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THE EFFECTS OF RESPONSE COST AND RESPONSE RESTRICTION ON A MULTIPLE-RESPONSE REPERTOIRE WITH HUMANS

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In two experiments a multiple-response repertoire of four free-operant responses was developed with university students as subjects using monetary gain as reinforcement. Following baseline, one of the responses was reduced either by making monetary loss contingent upon it (response cost) or by removing it from the repertoire (response restriction). In Experiment 1 a multielement baseline design was employed in which baseline and restriction or response-cost contingencies alternated semirandomly every 3 minutes. In Experiment 2 a reversal design was employed (i.e., baseline, restriction or response cost, then baseline), and each response required a different amount of effort. Both experiments had the following results: (a) The target response decreased substantially; (b) most nontarget responses increased, and the rest remained near their baseline levels; and (c) no support was found for Dunham's hierarchical, most frequent follower, or greatest temporal similarity rules. For several subjects, the least probable responses during baseline increased most, and the most probable responses increased least. Furthermore, in Experiment 2, responses with the lowest frequency of reinforcement increased most (for all 7 subjects), and those with the greatest frequency of reinforcement increased least (for 5 subjects).

Key words: response cost, response restriction, multiple-response repertoire, variable-interval schedules, response force, multielement baseline, reversal design, time allocation, humans

When responding is reinforced with identical variable-interval (VI) schedules in both components of a multiple schedule (Ferster & Skinner, 1957), similar response rates are obtained in each component (de Villiers, 1977; Herrnstein, 1970, 1974). If reinforcement is later withheld in one component, responding in that component decreases and responding in the other component increases (Reynolds, 1961; Skinner, 1938). This phenomenon is called *behavioral contrast.* Similar contrast has been found when punishment is introduced in one component of a multiple schedule or is made contingent on one response in a concurrent schedule (Azrin & Holz, 1966; Bradshaw, Szabadi, & Bevan, 1979; Brethower & Reynolds, 1962; Deluty, 1976; Dunham, 1972). When only two responses are employed and one is punished, it has been shown consistently that the rate of the unpunished response increases (Azrin & Holz, 1966). When more than one unpunished response is employed, however, more complex patterns have been found. The most extensive experimental assessments of the effects of punishment on more than one unpunished response have come from the laboratories of Dunham and Crosbie.

Dunham's Studies

Dunham and his colleagues (Dunham, 1971, 1972, 1978; Dunham & Grantmyre, 1982) studied gerbils in an experimental chamber in which several activities (e.g., eating, running, drinking, shredding cardboard, digging in sand, and grooming) were freely available (i.e., no shaping or active manipulation of contingencies was employed). The animals were given several sessions for behavioral preferences to stabilize, then electric shock was presented contingent on one of the responses in this multiple-response repertoire. It was found that shock increased the most probable of the unpunished baseline responses (Dunham, 1978), and decreased the response that had most frequently followed the punished response during baseline (Dunham & Grantmyre, 1982). Initially, Dunham (1978) argued that the in-

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crease of the most probable baseline response can be explained by implicit avoidance. According to this explanation, because the punisher was never presented while an unpunished response was performed, the most probable response during baseline (which is likely to be the most probable response during the punishment phase) would most frequently postpone the punisher, and therefore increase by adventitious avoidance conditioning. Later this explanation was abandoned when it was found that response restriction also increases the most probable baseline response (Dunham & Grantmyre, 1982). The label *implicit avoidance* was therefore replaced by the theoretically neutral *hierarchical rule.*

The reduction of the most frequent follower of the target response during baseline was explained in terms of chains of responses and stimulus control. It was proposed that a stable chain of responses would emerge during baseline, and the target response would function as a discriminative stimulus (S^D) for the next response in the chain (the follower). When the target response decreased during the punishment phase, the follower would also decrease because its S^D (the target) was removed (Dunham & Grantmyre, 1982).

In summary, Dunham's work with gerbils had three major findings: (a) Punishment increased the most probable unpunished baseline response, (b) punishment decreased the most frequent follower of the punished response, and (c) these effects were not produced only by the aversive aspects of punishment, because response restriction also had similar consequences.

In an assessment of the external validity of these findings, Dunham, Cornwall, and Hurshman (1986) performed a systematic replication of the gerbil studies in which human subjects engaged in games or leisure activities, and response restriction was employed instead of electric shock. In Experiment 1, university students played pinball, pool, darts, and a video game in a multiple-response repertoire. After four sessions of baseline, one of responses was removed for four sessions, and then there were four more sessions of baseline. During the restriction phase, there was an increase in response duration only for the response that, during baseline, had the most similar temporal pattern to the restricted response (i.e., the most similar mean bout time for the response, and the most similar period between bouts of responding); response durations did not change significantly for the other responses in the repertoire. It was also found that the most probable baseline response often had the most similar temporal pattern to the restricted response. This new temporal similarity rule was therefore compatible with the hierarchical rule. Unfortunately, there was insufficient switching between responses to provide a good test of the generality of the greatest follower proposition.

Crosbie's Studies

In Crosbie's initial studies (1988, 1990a, 1991), university students pressed numeric keys (0 to 9) on a computer keyboard and won and lost points that were later exchanged for money. The rates of all 10 responses were recorded, but only the target response "3" was punished: 25 cents was deducted every time "3" was pressed. In one study (Crosbie, 1990a), only the target response "3" was reinforced (VI 15 s, +5 cents); the other nine responses were neither reinforced nor punished. Response cost temporarily reduced the rate of all unpunished responses, but they eventually recovered to their baseline levels. Dunham's hierarchical rule was not supported, but there was some support for the greatest follower proposition; the data were collected before those of Dunham et al. (1986) were published, so the temporal similarity rule was not assessed. In another study (Crosbie, 1991), all 10 responses (0 to 9) were reinforced on a single schedule (VI 15 s, +5 cents), but only the target response "3" was punished (−25 cents for every response). For 2 subjects, punishment produced an increase in nontarget responding, nontarget responses decreased slightly for 1 subject, and there was no change for 1 subject. Neither the hierarchical rule nor the greatest follower rule was supported.

In Crosbie's most recent study (1990c), four or five colored squares were displayed on a computer screen, and university students won and lost points by moving the mouse cursor into any of the response squares and pressing the mouse button. For each response, the magnitude of reinforcement was equal to the response number (e.g., in Experiment 1, Response 1 received VI 20 s +1 cent, Response 2 received VI 20 s +2 cents, etc.), and 25 cents was subtracted every time the target response was made. Virtually all unpunished responses increased, and there was no support for the hierarchical or greatest follower rules; the temporal similarity proposition was not assessed.

Procedural Differences Between the Studies of Dunham and Crosbie

The major difference between the results of Dunham and Crosbie is that Dunham consistently found change in only one unpunished or unrestricted response (selective change), whereas Crosbie consistently found change in most unpunished responses (general change). Because there are so many procedural differences between the two projects, it is difficult to determine with confidence the factors responsible for the different results. The following differences, however, are possible candidates: (a) Dunham employed temporally extended responses, whereas Crosbie used discrete responses (button presses); (b) Dunham employed topographically dissimilar effortful responses, whereas Crosbie's responses were very similar and required little effort; (c) Dunham employed intrinsic reinforcers, whereas Crosbie employed extrinsic reinforcers; (d) Dunham employed electric shock or response restriction, whereas Crosbie employed response cost; and (e) Dunham employed an ABA design (Barlow, Hayes, & Nelson, 1984) to assess change, whereas Crosbie programmed only baseline and response cost phases and assessed change with multielement comparisons (Sidman, 1960; Ulman & Sulzer-Azaroff, 1975), interrupted time-series analysis (Crosbie & Sharpley, 1989), or visual inspection.

The Present Experiments

One purpose of the present experiments was to manipulate some of the procedural differences described above to determine why Dunham and Crosbie consistently obtained different results. Consequently, in both experiments temporally extended responses were employed. Different variable-interval (VI) schedules of reinforcement plus a 2-s changeover delay (i.e., a reinforcer was not available within 2 s of switching responses; COD) were employed for each response to obtain a differentiated baseline with sufficient switching between responses to provide a test of both the greatest follower and greatest temporal similarity propositions. Furthermore, both response cost and response restriction were programmed.

Regardless of whether these manipulations would produce results similar to those obtained by Dunham, a more general, and perhaps more important, goal of the present experiments was to determine how humans redistribute their time when one free-operant response in their repertoire is punished or restricted.

