedule transitions (C). The procedure remained identical in all respects except that the left key remained on until a variable time averaging 40 s had elapsed and a left-key peck occurred. Immediately after that final left-key peck, the right key was lighted green, signaling the VI 36-s schedule. Twelve such sessions were conducted, 6 days per week, to evaluate the effects of response-contingent versus noncontingent transitions from a VI 180-s component to a VI 36-s component.

Within-session comparison of contingent and noncontingent transitions (C vs. NC). Sessions began with a 30-s timeout, during which the houselight was on but the keys were dark. At the end of the timeout, the left key was lighted either white or red equally often in a quasi-random sequence. If the left key was white, noncontingent transitions (NC) were arranged: The left key went off and the right (green) key came on after an average of 40 s irrespective of behavior. If the left key was lighted red, response-contingent transitions (C) were arranged: The left key went off and the right (green) key came on immediately following the first peck after an average of 40 s. In either case, food was available according to a VI 180-s schedule whenever the left key was lighted. Green-key components always lasted 30 s and accompanied a VI 36-s food schedule, regardless of the preceding left-key color. A 30-s timeout followed each green-key component, after which a new cycle began with red or white on the left key. The houselight was on throughout each session, which ended after the 50th green-key period. Sessions were conducted 6 days per week.

Prefeeding. After 48 training sessions, resistance to change was assessed by prefeeding various amounts of grain in the home cage 1.75

hr before the regular Friday sessions. Body weights returned to their usual 80% levels by Monday or Tuesday of the following week, so at least three baseline sessions preceded each prefeeding session. Three prefeeding sessions at each of three amounts were arranged for each bird, in an irregular order. The amounts varied across birds and are indicated on the *x*-axis of Figure 3.

Extinction. After 18 more sessions of baseline training, resistance to change was again assessed by discontinuing food in all components, while all other contingencies remained unchanged. Six such extinction sessions were conducted on consecutive days.

Measures

In studies of resistance to change, the effects of prefeeding, extinction, or other assessment procedures have consistently been expressed as proportions of baseline response rate. For prefeeding, the primary dependent variables are response rates in C and NC components expressed as proportions of the corresponding baseline response rates of the immediately preceding session. A summary statistic, $\bar{p}$, gives a weighted average for each condition across different prefeeding levels. The greater the proportion of baseline in each session, and the greater the value of $\bar{p}$, the greater is resistance to prefeeeding.

For extinction, response rates in each session are expressed as proportions of baseline in C and NC components during the three preceding baseline sessions. These proportions are not independent, because each is expressed in relation to the same baseline value, so that (for example) a spuriously low baseline would inflate all proportions during extinction. With this caveat, the summary statistic $\bar{p}$ serves to characterize the average level of the extinction curve. However, it does not capture the slope of the curve during extinction, independent of baseline levels. To estimate this slope, a regression line was fitted to response rates for the second and subsequent extinction sessions, expressed as log proportions of response rate in the first extinction session. The shallower the slope, the greater is resistance to extinction.

Appendix 1 reviews some general issues in the measurement of resistance to change and provides detailed rationales and calculating procedures for the measures used in this report.
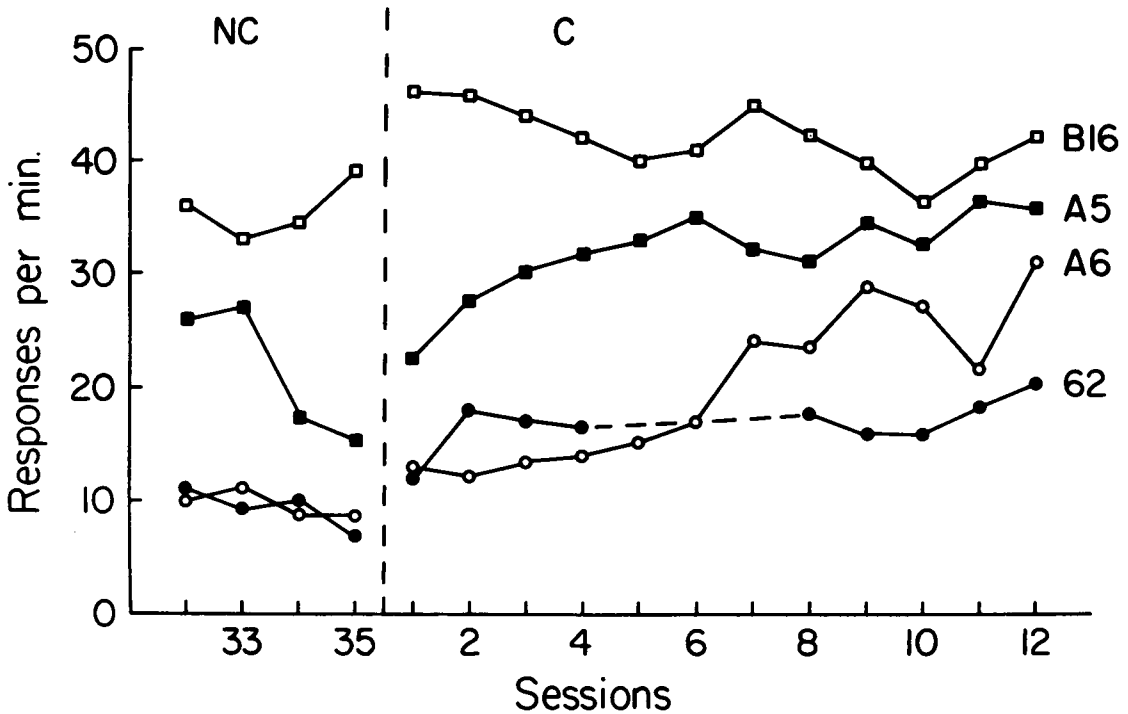
Fig. 1.   Rate of responding maintained by a VI 180-s schedule of food reinforcement when transitions to a signaled VI 36-s schedule were noncontingent (NC) or response contingent (C). For Bird 62 Sessions 5 through 7 occurred as usual, but the data were lost through recording failures.
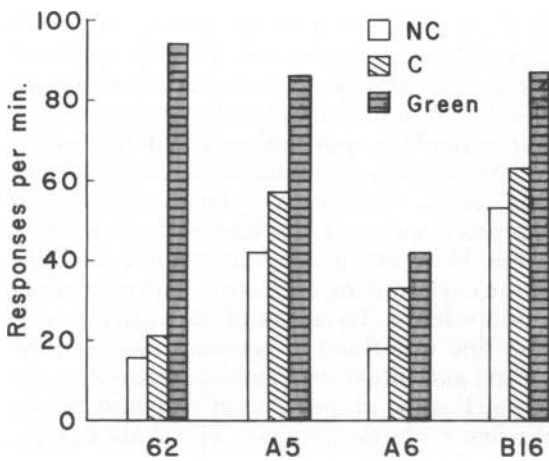

Fig. 2.   Rates of responding during two components with VI 180-s schedules of food reinforcement, accompanied by white and red, and during a third component with a VI 36-s schedule, accompanied by green. Transitions from white to green were noncontingent (NC), whereas transitions from red to green were response contingent (C).

RESULTS

Response rates on the left key during the final four sessions of noncontingent transitions to the richer schedule (NC) and all 12 sessions with contingent transitions (C) are shown in Figure 1. For every subject, response rate increased when the transition was made response contingent, although the increase was small for B16. The average response rates were 21.5 and 29.8 responses per minute during the final four sessions of NC and C, respectively. Thus, peck-produced onset of a light accompanied by the VI 36-s schedule functioned as a reinforcer for pecking maintained by the VI 180-s schedule. There was no systematic change in pecking rates during the green, VI 36-s component: The average rates were 78.9 and 78.7 responses per minute during the final four sessions of NC and C procedures, respectively.

When contingent (C) and noncontingent (NC) transitions were compared within single sessions (Phase 3 in the sequence of proce-
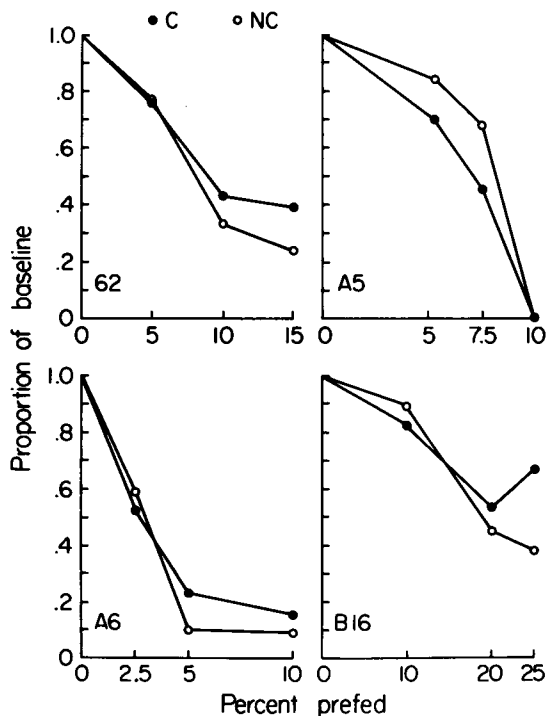
Fig. 3. Proportions of baseline response rates on white (NC) and red (C) keys when subjects received various amounts of grain (expressed as percentages of their body weights) before weekly sessions.

Fig. 4. Proportions of baseline response rates on white (NC) and red (C) keys over the course of six sessions of extinction.

dures), response rates were higher when the left key was red (C) than when it was white (NC). Mean response rates pooled over the nine individual baseline sessions immediately preceding the nine individual prefeeding sessions are shown in the histograms of Figure 2. These differences were present in nine of nine sessions for Birds 62 and A6 and in eight of nine for Birds A5 and B16. For all subjects, response rate was highest on the green, VI 36-s key. Again, the onset of the green key, and its accompanying schedule, functioned as a reinforcer for pecks maintained by the VI 180-s schedule. For all subjects except A5, the differences between C and NC response rates were maintained during the baseline sessions immediately preceding extinction.

Relative resistance to change was assessed first by prefeeding and then by discontinuing food in all components. Figure 3 presents the prefeeding data, averaged within subjects for the three sessions at each prefeeding level, and Figure 4 presents the extinction data (see Measures, above). In Figure 3, it appears that
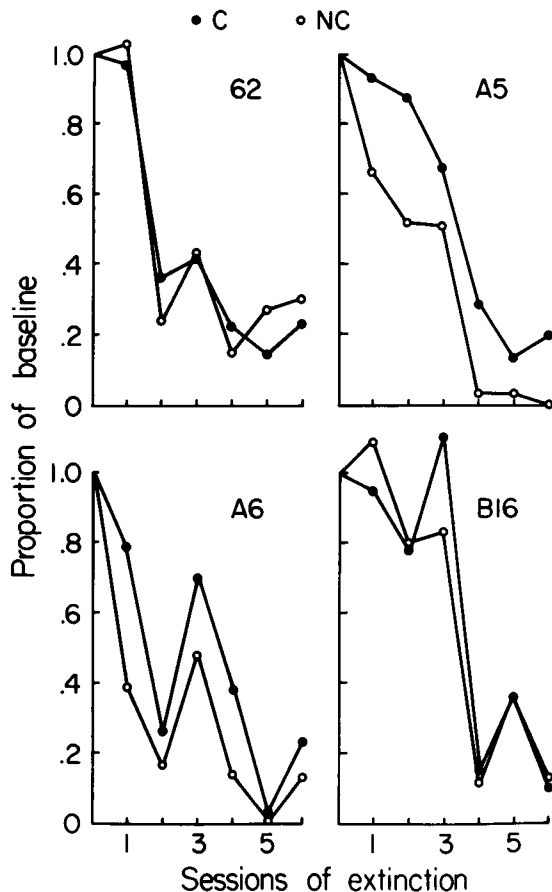
responding in the C component was more resistant to prefeeding than in the NC component for 62, A6, and B16, as the C function is higher for these birds at the two largest prefeeding amounts. Overall, however, the pattern is not consistent, with just 6 of 12 comparisons showing a higher proportion of baseline in C components. Figure 4 shows no difference for Birds 62 and B16, but response rates were more resistant to extinction in C than in NC components for A5 and A6.

A quantitative summary of the differences portrayed in Figures 3 and 4 is presented in Table 1. (Calculation of the summary statistic, $\bar{p}$, and the extinction curve slope are described in Appendix 1.) With reference to $\bar{p}$, Table 1 shows that responding of 3 of the 4 birds was more resistant to prefeeding in C than in NC components, and that responding of 2 of the 4

Table 1

Weighted average proportions of baseline response rates for prefeeding and extinction, and slopes of extinction curves in Experiment 1.

Compo-nent	Bird			
	62	A5	A6	B16
Prefeeding ($\bar{p}$)				
NC	.36	.41	.16	.50
C	.47	.31	.23	.65
Green	.62	.37	.50	.83
Extinction ($\bar{p}$)				
NC	.31	.17	.17	.40
C	.28	.36	.31	.41
Green	.14	.22	.16	.42
Extinction (slope)				
NC	.005	−.514	−.176	−.194
C	−.087	−.239	−.154	−.223
Green	−.268	−.307	−.006	−.162

birds was clearly more resistant to extinction in C than in NC components, with the responding of the other 2 birds being virtually identical. Table 1 also shows that the slopes of extinction curves were shallower in C than in NC components for Birds A5 and A6, whereas Birds 62 and B16 exhibited the reverse. Taken together, the data on resistance to prefeeding and extinction do not suggest that contingent reinforcement reliably increases resistance to change relative to noncontingent reinforcement with equal rates of food presentation.

Table 1 also presents $\bar{p}$ values and extinction slopes for responding during the green, VI 36-s component. With one exception (Bird A5, NC component), responding during green was more resistant to prefeeding than was responding during the C or NC components, which were correlated with VI 180-s food schedules. These results are consistent with many previous findings that more frequent reinforcement establishes greater resistance to change (Nevin, 1979). By contrast, Table 1 shows that resistance to extinction in the green component was not reliably greater than in the C and NC components (three of eight comparisons with $\bar{p}$, and five of eight with slopes). These results are contrary to previous findings that have shown reliably greater resistance to extinction in the presence of stimuli previously correlated with higher rates of reinforcement (e.g., Nevin, in press; Nevin et al., 1983). Relative resis-

tance to extinction in the component with the richer schedule must be affected by some unusual feature of the present procedure, such as the timeout after green but not after red or white components.