EXPERIMENT 1

METHOD

Subjects

Six undergraduate students, 4 females (D10, D11, D12, and D16) and 2 males (D17 and D18), served as subjects. They ranged in age from 19 to 23 years, and none had participated previously in psychological experiments.

Apparatus

Experimental sessions were conducted in a sound-attenuating experimental cubicle (163 cm by 133 cm) containing a Samsung® S330 (IBM® PC compatible) personal computer, an ECM-5400® enhanced color graphics monitor, a Microsoft® mouse, and a rubber mouse pad. All equipment was placed on a shelf (163 cm by 61 cm) that ran along the back wall of the cubicle 75 cm above the floor. The subject sat in the center of the cubicle in front of the monitor, with the mouse resting on the mouse pad slightly to the right of the monitor (all subjects were right handed); the computer was placed on the far right of the shelf. The keyboard was removed from the computer so that the subject would not be distracted by it and could not use it to interfere with the experimental program. An exhaust fan operated continuously during all sessions to provide ventilation and masking noise.

The mouse was the response device (Crosbie, 1990b), and a computer program controlled the experiment. During experimental sessions, four colored squares (2 cm) were displayed in the shape of a cross in the center of the blue screen (25 cm by 16 cm). The top and bottom squares were 3.5 cm apart, as were the left and right squares. The top square was Location 1, the left square was Location 2, the right square was Location 3, and the bottom square was Location 4. The program recorded how many times the subject moved the block mouse cursor (0.33 cm by 0.66 cm) into each of the response squares, plus the total time the cursor was in each square (the principal de-

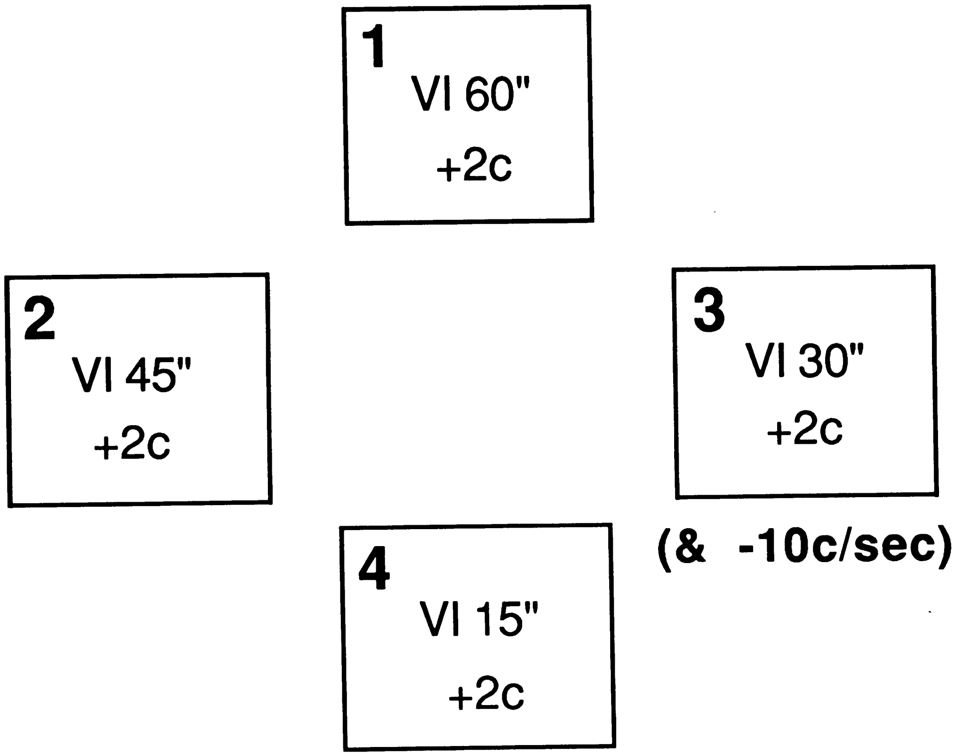

Fig. 1. A schematic representation of the layout of response locations plus the contingencies arranged for each location in Experiment 1. The number assigned to a location is shown in the top left corner of the square. During the experiment, none of the information shown in the figure was displayed to subjects.

pendent variable). Figure 1 shows the layout of the response squares and the contingencies arranged for each square.

Procedure

Instructions. Before the first session, each subject read the following instructions:

> This is a situation in which you can earn money. When the block cursor is in any of the green or red squares in the center of the screen, you can win and lose points. To move the cursor you merely move the mouse on the rubber mouse pad; you will know when the cursor is in a colored square because the cursor will change color. At the end of the experiment you will receive either your total score in cents (e.g., 2,000 points equals $20) or $50, whichever is greater. Your score will be continuously displayed at the top of the screen. Throughout this experiment, green or red squares will be displayed in the center of the screen for 3 minutes, then they will disappear for 15 seconds, then they will reappear. You can only win and lose points when the cursor is in a square, so when the squares disappear, rest for 15 seconds. You may move the mouse anywhere on the mouse pad and press the buttons on the mouse, but do not touch any buttons or knobs on the computer because this may crash the program and your money may be lost.

Design. A multielement baseline design (Sidman, 1960; Ulman & Sulzer-Azaroff, 1975) was employed. Each session consisted of five 3-min presentations of red squares and five 3-min presentations of green squares (in a semirandomized order; Gellermann, 1933), with each 3-min period separated by 15 s of timeout. For all subjects, both green and red squares were correlated with baseline conditions throughout the 13 sessions of Phase 1 (baseline). During Phase 2 (12 sessions) for D10, D12, D16, and D18, green squares continued to be correlated with baseline conditions, whereas red squares were correlated with response cost or response restriction; for D11 and D17, red squares continued to be correlated with baseline conditions, whereas green squares were correlated with response cost or response restriction.

During the baseline phase, 2 points were obtained whenever the cursor was in a response square after an interval that averaged 60 s, 45 s, 30 s, and 15 s, for Locations 1 to 4, respective (VI 60 s, 45 s, 30 s, and 15 s; Catania & Reynolds, 1968, p. 343, arithmetic sequence). Each location had its own independent timer, and a 2-s COD was programmed so that reinforcers were not presented within 2 s of switching between response locations. There were no programmed consequences between experimental periods or when the cursor was not in a response square. At the start of each experiment period, a 1000-Hz tone was presented for 100 ms. Whenever a reinforcer was presented, the point score (continuously displayed in white in a 5-cm by 2-cm yellow box in the center, and 1 cm from the top, of the screen) was incremented by the value of the reinforcer, and a 1500-Hz tone was presented for 150 ms. Response cost was a reduction of points and the presentation of a 100-Hz tone for 300 ms.

To maintain conditions comparable to those in Dunham and Crosbie's studies, all subjects received 13 sessions during Phase 1 (similar in number to those in Dunham and Grantmyre, 1982, and Crosbie, 1990c, and more sessions than in Dunham et al., 1986) and 12 sessions during Phase 2 (response cost or response restriction). During the response cost phase, baseline conditions continued, but Response 3 also produced a 10-point loss for every second that the cursor was in Square 3. During the response restriction phase, Square 3 was not displayed, and there were no programmed consequences for moving the cursor into the area where it had been displayed during baseline (the program, however, recorded time spent in all four locations and response sequences in the same way it did during baseline). D10, D11, and D12 received response restriction; D16, D17, and D18 received response cost.

Results and Discussion

Figures 2 and 3 show that both restriction and response cost produced an immediate, sustained reduction in time spent in the target square (3). Restriction also increased time spent in six of the nine nontarget locations shown in Figure 2; time in the other nontarget locations was similar in both multielement components. Similarly, response cost increased time spent in seven of the nontarget locations shown in Figure 3, and in the other nontarget locations there was no systematic difference in total response duration between the two components. Contrary to Dunham's findings, restriction and response cost did not reduce time spent in any nontarget location.

Figure 4 shows that restriction produced the smallest percentage increase in response duration for the most probable nontarget location during baseline (4, 1, and 2 for D10, D11, and D12, respectively; see Table 1 for percentage changes). Similarly, for 2 subjects (D16 and D18), response cost also produced the smallest percentage increase in response duration for the most probable nontarget location during baseline (4 for all subjects) and an intermediate percentage increase for the other subject (D17). Clearly, these data do not support the hierarchical rule.