EXPERIMENT 2

It is possible that the procedure of Experiment 1 was not sufficiently sensitive to detect the effects of contingent transitions to a richer food schedule on resistance to change, despite their enhancement of baseline response rate. Using noncontingent schedule transitions, Nevin (1984) found that performance is more resistant to prefeeding or extinction in a component followed by a richer schedule than in a component followed by nonreinforcement. Accordingly, Experiment 2 extends the method of Experiment 1 to include contingent and noncontingent transitions to nonreinforcement as well as to a richer schedule, in order to determine whether the procedure is sensitive enough to replicate Nevin's (1984) finding. Experiment 2 also includes controls for possible color biases that might have affected the outcome of Experiment 1.

METHOD

Subjects

The same birds were used as in Experiment 1. Several months elapsed between experiments, during which the birds had free access to food, grit, and water in their home cages.

Apparatus

The experiment was conducted in a three-key Lehigh Valley chamber equipped with a houselight above the center key and a grain feeder below it. Feeder presentations lasted 3.5 s throughout the study. A blower provided ventilation and masking noise. The experiment was controlled by electromechanical equipment in an adjacent room.

Procedure

The procedure was modeled on that for within-session comparisons in Experiment 1. Sessions began with a 30-s timeout, with houselight on but all keys dark. Then, with equal frequency in quasi-random order, either the left key or the right key was lighted white or red, with a VI 100-s schedule of food reinforcement in effect identically across keys

Table 2

Experiment 2. Sequence of conditions and number of sessions in each condition for all subjects.

Condi-	Left key		Right key		Ses-
tion	Red	White	Red	White	sions
1	C-X	NC-X	C-R	NC-R	10
2	C-R	NC-R	C-X	NC-X	11
3	NC-R	C-R	NC-X	C-X	15
4	NC-X	C-X	NC-R	C-R	15
5	C-X	NC-X	C-R	NC-R	32
6	NC-X	C-X	NC-R	C-R	20

Conditions 5 and 6 were each followed by five sessions of extinction.

and colors. If the left key was lighted white, it remained on for a varying time averaging 40 s. It then went dark and the center key was lighted green. If the left key was lighted red, it remained on until a varying time averaging 40 s had elapsed and a peck occurred on that key. It then went dark and the center key was lighted green. In either case, the center key remained green for 30 s, and food was never available. Thus, transitions from left white (VI 100-s food) to nonreinforcement on the green center key were not contingent on left-key pecks (NC-X), whereas transitions from left red (VI 100-s food) to nonreinforcement on the green center key were contingent on a left-key peck (C-X).

If the right key was lighted white, it remained on for a varying time averaging 40 s. It then went dark and the center key was lighted blue. If the right key was lighted red, it remained on until a varying time averaging 40 s had elapsed and a peck occurred on that key. It then went dark and the center key was lighted blue. In either case, the center key remained blue for 30 s, with food available for center-key pecks according to a VI 20-s schedule. Thus, transitions from right white (VI 100-s food) to the richer schedule on the blue center key were not contingent on right-key pecks (NC-R), whereas transitions from right red (VI 100-s food) to the richer schedule on the blue center key were contingent on a right-key peck (C-R).

After the center-key period ended, a 30-s timeout ensued and the cycle was repeated. Daily sessions ended after 40 cycles, 10 each of NC-X, C-X, NC-R, and C-R.

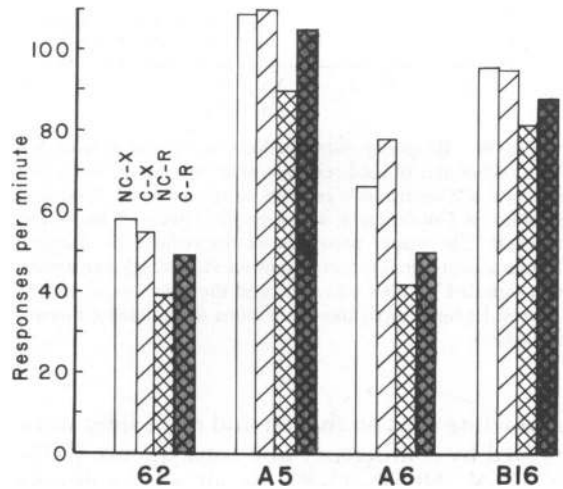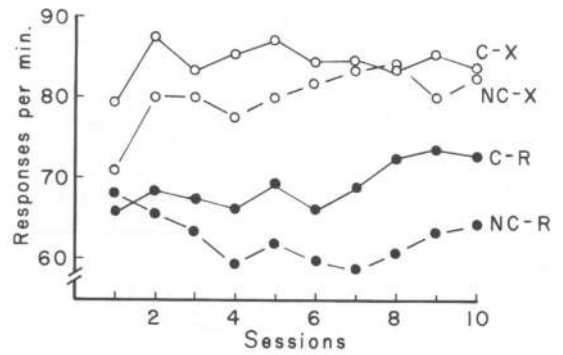To ensure that the results were not confounded by side-key color or position biases,

Fig. 5. Rates of responding in four components with VI 100-s schedules of food reinforcement. C-X and NC-X components end with contingent and noncontingent transitions to signaled periods of nonreinforcement; C-R and NC-R components end with contingent or noncontingent transitions to a signaled VI 20-s schedule. In the upper panel, data are pooled for the first 10 sessions of six conditions during which key colors and positions varied, and then averaged across subjects. The lower panel shows individual birds' data pooled across Sessions 8 through 10 for all conditions.

the roles of the side-key colors and positions were varied in the sequence given in Table 2. (The first and fifth conditions were as described above.) To assess resistance to change, five consecutive sessions of extinction were conducted after the fifth and sixth conditions. These sessions were exactly as described above except that food was never given.

RESULTS

Differential responding as a result of the experimental contingencies developed within the first 10 sessions of each condition. To summarize the differences, response rates on red

62   A5   A6   B16

Right key

○ NC-R → C-R (white)
● C-R → NC-R (red)

Left key

○ NC-X → C-X (white)
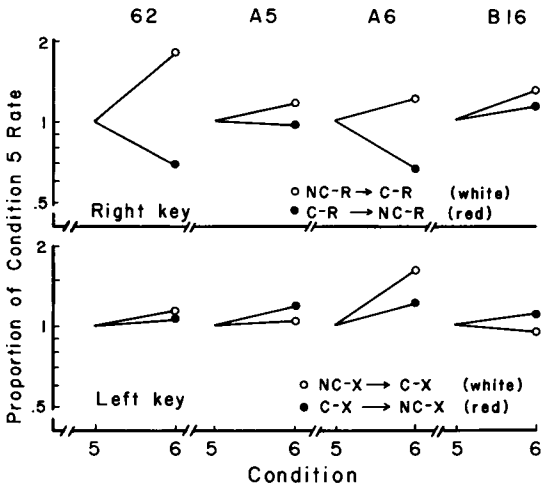● C-X → NC-X (red)

Condition

Fig. 6. Response rates in four components with VI 100-s schedules of food reinforcement during the final five sessions of Condition 6 relative to those in the final five sessions of Condition 5, showing the effects of key-color reversal. The upper panel shows the results for changes from noncontingent to contingent (or vice versa) transitions to a signaled VI 20-s schedule, and the lower panel shows the results for comparable transitions to signaled nonreinforcement.

Table 3

Average response rates for the final five training sessions of Conditions 5 and 6.

Condition and key		Bird			
		62	A5	A6	B16
5	Left Red C-X	51.3	77.8	80.8	91.6
6	Left Red NC-X	53.8	91.6	97.0	99.6
5	Left White NC-X	46.6	83.1	63.9	109.4
6	Left White C-X	52.9	85.2	102.9	102.6
5	Right Red C-R	56.2	113.6	43.0	73.2
6	Right Red NC-R	38.6	109.8	28.8	82.6
5	Right White NC-R	27.2	90.8	32.6	84.6
6	Right White C-R	49.0	105.5	39.4	108.4

and white keys on the left and right sides were pooled by contingency and consequence (NC-X, C-X, NC-R, C-R) for all six conditions and averaged across subjects. The data, presented at the top of Figure 5, show that higher response rates were developed and maintained during C-R than during NC-R components, but that there was no consistent difference between C-X and NC-X components.

Individual data for Sessions 8 through 10, pooled across all six conditions, are shown at the bottom of Figure 5. All subjects had higher average response rates during C-R than during NC-R components (this difference held in five of the six conditions for 62, A5, and A6 and in four of six for B16). The differences between response rates during C-X and NC-X components were inconsistent across birds.

Comparisons across keys show that all birds had higher average response rates during NC-X than during NC-R components (this difference held in all six conditions for 62 and A6 and in five of six for A5 and B16). Response rates during C-X were also higher than during C-R components, but this difference was slightly less reliable (five of the six conditions for A6 and B16 and four of six for 62 and A5).

Baseline response rates maintained by the

VI 20-s schedule on the blue center key were higher than response rates in any of the side-key components, averaging 116, 173, 106, and 149 responses per minute for 62, A5, A6, and B16, respectively. After the first few sessions of Condition 1, the green (nonreinforcement) key was rarely pecked more than once per session.

Side-key response rates during the final five sessions of training in Conditions 5 and 6 are presented in Table 3. The relative effectiveness of contingent transitions to the richer schedule or to nonreinforcement in these conditions is shown in Figure 6. The upper panel presents response rates in Condition 6 relative to those in Conditions 5 for the right key, which led to the richer schedule, and the lower panel presents the same data for the left key, which led to nonreinforcement.

On the right key, every subject exhibited a rate increase from Condition 5 to Condition 6 when white-key conditions were changed from NC-R to C-R, and 3 of 4 exhibited a decrease when red-key conditions were changed from C-R to NC-R (the 4th, B16, exhibited a smaller increase in the latter case, and could be said to have a white-key bias). Together with the data for Sessions 8 through 10 (Figure 5), these differential effects provide strong evidence that transitions to the richer, VI 20-s schedule functioned as a reinforcer for pecking maintained by the VI 100-s schedule, confirming the results of Experiment 1 with somewhat different schedules and with color bias controlled.

On the left key, 3 of 4 birds exhibited rate increases when white-key conditions were changed from NC-X to C-X, and all birds exhibited increases when red-key conditions

were changed from C-X to NC-X. There was, however, no evidence of differential changes of the sort that were apparent for all birds on the right key. Evidently, transitions to periods of nonreinforcement were neither consistently reinforcing nor punishing.

To provide an overall characterization of the course of extinction after Conditions 5 and 6, response rates in each extinction session were expressed as proportions of the means for the three preceding baseline sessions, pooled for the two extinction assessments, and then averaged across subjects. These average proportions of baseline response rates are presented in Figure 7. The functions for the four side-key conditions are quite similar, but it is worth noting that the extinction curve for NC-R is slightly but consistently higher than for C-R, and that the function for NC-X is generally lower than for NC-R. Also, responding extinguished more rapidly in the presence of blue on the center key, which had been correlated with a VI 20-s schedule of food delivery, than in any of the side-key components, all of which had been correlated with a VI 100-s schedule.

The individual levels and slopes of extinction curves following Conditions 5 and 6, as characterized by $\bar{p}$ and fitted regression lines, are summarized in Table 4 (see Measures, Experiment 1, and Appendix 1). Examination of this table shows that noncontingent transitions to a richer following schedule (NC-R) generally increased resistance to extinction relative to noncontingent transitions to nonreinforcement (NC-X): six of eight $\bar{p}$ comparisons
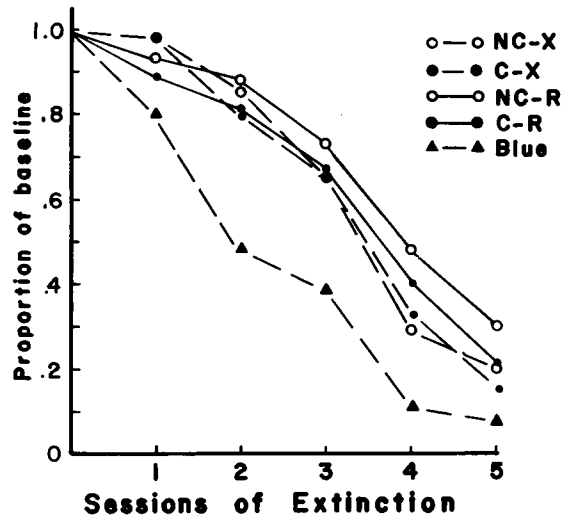

Fig. 7. Response rates during five sessions of extinction, expressed as proportions of baseline, pooled across Conditions 5 and 6, and averaged across subjects. The five curves are for components with noncontingent or contingent transitions to signaled nonreinforcement (NC-X and C-X), for components with noncontingent and contingent transitions to a blue key signaling a VI 20-s schedule (NC-R and C-R), and for responding during the blue-key component.

and seven of eight slope comparisons support this conclusion. By contrast, contingent transitions to a richer schedule (C-R) did not in general increase resistance to extinction relative to noncontingent transitions (NC-R): Only two of eight $\bar{p}$ comparisons and two of eight slope comparisons favor C-R responding. No consistent differences emerged in comparisons

Table 4

Weighted average proportions of baseline during the course of extinction, and slopes of extinction curves, following conditions 5 and 6 of Experiment 2.