For the subjects who received restriction, the greatest follower had the smallest percentage increase (D11), an intermediate increase (D10), and the greatest percentage increase (D12). Similarly, for the subjects who received response cost, the greatest follower also had the smallest percentage increase (D18), an intermediate increase (D17) and the greatest percentage increase (D16). These results provide no support for the greatest follower proposition.

Table 1 shows temporal similarity (TS) to the target location data. Mean bout duration (Mbout) was the total time in a location divided by the number of occasions on which that location was entered. Mean interbout interval (MIBI) was the mean time between leaving a location and entering it on the next occasion. TS was computed with the formula $TS = ABS\ (Mbout_L - Mbout_T) + ABS\ (MIBI_L - MIBI_T)$, where ABS is the absolute value, $Mbout_L$ and $MIBI_L$ are Mbout and MIBI for the location, and $Mbout_T$ and $MIBI_T$ are Mbout and MIBI for the target (3). Small TS values suggest greater temporal similarity to the target. For the subjects who received restriction, the location with the greatest TS (1, 2, and 2 for D10, D11, and D12, respectively) had either an intermediate or small percentage increase in time (see Table 1). For the subjects who received response cost, the location with the greatest TS (4, 2, and 4 for D16, D17, and D18, respectively) had either a slight decrease or the smallest percentage increase in

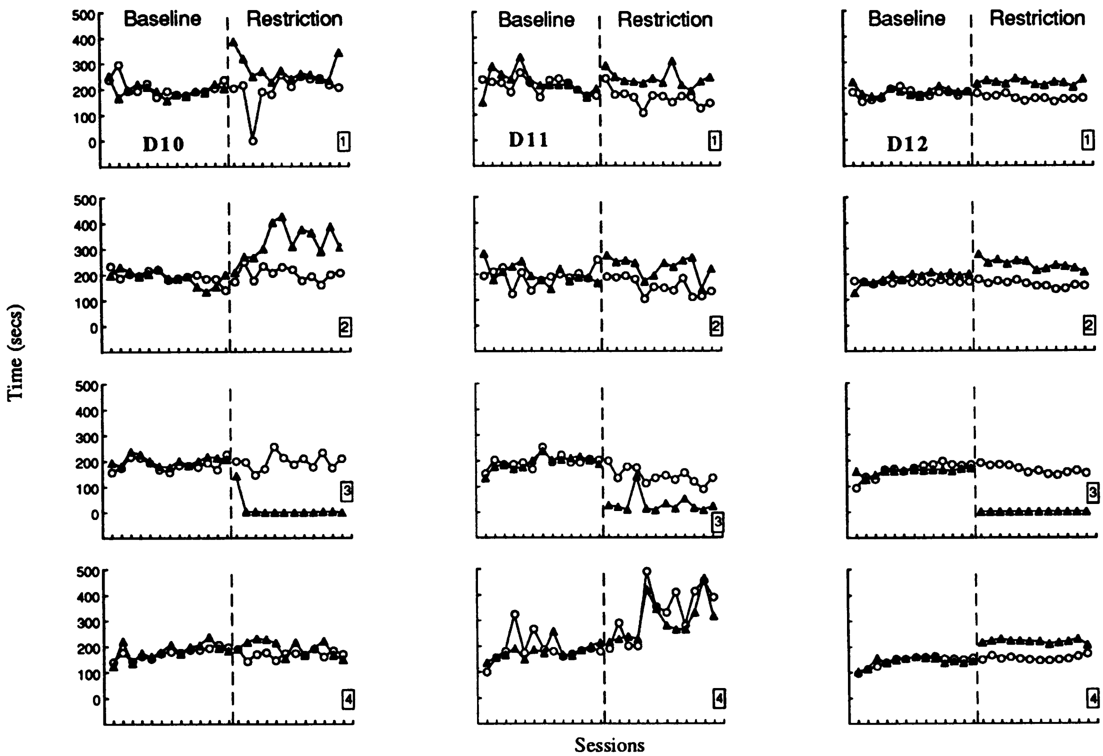

Fig. 2. For the subjects in Experiment 1 who received response restriction, total response duration for each location during each session. Open circles indicate the multielement component correlated with baseline conditions throughout the study, and closed triangles show the component correlated with the restriction of Location 3.

time. The present data do not support the temporal similarity rule.

The present experiment substantially replicated that of Crosbie (1990c): Response cost and restriction quickly reduced response duration in the target location, time spent in most nontarget locations increased, and the hierarchical and greatest follower rules were not supported. The greatest temporal similarity rule also was not supported. Hence, Dunham's use of temporally extended responses cannot explain the differences between his results and those of Crosbie (1990c).

In addition to the general increase in nontarget responding regularly found with punishment and several free-operant responses (Crosbie, 1990a, 1990c, 1991), the present experiment also found that response duration during baseline can predict the relative magnitude of changes in response duration for nontarget locations during restriction and response cost. The least probable locations during baseline had the greatest percentage increase for 4 subjects (D10, D12, D17, and D18), and the most probable locations had the smallest percentage increase for 5 subjects (D10, D11, D12, D16, and D18).

EXPERIMENT 2

In Experiment 1 all responses were topographically similar, differing only in the reinforcement frequency programmed for each location. This may be why response durations were so similar for all locations (see Figure 4). To increase topographical dissimilarity, in the present experiment each location had a different response force requirement (10 to 40 N), with Location 1 requiring the most force and Location 4 the least force. It was also anticipated that employing a moderate response force requirement (instead of the very low force requirement used in Experiment 1) would improve matching between the programmed contingencies and response duration (Elsmore, 1971).

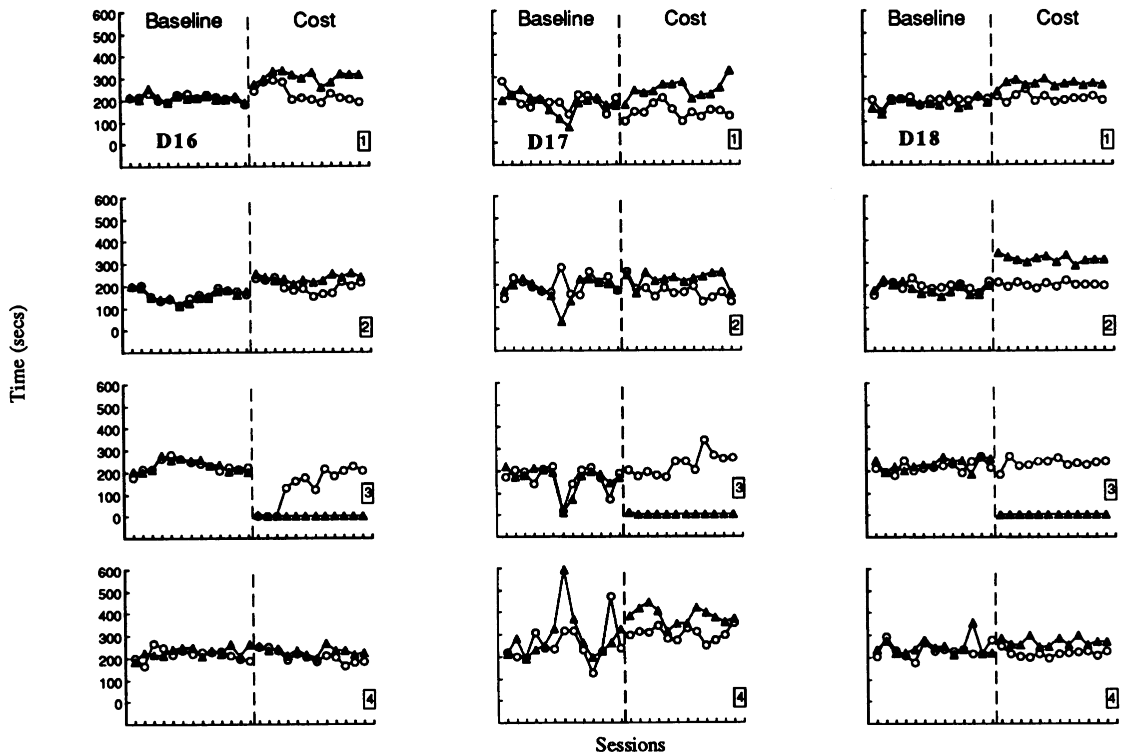

Fig. 3. For the subjects in Experiment 1 who received response cost, total response duration for each location during each session. Open circles indicate the multielement component correlated with baseline conditions throughout the study, and closed triangles show the component correlated with response cost contingent on staying in Location 3.