Bird cond.	62		A5		A6		B16	
	5	6	5	6	5	6	5	6
$\bar{p}$ values								
NC-X	.55	.28	.71	.64	.42	.21	.43	.40
C-X	.54	.23	.76	.51	.43	.25	.36	.37
NC-R	.68	.21	.65	.71	.54	.42	.67	.46
C-R	.42	.37	.54	.50	.55	.32	.53	.38
Blue	.21	.20	.36	.20	.30	.18	.28	.28
Slopes								
NC-X	−.153	−.226	−.242	−.059	−.414	−.593	−.315	−.365
C-X	−.114	−.391	−.231	−.277	−.330	−.463	−.361	−.368
NC-R	−.110	−.361	−.129	−.054	−.194	−.416	−.141	−.282
C-R	−.179	−.142	−.517	−.325	−.135	−.467	−.215	−.324
Blue	−.246	−.444	−.518	−.204	−.300	−.532	−.251	−.105

of $\bar{p}$ or slope values for NC-X and C-X, or for C-R and C-X conditions.

The values of $\bar{p}$ for the blue component were lower, relative to baseline, than for any of the four initial components (NC-X, C-X, NC-R, or C-R). Also, the slopes of extinction curves for the blue component were not consistently shallower than for the four initial components. Indeed, they were steeper in 21 of 32 comparisons, demonstrating generally less resistance to extinction in a component previously correlated with a higher rate of reinforcement. This result is clearer than in Experiment 1 and remains problematic.

DISCUSSION

Here we will emphasize comparisons of effects in the initial components. Different aspects of the results are discussed in order, beginning with effects on resistance to change followed by effects on response rate. We will conclude by discussing some implications of the results for the concept of reinforcement.

Resistance to Change

Effects of the following schedule. In Experiment 2, responding was usually more resistant to extinction in NC-R components than in NC-X components, despite the fact that baseline response rates were lower in the former case. That is, responding in a component that precedes a signaled noncontingent increase in food rate is more resistant to extinction than in an otherwise identical component that precedes a signaled noncontingent decrease in food rate. This difference suggests that resistance to change depends on stimulus–reinforcer relations within a sequence of signaled reinforcement schedules. However, this difference was not evident in the comparison of C-R and C-X components, where the transition to an increase or to a decrease was contingent upon key pecking, even though stimulus–reinforcer relations were the same as in NC-R and NC-X components. Further work is needed on the possible role of response–reinforcer contingencies in modulating the effects of stimulus–reinforcer relations.

It is not surprising that transitions to the following schedule had only small effects on resistance to extinction, because responding had been maintained by a VI 100-s schedule of reinforcement in all four pretransition com-

ponents. This common food schedule would be expected to mask, at least in part, the relatively subtle effects of the impending transitions to the richer schedule or to nonreinforcement. In this situation, replicability may be more important than magnitude of the effect, and the present results replicate Nevin's (1984) findings quite well. Nevin (1984) conducted three replications of resistance to extinction for two birds, and two replications for the third, which died during the final condition. Resistance to extinction was greater in the component that preceded the richer schedule than in the component that preceded nonreinforcement in six of eight comparisons, as in the present Experiment 2. Pooling across replications, all birds exhibited this difference in both $\bar{p}$ and slope measures. The average values of $\bar{p}$ were .62 and .43 for transitions to the richer schedule and to nonreinforcement, with average slopes of $-.151$ and $-.216$, respectively. Average $\bar{p}$ values for the equivalent transitions in the present study were .56 and .45, and average slopes were $-.175$ and $-.247$ (Table 4). The repeatability of these small differences suggests considerable robustness despite the masking effects of the common background schedules. It also suggests that the present procedure is sufficiently sensitive to detect small but consistent differences in resistance to change.

Effects of the response contingency. When we designed these experiments, we expected that response-contingent transitions to the richer schedule would increase resistance to change, relative to noncontingent transitions. However, in Experiment 1, responding was about equally resistant to prefeeding and to extinction in C-R and NC-R components, except that C-R responding was somewhat more persistent for 2 birds during extinction. In Experiment 2, responding in C-R components tended to extinguish more rapidly than in NC-R components for all subjects. All in all, our data give no consistent evidence that response-contingent reinforcement increases resistance to change.

An earlier study in our laboratory, conducted by Peter Yarensky and reported by Nevin (1979), seemed to have arrived at the expected result. Yarensky exposed 3 pigeons to a discrete-trial procedure in which at least one peck was required for food presentation at the end of 10 s if the response key was green,

whereas food was given independently of responding at the end of 10 s if the key was white. Resistance to change was assessed by presenting free food during intertrial intervals. Two measures of behavior were examined, response totals and trials with at least one peck, and it appeared that both measures were less affected by free food on green-key than on white-key trials. However, the calculated values of $\tilde{p}$ for those data suggest otherwise. The values of $\tilde{p}$ for contingent and noncontingent reinforcement presented in Table 5 show that only 1 of the 3 birds exhibited substantial differences in the expected direction on both measures.

A study by Nevin (1981) employed 5 pigeons trained on multiple VI 24-s, VT 24-s schedules with timeouts between components. Three birds responded at moderate rates in the VT component and at substantially higher rates in the VI component; the other 2 did not respond at all in the VT component. Of the 3 that responded in both components, only 1 exhibited a consistent difference in relative resistance to prefeeding ($\tilde{p}$ values for these data are also presented in Table 5).

Considering all the data presented and reviewed here, there is no consistent evidence that reinforcement—defined as the increase in response rate effected by a contingent reinforcer—increases resistance to change. With respect to $\tilde{p}$, Experiments 1 and 2 found greater resistance to prefeeding or extinction for C-R than for NC-R conditions in 8 of 16 comparisons. With respect to the slopes of extinction curves, Experiments 1 and 2 demonstrated greater resistance to change for C-R than for NC-R in 4 of 12 comparisons. Considering Yarensky's data (Table 5) on trials with a peck and total pecks separately, four of six $\tilde{p}$ values were greater for C than for NC conditions. In Nevin's (1981) data (Table 5), two of three $\tilde{p}$ values were greater for C than for NC conditions. Pooling across experiments, using $\tilde{p}$ as the measure, resistance to change is greater when reinforcement is response contingent than when it is noncontingent in 14 of 25 comparisons ($p > .30$, sign test), with a mean difference of .005 ($p > .75$, t-test). Logically, it is not possible to prove the null hypothesis, but the overall accumulation of data suggests that contingent reinforcement does not increase resistance to change.

Resistance to change in the rich-schedule component. In Experiment 1, responding in the

Table 5

Weighted proportions of baseline ($\tilde{p}$) in previous studies comparing resistance to change for contingent (C) and noncontingent (NC) reinforcement.

Discrete-trial experiment by Yarensky (reported by Nevin, 1979); resistance to change assessed by free food between trials.

		Bird		
		58	59	60
Trials with one or more	NC	.23	.91	.15
pecks	C	.25	.84	.68
Total responses	NC	.21	.26	.27
	C	.14	.35	.61

Multiple VI 24-s VT 24-s (Nevin, 1981); resistance to change assessed by prefeeding.

		Bird		
		B7	49	58
Total responses	NC	.73	.39	.12
	C	.91	.34	.13

green, VI 36-s component was generally more resistant to prefeeding than in either C or NC conditions, which included food presentations on a VI 180-s schedule. This result is in agreement with many earlier findings (e.g., Nevin et al., 1981; see Nevin, 1979, in press, for review). However, for some subjects in Experiment 1 and more generally in Experiment 2, responding in the rich-schedule component was often less resistant to extinction than in any of the preceding components, all of which had five-fold less frequent reinforcement. This result is decidedly at variance with many earlier findings (see Nevin, 1979, in press, for review). However, it is not unique. An analogous result has been reported by Fantino (1965) for extinction after training on chained VI FR schedules: Responding extinguished relatively more rapidly in the terminal link, previously correlated with food, than in the initial link, in which food had never been obtained. Our procedure may be construed as a chained schedule with infrequent food in the initial links and frequent food in the terminal link, and our results are functionally similar to those obtained by Fantino. Both findings may arise in part from the greater discriminability of the transition to extinction from frequent food than that from infrequent food—a factor that in some of our previous work has reduced differences in resistance to extinction relative to differences in resistance to change

obtained with other assessment methods (e.g., Nevin et al., 1983; for discussion, see Nevin, in press). This difference in discriminability may interact with the use of a timeout after the richer schedule, a procedure that reduced resistance to extinction in the NC-X component relative to that in the NC-R component (see above). It is clear that much remains to be learned about the determinants of resistance to extinction in sequences of reinforcement schedules (see Nevin et al., 1981, for further discussion). However, this uncertainty does not affect comparisons of different components occupying equivalent positions in schedule sequences and having the same rate of food reinforcement, as for the NC-X, C-X, NC-R, and C-R components discussed above.

Response Rate

Effects of the value of the following schedule. In Experiment 2, response rates were higher preceding transitions to nonreinforcement (C-X and NC-X components) than preceding transitions to the richer schedule (C-R and NC-R components). These differences cannot be based on absolute or relative overall rates of reinforcement, because those variables were the same for all components. Therefore, these differences exemplify and replicate the following-schedule contrast effect first reported by Pliskoff (1963) and studied further by Williams (1979, 1983).

Effects of the response contingency for transitions to nonreinforcement. In Experiment 2, response rates in C-X components were roughly equal to those in NC-X components. Thus, there was no evidence that contingent transitions to a signaled period of nonreinforcement (timeout) had any punishing effect. Such an effect might have been expected on the basis of a study by Branch, Nicholson, and Dworkin (1977). They trained pigeons to peck a key on a multiple VI 1-min, VI 6-min schedule, and showed that response rates in the VI 1-min component decreased from an average of about 100 responses per minute when 20-s timeouts were noncontingent to about 50 responses per minute when timeouts were response contingent. However, Branch et al. (1977) presented contingent timeouts after every third response on the average, with the result that overall food rates per hour spent in the VI 1-min component increased by 80% if response rate decreased from 100 to 50 re-

sponses per minute (for calculations, see Appendix 2). By contrast, our schedule of timeout presentation was VI 40 s. If response rate decreased from 90 to 80 responses per minute in the C-X component (these numbers are representative—see Figure 5) there would be a net improvement of only 0.08% (see Appendix 2). There is a long-standing problem of separating the punishing effects of timeout from the accompanying changes in overall reinforcement rate (e.g., Leitenberg, 1965), and it may well be that timeout from reinforcement per se is not an effective punisher when contingent and noncontingent transitions are compared. Some observing-response studies have found evidence of punishment by stimuli correlated with extinction in the absence of changes in overall reinforcement rate (e.g., Mulvaney, Dinsmoor, Jwaideh, & Hughes, 1974) but they have not compared contingent and noncontingent punishment, so the question remains open.

Effects of the response contingency for transitions to the richer schedule. In both Experiments 1 and 2, response-contingent transitions to a richer schedule (C-R components) established and maintained higher response rates than did noncontingent transitions (NC-R components). In Experiment 1, this difference was observed both across successive conditions and within sessions. In Experiment 2, this difference was consistently observed in a still more complex within-session procedure. This finding demonstrates that the transition meets the fundamental definition of reinforcement (cf. Baum, 1973, on the notion of reinforcement as situation transition).

This reinforcement effect cannot plausibly be ascribed to a net increase in overall food rates achieved by higher response rates in the C-R component. For example, an increase from 60 to 70 responses per minute (which is representative for Experiment 2—see Figure 5) leads to a net increase of about 0.12% in food reinforcers per hour in the C-R component and the following, richer schedule (see Appendix 2). It seems extremely unlikely that such a small difference in reinforcement rate could appreciably affect behavior. We conclude that the increase in response rate in C-R relative to NC-R components depended on the immediate, peck-produced onset of the cue for the richer schedule, despite the probable absence of any detectable change in overall food rate. A recent study of delayed reinforcement

IMPLICATIONS

Given these results, how shall we talk about response strength in relation to the reinforcement process? K. Smith (1974) suggested that behavioral situations can be ordered on a continuum, where upward transitions are reinforcing and downward transitions are punishing (cf. Baum, 1973). Smith went on to argue that response strength in any given situation should be identified with the location of that situation on the continuum, as determined by the intensity of punishment required to bring responding in that situation all the way down to zero. We quote: "To reinforce—to 'strengthen'—is thus to make refractory to attenuation. 'Strong' behavior, 'strong' responses, 'strong' S-R connections are, accordingly, those least liable to disruption by punishment. Ergo, 'strength of behavior' is essentially synonymous with 'resistance to cancellation by attenuation' " (p. 141). Although Smith argued that resistance to attenuation should be measured by finding the intensity of punishment that is just exactly sufficient to cancel the response, we have argued elsewhere (Nevin, 1979) that many other variables are functionally equivalent to punishment in this respect, and that the levels or slopes of functions relating relative response rates to these variables are at least ordinally equivalent to points of cancellation. In all other respects, we concur with Smith's approach.

In Smith's (1974) terms, we found that contingent upward transitions (C-R) increased rate of responding relative to noncontingent upward transitions (NC-R) from a common situation, but did not affect relative resistance to change in those situations. We also found greater resistance to change for noncontingent upward transitions (NC-R) than for noncontingent downward transitions (NC-X) from a common situation. These results can be reconciled with our previous findings of greater resistance to change in components correlated with higher rates, greater magnitudes, or lesser delays of reinforcement by reference to stimulus–reinforcer relations. For example, in a two-component multiple schedule, there is a stronger stimulus–reinforcer correlation in the component with the higher rate of reinforcement, and resistance to change is greater in that component. Likewise, there is a stronger stimulus–reinforcer correlation for the NC-R component (which reliably precedes a transition to a higher rate of reinforcement) than for the NC-X component (which reliably precedes a transition to a lower rate of reinforcement), and resistance to extinction is greater in the former case (see also Nevin, 1984). Conversely, stimulus–reinforcer relations do not differ for the C-R and NC-R conditions, and there is no reliable difference in resistance to extinction.

Staddon (1975) places a similar emphasis on stimulus–reinforcer contingencies. He views behavior as being strengthened or "fixed" in a stimulus situation by the strength of the stimulus–reinforcer contingency, where response–reinforcer contingencies act only indirectly through their effects on stimulus–reinforcer contingencies. He suggests that resistance to extinction is determined by the strength of response at the beginning of extinction, minus a generalization-decrement factor arising from the absence of reinforcers (as stimuli). Our results and interpretations are entirely consistent with Staddon's position.