Experiment 1 employed a multielement design with 25 sessions per subject to maintain comparability with Crosbie's studies (1990a, 1990c). Although most responses were reasonably stable, greater confidence could be placed in the results if more sessions were used and all responses were stable before the conditions were changed. Furthermore, a reversal (ABA) design (i.e., baseline, restriction or response cost, then a return to baseline) would highlight any changes produced by the experimental conditions, and make the procedure more similar to that of Dunham et al. (1986). For these reasons, an ABA design was used in the present experiment and conditions did not change until all responses were stable.

METHOD

Subjects

Five subjects were undergraduate students (H06, H08, and H12, female; H11 and H13, male) and 2 were unemployed (H07 and H09; male and female, respectively); their ages ranged from 19 to 35 years. The only subject who had participated previously in a psychological experiment was H08, who also served in Experiment 1 as D16; she was not debriefed until both experiments were completed.

Apparatus

The computer, color monitor, mouse, and mouse pad were the same as in Experiment 1, but the present study was conducted in two areas (180 cm by 200 cm each) of a laboratory partitioned with room dividers (123 cm by 180 cm). Subjects sat at a desk (70 cm by 106 cm by 72 cm), with the computer and monitor at the back, the mouse and mouse pad at the front right (all subjects were right handed), and the response box and lever at the front left. The plywood box was 19 cm wide by 30 cm long by 19 cm high, with a slot in front for the steel rod (2 cm diameter) to protrude 4.5 cm at an angle of 24° below horizontal. The end of the rod was sealed with insulation tape, and the protruding section of the rod was wrapped in a spongy tape that is commonly used to cover

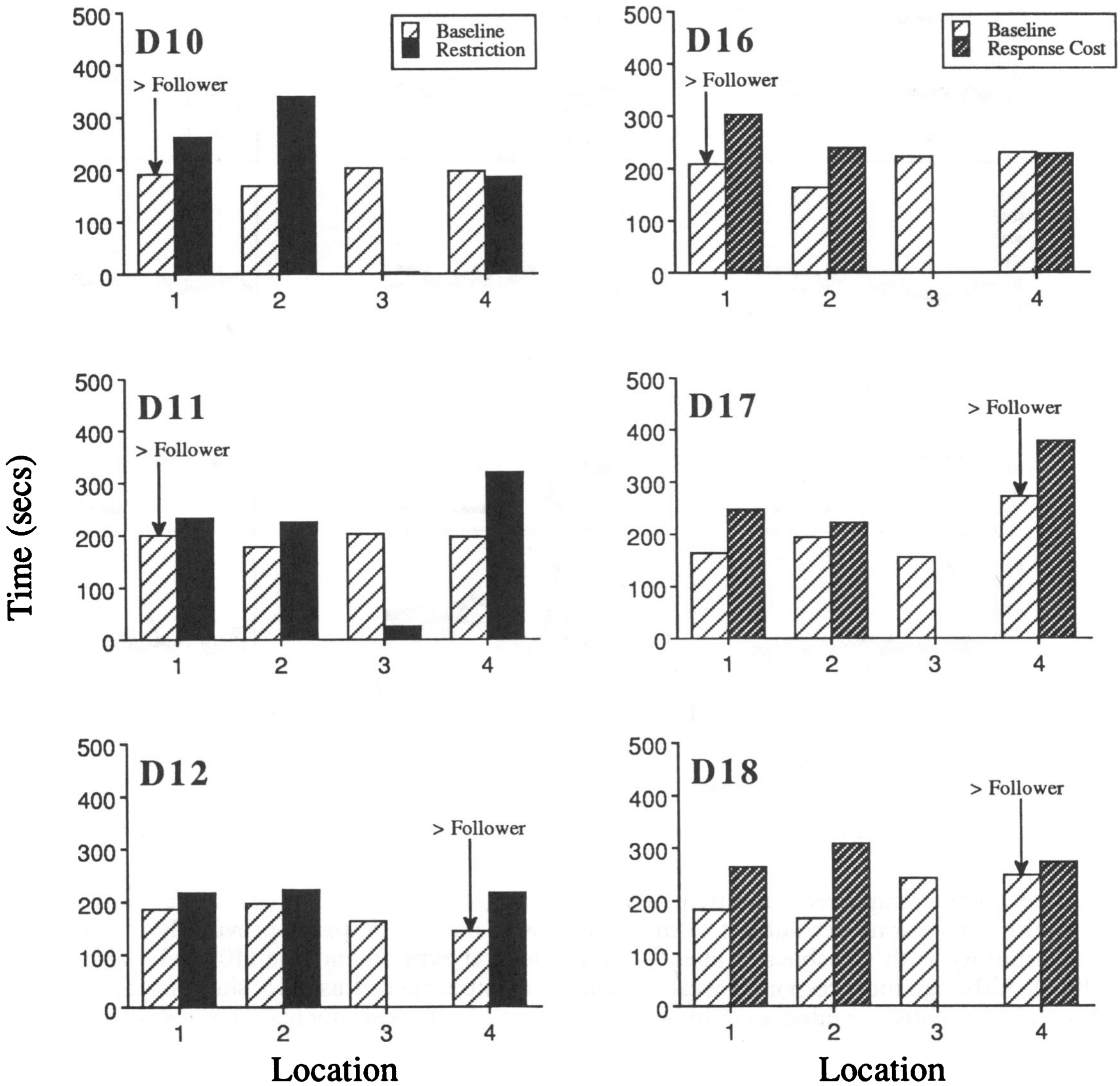

Fig. 4. For each subject in Experiment 1, mean response duration for each location during the last six sessions of baseline and the last six sessions of the restriction and response cost phases; data are shown only for the multielement component in which restriction and response cost were programmed (closed triangles in Figures 2 and 3). The target location was "3," and the location that followed the target most frequently during baseline is marked ">Follower." For example, during baseline D10 moved from the target location to Locations 1, 2, 3, and 4, on 216, 39, 61, and 97 occasions, respectively. Hence, for D10, Location 1 was the most frequent follower of the target location during baseline.

the grips of tennis racquets. Inside the box, a Lafayette 76613 force transducer was bolted to the bottom, with its five thin steel springs (4 cm by 1 cm) wrapped in nylon tape; with all five springs combined, force of 0 to 100 N (i.e., up to 10 kg weight) can be recorded. The lever was attached to a hinge on the top of the force transducer such that the lever rested on the end of the springs; the lever could move vertically and thus bend the springs. When force was applied to the springs, a small current was produced in the transducer, amplified, and converted to a number corresponding to the force.

Procedure

Instructions. Before the first session subjects read the following instructions:

> This is a situation in which you can earn money. You can earn money when the cursor is in any

Table 1

Experiment 1: Mean bout duration (Mbout), mean interbout interval (MIBI), and temporal similarity to the target response (TS) for each of the four locations during the last six baseline sessions. Percentage of change relative to baseline is also shown.

Subjects		Locations			
		L1	L2	L3	L4
Restriction					
D10	Mbout	2.772	2.788	2.890	2.505
	MIBI	48.957	65.498	51.535	48.332
	TS	2.697[a]	14.066	—	3.589
	% Change	135.99	200.23	0.80	93.73
D11	Mbout	3.611	3.401	3.671	3.237
	MIBI	66.065	66.628	67.063	61.218
	TS	1.058	0.705[a]	—	6.279
	% Change	116.75	125.46	11.75	162.46
D12	Mbout	2.796	3.333	2.904	2.112
	MIBI	53.337	60.488	64.693	58.590
	TS	11.465	4.634[a]	—	6.895
	% Change	115.70	111.72	0.20	148.95
Response cost					
D16	Mbout	3.792	3.377	3.728	3.753
	MIBI	59.988	71.402	57.010	59.007
	TS	3.042	14.742	—	2.022[a]
	% Change	146.04	144.65	0.24	98.88
D17	Mbout	3.106	3.291	2.538	3.662
	MIBI	65.712	54.010	53.855	44.258
	TS	12.425	0.909[a]	—	10.720
	% Change	150.94	114.38	0.11	138.93
D18	Mbout	2.352	2.157	2.469	2.705
	MIBI	44.868	45.585	33.093	37.190
	TS	11.892	12.804	—	4.333[a]
	% Change	143.60	183.66	0.08	109.58

[a] Greatest temporal similarity to the target location.

of the colored squares in the center of the screen. To move the cursor into a square you move the mouse on the grey rubber pad while you press the lever; you will know when the cursor is in a square because the cursor will change color. The cursor will not move into, or remain in, a square unless the lever is pressed with sufficient force for that square; each square requires a different amount of force on the lever. Sometimes when the cursor is in a square you will hear a tone and points will be added to your score. Sometimes when you are in a square you will hear another tone and points will be subtracted from your score. Throughout the experiment your point score will be shown in the box at the top of the screen. At the end of the experiment you will receive 1 cent for every point in your score (e.g., 2,000 points equals $20). It is very important that you come to every session. If you come to *all* scheduled sessions you will receive a bonus of $50. If, however, you miss sessions, you will not receive the bonus, and furthermore you will lose $10 for every scheduled session that you miss. You may move the mouse and press the lever, but do not touch anything on the computer or screen because this may crash the program and lose your points. Press the lever, do not hit it! If you hit the lever or lever box you may damage the equipment and lose all your points.

Subjects were told that metal on the wrist and hands would affect delicate equipment in the response box; consequently, they removed all metal jewelry at the beginning of each session. Thus, they were unable to use a watch to time schedules.

Design. Table 2 shows the sequence of conditions and the corresponding number of sessions for each subject. Each condition was maintained for at least 10 sessions, and until all responses had a coefficient of variation and linear trend less than or equal to .18 for the most recent eight sessions (Killeen, 1978). H06, H08, H11, and H13 had green response

Table 2

Sequence of conditions and number of sessions for the subjects in Experiment 2.

Subject	Number of sessions	Condition
Target location: L3		
H06	29	Baseline
	11	Response cost
	15	Baseline
H07	39	Baseline
	11	Response restriction
	10	Baseline
H08	14	Baseline
	18	Response restriction
	14	Baseline
H09	21	Baseline
	24	Response cost
	13	Baseline
Target location: L2		
H11	24	Baseline
	15	Response cost
	3	Baseline
H12	15	Baseline
	19	Response restriction
	12	Baseline
H13	18	Baseline
	12	Response cost
	27	Baseline

Note. H08 also served in Experiment 1 as D16.

squares throughout all phases of the experiment; H07, H09, and H12 had red squares throughout. Subjects participated for six 25-min sessions per day (Monday to Friday) with at least a 30-min break between sessions. During each session, 2 subjects worked concurrently in their respective partitioned sections of the laboratory.

During baseline, 10 points were obtained (and a 1500-Hz sound was presented for 100 ms) whenever the cursor was in a response location after an interval that averaged 120 s, 90 s, 60 s, and 30 s, for Locations 1 to 4, respectively (VI 120 s, 90 s, 60 s, and 30 s; Catania & Reynolds, 1968, p. 343, arithmetic sequence). Each location had its own independent timer. A 2-s COD was also programmed so that reinforcers were not presented within 2 s of entering a response location. The mouse cursor would move into, and remain in, a response square only if the lever was pressed with sufficient force for that square: Response force thresholds were 40, 30, 20, and 10 N for Locations 1 to 4, respectively. If the force dropped below threshold, a 2000-Hz sound was presented for 2 ms, and the mouse cursor jumped to the middle of the screen equidistant from all squares. During the response cost phase, baseline conditions continued except that 100 points were also lost (and an 80-Hz tone presented for 300 ms) for every second that the cursor was in the target square (3 or right square for H06, H07, H08, and H09; 2 or left square for H11, H12, and H13). During the response restriction phase the target square was not displayed (and no force was required to move into, or remain in, that location), and there were no programmed consequences for moving the cursor into the area in which it had been displayed during baseline (the program, however, recorded time spent in all four locations and response sequences in the same way as it did during baseline). Figure 5 shows the layout of response locations, plus the force requirement and contingencies arranged for each location.

Results and Discussion

Figures 6, 7, 8, and 9 show that restriction and response cost completely eliminated time spent at the target location, but, in general, it quickly recovered when baseline contingencies were reinstated. For most subjects and locations, time spent in nontarget locations either increased significantly or did not change, then quickly returned to the baseline level when restriction or response cost was discontinued. For all 7 subjects, Location 1 had the largest increase as a percentage of baseline duration; for 5 subjects (H07, H12, H06, H09, and H13), Location 4 had the smallest percentage increase (see Table 3).

Figure 10 shows that for most subjects (H06, H09, H13, H07, and H12), the nontarget location with the longest response duration during baseline (Location 4 for these subjects) had the smallest percentage increase when restriction and response cost were introduced. For the other 2 subjects (H08 and H11), Location 1 was the nontarget location with the longest duration during baseline, and this location had the largest percentage increase in the restriction and response costs phases. Hence, the present data provide little support for the hierarchical rule.

For most subjects the greatest follower had either the greatest percentage increase in response duration (H06, H11, and H08) or an intermediate increase (H09 and H13). For only

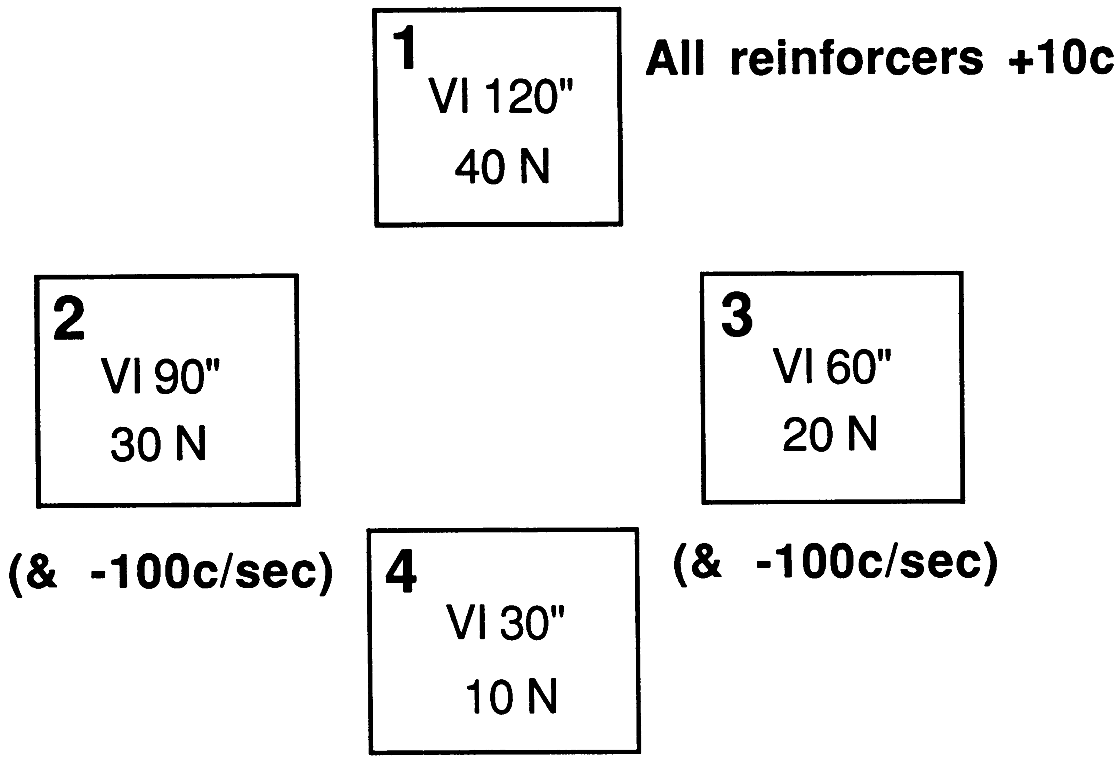

Fig. 5. A schematic representation of the layout of response locations plus the force requirement and contingencies arranged for each location in Experiment 2. The number assigned to a location is shown in the top left corner of the square. During the experiment, none of the information shown in the figure was displayed to subjects.

2 subjects (H07 and H12) did the greatest follower have the lowest percentage increase. Consequently, the present data do not support the greatest follower rule.

Table 3 shows that for only 1 of the subjects who received restriction did the location with the greatest TS have the greatest increase (H12: 1); for the other 2 subjects this location had either a moderate increase (H07: 2) or a small decrease (H08: 2). For none of the subjects who received response cost did the location with the greatest TS have the greatest increase; for 3 subjects this location had a moderate increase (H06: 2, H09: 2, and H13: 3), and for the other subject this location had the smallest increase (H11: 3). As was found in Experiment 1, the present data do not support the temporal similarity rule.