At this point, a major conceptual and terminological issue arises. The defining property of reinforcement is the increase in response rate when certain consequences are presented contingent upon that response; but it now appears that this defining property is not necessarily correlated with an increase in resistance to change, over and above the effects of environmental stimuli that precede or accompany those consequences. If resistance to change is identified with response strength, and reinforcement is presumed to strengthen responding, one must conclude that response-contingent reinforcement does not reinforce!

Clearly, a distinction must be made between the separable effects of the contingencies between responding and its consequences, and the relations between stimuli and those consequences. Morse (1966) made a related distinction between the "shaping" and "strengthening" effects of reinforcement, but he identified the basic operant contingency with "strengthening." It may be preferable to speak of "enhancement" when the contingency between a response and a consequent stimulus increases response rate, because that term

avoids any implication of strengthening. When a consequent stimulus increases resistance to change in the presence of a distinctive stimulus because of its relation to that stimulus, the process should be termed "strengthening." Thus, in broad terms, enhancement involves the effects of operant contingencies on ongoing action, whereas strengthening involves the effects of Pavlovian contingencies on enduring stimulus control.

Given the frequency with which the word "reinforcement" has appeared in experimental and theoretical accounts of behavior to designate the process whereby response rate increases, and the presumed strengthening consequences of this verbal practice, the traditional use of the term is itself likely to be exceedingly resistant to change. A substantial program of research is required to evaluate the utility of the distinction we suggest here, but at least it is clear in the present research that the contingency between a response and a reinforcer does not strengthen operant behavior over and above the effects of the contingency between a controlling environmental stimulus and that reinforcer. This result, if replicated with other species and in other experimental settings, will be significant for behavior modification and therapy as well as for theoretical and experimental analyses of behavior.

REFERENCES

Appel, J. B., & Hiss, R. H. (1962). The discrimination of contingent from noncontingent reinforcement. *Journal of Comparative and Physiological Psychology, 55,* 37–39.

Baum, W. M. (1973). The correlation-based law of effect. *Journal of the Experimental Analysis of Behavior, 20,* 137–153.

Blackman, D. (1968). Response rate, reinforcement frequency, and conditioned suppression. *Journal of the Experimental Analysis of Behavior, 11,* 503–516.

Blough, D. S. (1975). Steady state data and a quantitative model of operant generalization and discrimination. *Journal of Experimental Psychology: Animal Behavior Processes, 1,* 3–21.

Branch, M. N., Nicholson, G., & Dworkin, S. I. (1977). Punishment-specific effects of pentobarbital: Dependency on the type of punisher. *Journal of the Experimental Analysis of Behavior, 28,* 285–293.

Fantino, E. (1965). Some data on the discriminative stimulus hypothesis of secondary reinforcement. *Psychological Record, 15,* 409–415.

Halliday, M. S., & Boakes, R. A. (1971). Behavioral contrast and response independent reinforcement. *Journal of the Experimental Analysis of Behavior, 16,* 429–434.

Leitenberg, H. (1965). Is time-out from positive reinforcement an aversive event? *Psychological Bulletin, 64,* 428–441.

Morse, W. H. (1966). Intermittent reinforcement. In W. K. Honig (Ed.), *Operant behavior: Areas of research and application* (pp. 52–108). New York: Appleton-Century-Crofts.

Mulvaney, D. E., Dinsmoor, J. A., Jwaideh, A. R., & Hughes, L. H. (1974). Punishment of observing by the negative discriminative stimulus. *Journal of the Experimental Analysis of Behavior, 21,* 37–44.

Nevin, J. A. (1974). Response strength in multiple schedules. *Journal of the Experimental Analysis of Behavior, 21,* 389–408.

Nevin, J. A. (1979). Reinforcmeent schedules and response strength. In M. D. Zeiler & P. Harzem (Eds.), *Advances in analysis of behaviour: Vol. 1. Reinforcement and the organization of behaviour* (pp. 117–158). Chichester, England: Wiley.

Nevin, J. A. (1981, April). Does contingent reinforcement affect response strength? Paper presented at the meeting of the Eastern Psychological Association, New York.

Nevin, J. A. (1984). Pavlovian determiners of behavioral momentum. *Animal Learning & Behavior, 12,* 363–370.

Nevin, J. A. (in press). Behavioral momentum and the partial reinforcement effect. *Psychological Bulletin.*

Nevin, J. A., & Baum, W. M. (1980). Feedback functions for variable-interval reinforcement. *Journal of the Experimental Analysis of Behavior, 34,* 207–217.

Nevin, J. A., Mandell, C., & Atak, J. R. (1983). The analysis of behavioral momentum. *Journal of the Experimental Analysis of Behavior, 39,* 49–59.

Nevin, J. A., Mandell, C., & Yarensky, P. (1981). Response rate and resistance to change in chained schedules. *Journal of Experimental Psychology: Animal Behavior Processes, 7,* 278–294.

Pliskoff, S. S. (1963). Rate-change effects with equal potential reinforcements during the "warning" stimulus. *Journal of the Experimental Analysis of Behavior, 6,* 557–562.

Roberts, J. E., Tarpy, R. M., & Lea, S. E. G. (1984). Stimulus–response overshadowing: Effects of signaled reward on instrumental responding as measured by response rate and resistance to change. *Journal of Experimental Psychology: Animal Behavior Processes, 10,* 244–255.

Royalty, P., Williams, B. A., & Fantino, E. (1987). Effects of delayed conditioned reinforcement in chain schedules. *Journal of the Experimental Analysis of Behavior, 47,* 41–56.

Skinner, B. F. (1938). *The behavior of organisms.* New York: Appleton-Century.

Smith, K. (1974). The continuum of reinforcement and attenuation. *Behaviorism, 2,* 124–145.

Smith, L. D. (1979). The resistance to change of responding controlled by single and double cues. Unpublished master's thesis. University of New Hampshire, Durham.

Staddon, J. E. R. (1975). Learning as adaptation. In W. K. Estes (Ed.), *Handbook of learning and cognitive processes: Vol. 2. Conditioning and behavior theory* (pp. 37–98). Hillsdale, NJ: Erlbaum.

Staddon, J. E. R., & Motheral, S. (1978). On matching and maximizing in operant choice experiments. *Psychological Review, 85,* 436–444.

Tarpy, R. M., & Roberts, J. E. (1985). Effects of signaled reward in instrumental conditioning: Enhanced learning on DRL and DRH schedules of reinforcement. *Animal Learning & Behavior, 13,* 6–12.

Thorndike, E. L. (1913). *Educational psychology: Vol. II. The psychology of learning.* New York: Teachers College, Columbia University.

Williams, B. A. (1979). Contrast, component duration, and the following schedule of reinforcement. *Journal of Experimental Psychology: Animal Behavior Processes, 5,* 379–396.

Williams, B. A. (1983). The following schedule of reinforcement as a fundamental determinant of steady state contrast in multiple schedules. *Journal of the Experimental Analysis of Behavior, 35,* 293–310.