GENERAL DISCUSSION

One aim of the present experiments was to determine which procedural variables can explain why Dunham and Crosbie obtained different results. To do this, Crosbie's free-operant procedures were modified to make them more similar to those of Dunham and colleagues. Although these modifications produced results that were consistent across subjects and the present experiments, they did not produce findings similar to those obtained by Dunham. Hence, this objective was not achieved.

The other aim of the present experiments was to learn more about how subjects redistribute their time when one free-operant response is removed from the repertoire by punishment or restriction. This was achieved. As has been found consistently in Crosbie's studies (1990a, 1990c, 1991), in the present experiments there was a general increase in response duration for unpunished and unrestricted locations. This is in sharp contrast to the selective change in one response reported by Dunham. In addition to replicating a nonselective increase in duration for most nontar-

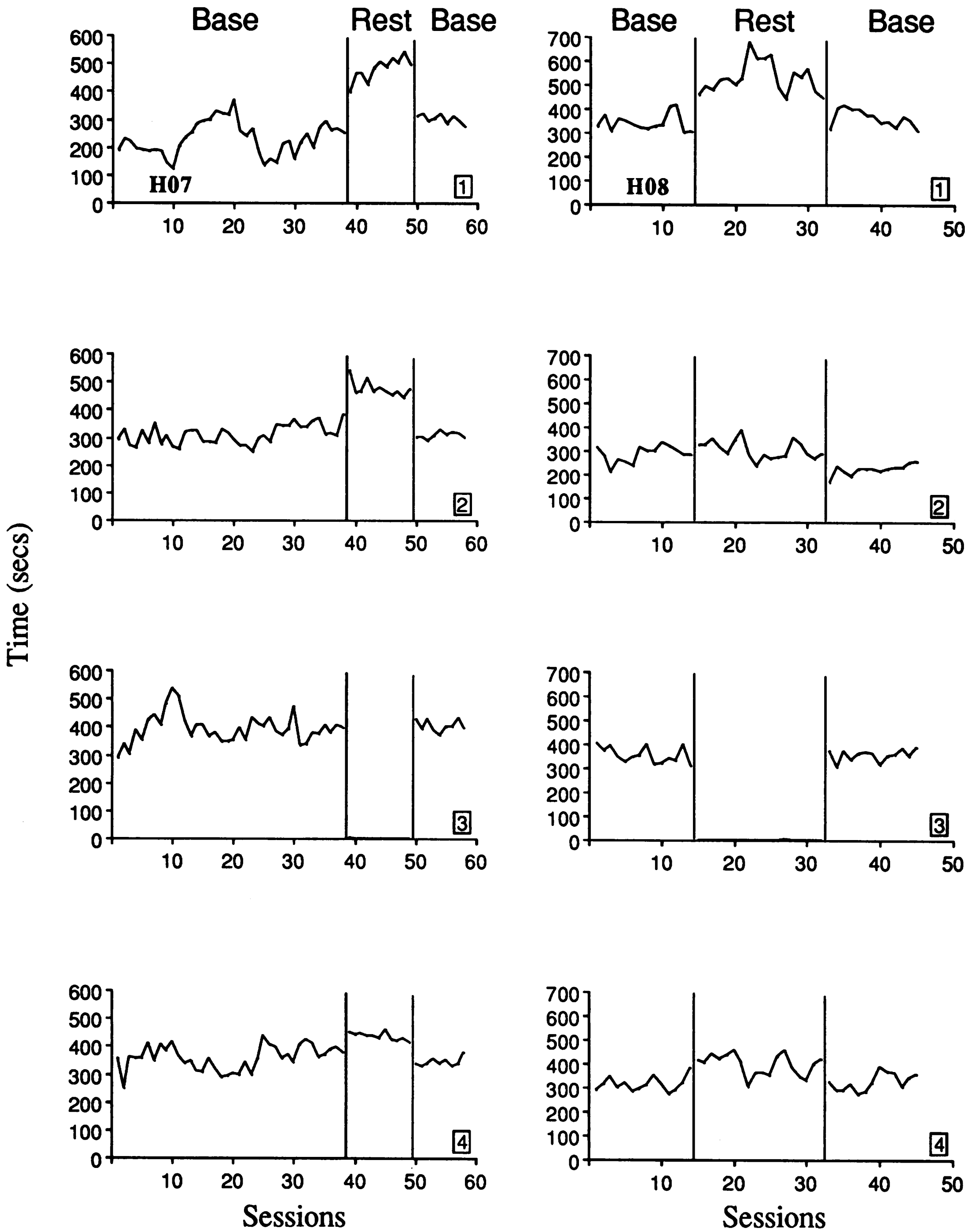

Fig. 6. For the subjects in Experiment 2 for whom Location 3 was restricted, total response duration for all locations during each session of the baseline, restriction, and return to baseline phases.

get locations, the present experiments also found that these increases are moderately related to response duration and reinforcer frequency during the preceding baseline phase. The implications of these findings will be discussed below.

Dunham's Rules

It has been over 20 years since Dunham's first propositions were presented (1971); it is time for their current status to be examined. The hierarchical rule has not been supported by any experiment with adult humans (Crosbie, 1988, 1990a, 1990c, 1991; Dunham et al., 1986, Experiment 1; the present experiments), and in those experiments in which it has been supported (Dunham et al., 1986, Experiments 2 and 3), the hierarchical and temporal similarity rules made identical predictions. Given these failures to replicate and the uncertain theoretical status of the rule since the abandonment of the implicit avoidance explanation, the rule should be considered suspect and perhaps abandoned. Similarly, the greatest follower rule has not been replicated with human subjects and may not survive future data.

On the other hand, the temporal similarity rule has successfully predicted changes following restriction with university students, kindergarten children, and gerbils (Dunham et al., 1986), and, notwithstanding the present failure to replicate with free-operant responses, structural variables deserve further experimental attention. There is, however, a theoretical problem with this rule: It is not clear what temporal similarity measures. Responses with greater reinforcement value would be expected to have a large bout duration (B) and a small interbout interval (I) (Premack, 1965). By taking the absolute difference between B for a nontarget response and B for the target, the resultant score does not reflect whether the response has a greater or lower reinforcement value than the target. Combining the absolute difference in I for a nontarget response and the target also eliminates relative value information. By adding these two absolute differences to produce temporal similarity (TS), a TS score could reflect four patterns of B and I relative to the target: larger B, smaller B, larger I, and smaller I. What does a small TS tell us about a response? Dunham et al. found something, but it may not be functionally related to temporal similarity.

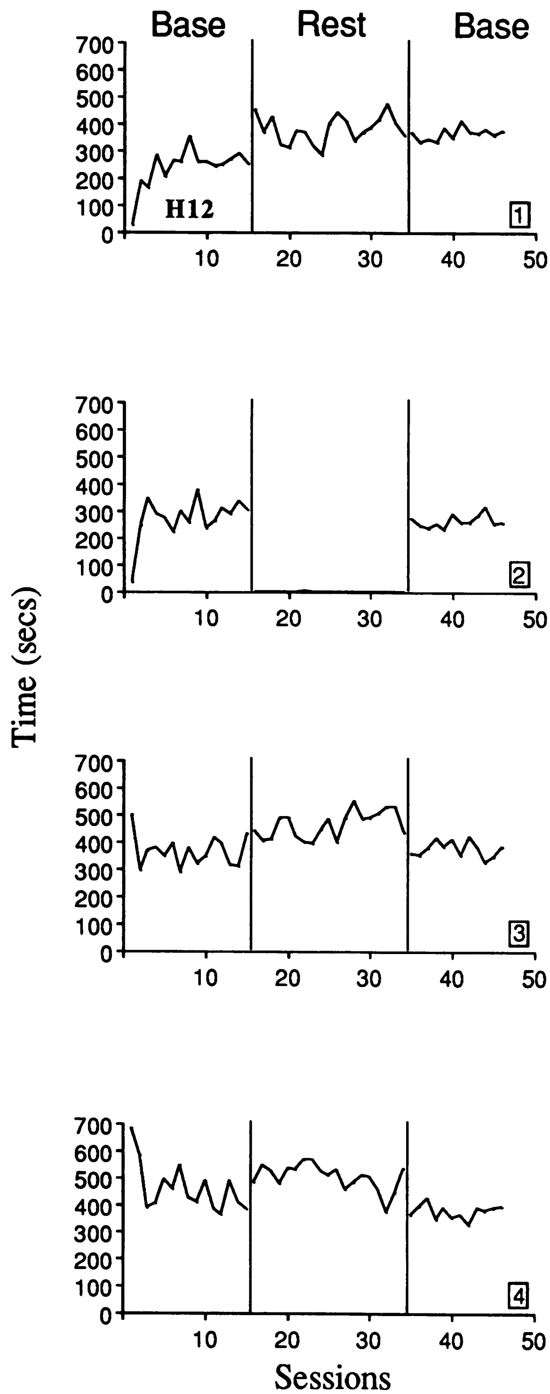

Fig. 7. For the subject in Experiment 2 for whom Location 2 was restricted, total response duration for all locations during each session of the baseline, restriction, and return to baseline phases.

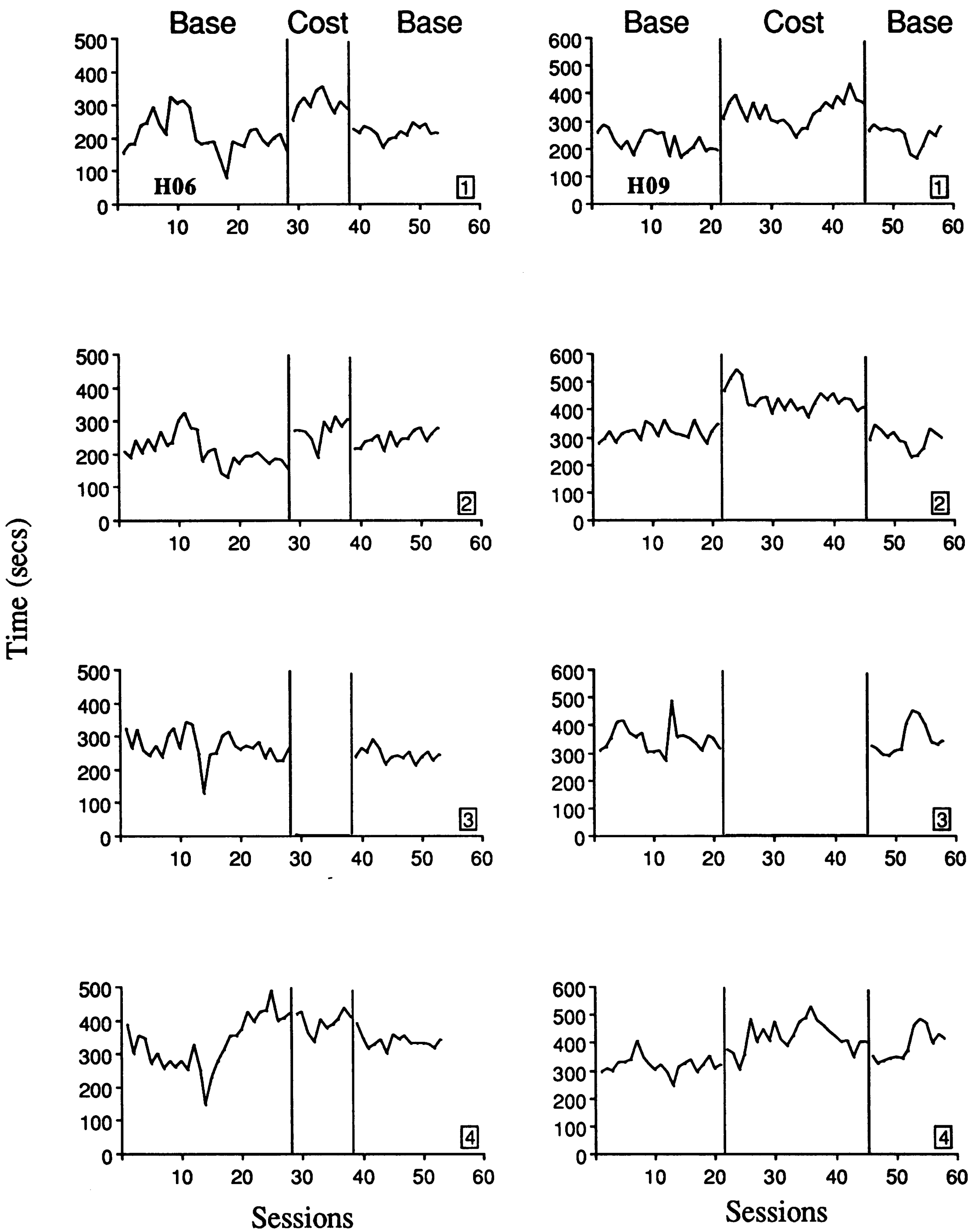

Fig. 8. For the subjects in Experiment 2 for whom staying in Location 3 was punished, total response duration for all locations during each session of the baseline, response cost, and return to baseline phases.

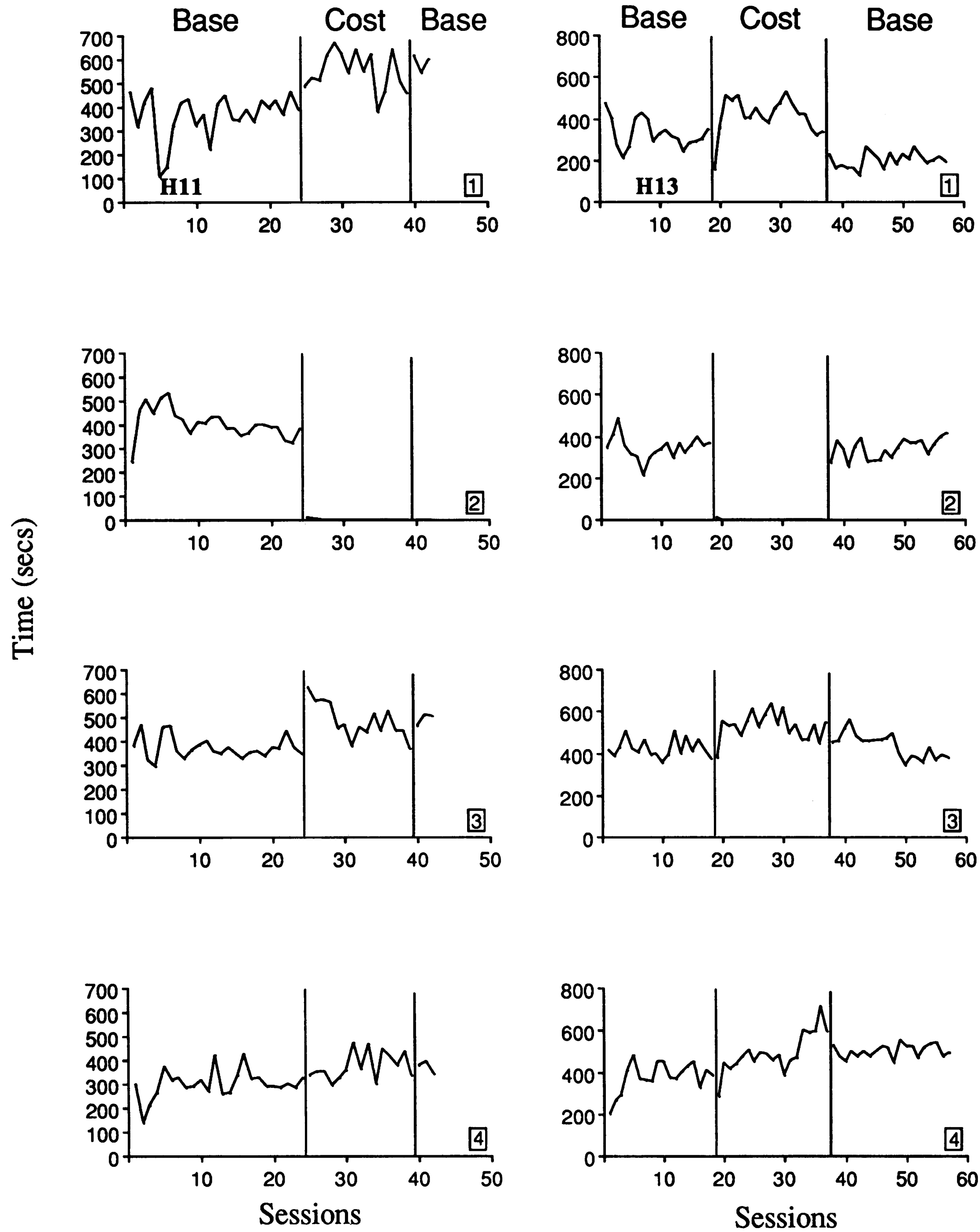

Fig. 9. For the subjects in Experiment 2 for whom staying in Location 2 was punished, total response duration for all locations during each session of the baseline, response cost, and return to baseline phases.