APPENDIX 1

MEASURING RESISTANCE TO CHANGE

The evaluation of resistance to change for two or more free-operant performances requires comparing the changes from response rates maintained under stable baseline conditions to the reduced response rates that result when conditions are altered: The performance with the smaller change has the greater resistance to change. Any metric will give the same ordering if baseline response rates are the same (e.g., Blackman, 1968); the problem is to identify an appropriate metric when the baseline response rates differ.

Two obvious candidates are the difference, $B_o - B_x$, and the proportion, B_x/B_o, where B_o is the baseline response rate and B_x is response rate when conditions are altered to x. The difference runs into trouble when baseline response rates are substantially different for the two performances. For example, if B_{o1} is 100 responses per minute, B_{o2} is 50 responses per minute, and conditions are altered to x so that B_{x1} is 20 and B_{x2} is 5, we would conclude that B_{o1} is less resistant to change than B_{o2} because $100 - 20$ is greater than $50 - 5$. But this conclusion would follow for any value of B_{x1} less than 50, and for any value of B_{x2} at all, because the latter cannot go below zero. Even with less extreme differences, downward variation is more limited for the performance with the lower baseline, biasing the comparison of differences in favor of the conclusion that the performance with the higher baseline rate is less resistant to change.

One way to avoid this bias is to transform response rates to logarithms, which range to minus infinity. For the example above, $\log B_{o1} - \log B_{x1}$ is 0.7, and $\log B_{o2} - \log B_{x2}$ is 1.0, so we would conclude that B_{o1} is more resistant to change than B_{o2}. If these hypothetical data were expressed as proportions, we would arrive at the same conclusion, because B_{x1}/B_{o1} is 0.2 and B_{x2}/B_{o2} is 0.1, where the larger proportion indicates a smaller change from baseline. Of course these conclusions must agree, because $\log B_o - \log B_x = -\log B_x/B_o$, which is simply the log proportion of baseline. For these reasons, our analyses have consistently used the proportion of baseline as the metric for resistance to change.

When several values of x are employed, each following an independent determination of baseline (as in prefeeding), a useful summary measure of resistance to change is the weighted average,

$$\bar{p} = \frac{\Sigma \, x_i p_i}{\Sigma \, x_i}$$

where x_i is the ith value of x, and p_i is the proportion of baseline at that value. This dimensionless statistic is designed to give greater weight to the effects of large values of x than to small values, because small values are less likely to produce large differential decrements in response rate. This measure was used

by Nevin (1984) to isolate the effects of noncontingent transitions in successive schedule components with different reinforcement rates, and by Nevin et al. (1981) to evaluate resistance to change in chained schedules. In the latter study, $\bar{p}$ was related to terminal-link reinforcer rate and duration in an orderly way, and the relation was the same for the initial and terminal links even though $\bar{p}$ was systematically lower in the initial links. The difference between initial-link and terminal-link values of $\bar{p}$ was also quantitatively similar across several studies of two-link chains from different laboratories and using different methods to assess resistance to change. Thus, $\bar{p}$ is a sensitive, orderly measure that enters into invariant relations.

Another useful summary measure is the slope of the relation between B_x/B_o and x. Empirically, it is often the case that $\log B_x/B_o$ is roughly linear with respect to x, where the function with the shallower slope identifies the performance with greater resistance to change (see Nevin, 1979, for examples). Slopes may be especially useful when successive values of x are explored after a single baseline determination, as in extinction (where x is number of extinction sessions).

A special problem arises in the analysis of extinction data following training on different schedules, because terminating reinforcement may lead to greater or lesser generalization decrement at the outset of extinction, depending on the baseline rate of reinforcement. For example, the initial decrement in response rate following continuous reinforcement may be far greater than that following intermittent reinforcement. However, the slopes of the extinction curves over subsequent extinction sessions are often shallower after continuous reinforcement, suggesting greater resistance to change despite the larger initial decrement (Nevin, in press). Therefore, we have reexpressed response rates in the second and subsequent extinction sessions as log proportions of the response rate in the first extinction session and calculated the slope of the function relating these log proportions to session number (x) by the method of least squares. The slope is expressed in units of log change per session. Since the relation is logarithmic, its slope is invariant with respect to multiplication or division, and the denominator for the calculation of log proportion can be chosen arbitrarily.

APPENDIX 2

Estimating the Effects of a Change in Response Rate on the Obtained Rate of Food Presentation

We begin by applying the method to response-contingent transitions to extinction (C-X) in our Experiment 2. The duration of a component is the sum of the scheduled duration and the time before the next response after the schedule elapses. Assuming that responding is randomly distributed, the time to the next response is well represented by the reciprocal of the response rate (Staddon & Motheral, 1978; see Nevin & Baum, 1980, for a more complex and precise expression, but its increment in precision is immaterial when response rates are high). The relation can be expressed as $T = t + 1/r$, where T is obtained component duration, t is scheduled duration, and r is response rate.

For a component duration of 40 s and a response rate of 90 per minute (1.5 responses per second), the expected duration is $40 + 1/1.5 = 40.67$ s. If the response rate drops to 80 per minute (1.33 per second), the expected duration is $40 + 1/1.33 = 40.75$ s. During this period, the subject receives the scheduled rate of food presentation, which is 36 per hour on a VI 100-s schedule. During the following 30-s period, the subject receives no food at all. The duration of the whole sequence is the duration of the first component plus 30 s. Thus, the overall average food rate is $36 \times 40.67/70.67 = 20.718$ per hour if response rate is 90

per minute, and 36 × 40.75/70.75 = 20.735 per hour if response rate is 80 per minute. The net relative improvement in food rate if response rate drops from 90 to 80 per minute is therefore .017/20.718 = 0.0008, or 0.08%.

The same sort of reasoning may be applied to the effects of contingent transitions to the richer schedule (C-R components). If response rate is 60 per minute (1 response per second), component duration is 40 + 1/1 = 41 s. If response rate increases to 70 per minute (1.17 per second), component duration becomes 40 + 1/1.17 = 40.86. During the C-X component, the subject receives 36 food presentations per hour, and during the following 30-s period with the richer schedule, it receives 180 per hour. The overall average food rate is therefore (36 × 41/71) + (180 × 30/71) = 96.845 per hour if response rate is 60 per minute, and (36 × 40.86/70.86) + (180 × 30/70.86) = 96.965 per hour if response rate increases to 70 per minute. The net relative increase in food rate is therefore 0.120/96.845 = .0012, or 0.12%.

Lower response rates, as in Experiment 1, will result in a somewhat larger relative increase, but it seems unlikely that the change in reinforcement rate resulting from a change in response rate in the present experiment can be a major factor in either C-X or C-R components.

Much larger changes in reinforcement rate resulted from changes in response rate in the study of response-contingent versus response-independent timeouts by Branch et al. (1977). The random-ratio 3 schedule of timeout presentation means that a rate of 100 responses per minute will produce 100 20-s timeouts in a 3-min component. Adding total timeout duration to component duration gives 2,180 s, during which the subject receives three food reinforcers on the VI 1-min schedule. If the rate drops to 50 responses per minute, 50 timeouts are produced per 3-min component, and the sum of timeout duration and component duration is now 1,180 s, during which three reinforcers are presented. The net relative increase in reinforcement rate is 0.85, or 85%.