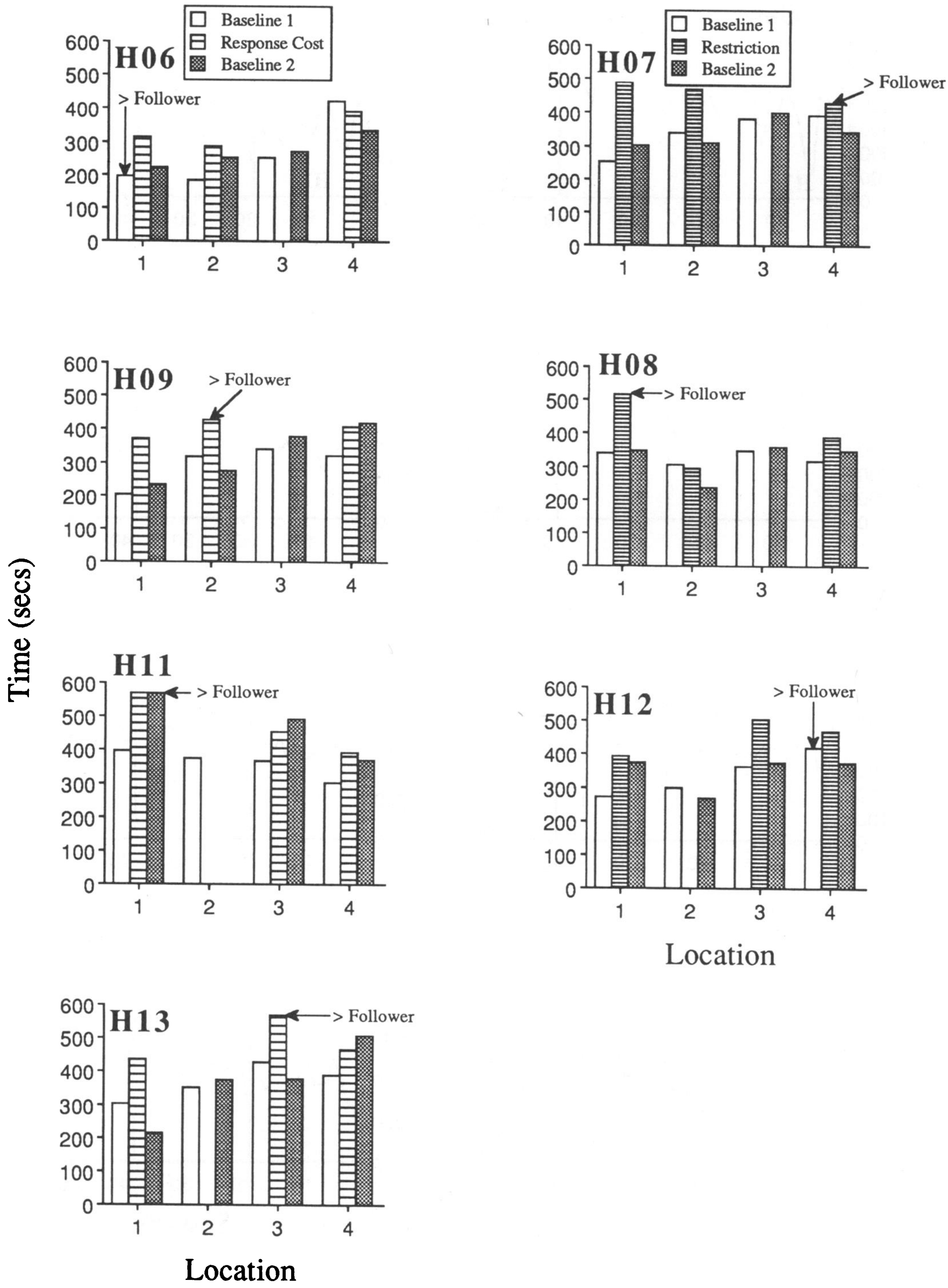

Fig. 10. For each subject in Experiment 2, mean response duration for each location during the last eight sessions of the baseline, response cost or restriction, and return to baseline phases. The target location was "3" for H06, H07, H08, and H09, and "2" for H11, H12, and H13. The location that followed the target most frequently during the first baseline phase is marked ">Follower."

Table 3

Experiment 2: Mean bout duration (Mbout), mean interbout interval (MIBI), and temporal similarity to the target response (TS) for each of the four locations during the last eight baseline sessions. Percentage of change relative to Baseline 1 is also shown.

Subjects		Locations			
		L1	L2	L3	L4
Restriction					
H07	Mbout	24.924	26.041	28.041	29.614
	MIBI	10.000	15.500	21.125	41.625
	TS	14.242	7.624[a]	—	22.073
	% Change	197.17	137.42	0.02	110.03
H08	Mbout	23.236	27.346	26.738	29.038
	MIBI	11.125	13.375	24.000	37.500
	TS	16.377	11.233[a]	—	15.800
	% Change	151.67	96.34	0.35	123.30
H12	Mbout	18.927	19.201	18.945	18.162
	MIBI	8.875	11.875	20.500	33.375
	TS	3.275[a]	—	8.882	22.539
	% Change	145.53	0.01	137.89	112.20
Response cost					
H06	Mbout	28.143	33.857	38.550	36.528
	MIBI	8.875	15.375	19.375	42.500
	TS	20.907	8.693[a]	—	25.147
	% Change	160.45	156.56	0.04	93.02
H09	Mbout	27.792	33.860	43.919	77.900
	MIBI	9.625	14.875	21.000	37.875
	TS	27.503	16.185[a]	—	49.965
	% Change	184.58	135.70	0.04	127.74
H11	Mbout	20.715	21.317	21.589	22.794
	MIBI	9.125	14.250	17.875	29.250
	TS	5.727	—	3.897[a]	16.477
	% Change	143.02	0.12	123.17	129.87
H13	Mbout	14.519	14.461	14.119	14.981
	MIBI	9.750	14.750	18.250	31.125
	TS	5.058	—	3.842[a]	16.895
	% Change	144.03	0.03	132.22	119.36

[a] Greatest temporal similarity to the target location.

It is not apparent how Crosbie's procedures can be modified further to make them more similar to those of Dunham et al. (1986), unless new topographically dissimilar naturally occurring or leisure responses are employed. I believe that this would be a retrograde step for the present project because such responses sometimes have a previous reinforcement history, they are not interchangeable, and variables such as reinforcer magnitude and schedule cannot be manipulated easily. Perhaps it is time for the projects of Dunham and Crosbie to proceed independently and to assess further the by-products of punishment and restriction within their respective paradigms; the task of determining why the two techniques produce different results can be left to future researchers.

Implications of the Present Results

The most consistent finding of the present experiments was that, when one response was removed from the repertoire by restriction or response cost, the time spent on all other responses increased. Furthermore, responses with the lowest rates of reinforcement and response duration during baseline often had the largest increases in time during the restriction or response cost phase. The present results can therefore be discussed not only within the context of punishment contrast and the findings of Dunham and Crosbie but also with respect to the time allocation and redistribution literature (e.g., Bernstein & Ebbesen, 1978; Deluty, 1976; de Villiers, 1981; Dunham, 1972; Luce, 1959; Premack, 1965; Tversky, 1972).

According to the constant proportions rule (Dunham, 1972; Luce, 1959), removing one response from a repertoire will not alter the relative proportions of time allocated to the remaining responses. Time allocated to each remaining response will increase, but this increase will be directly proportional to the time allocated to the response during baseline (i.e., all responses will have the same percentage change). In a similar vein, the matching law (Herrnstein, 1970) suggests that the time a response is allocated is proportional to its relative reinforcement frequency. If one response is removed from the repertoire and relative reinforcement frequency does not change for the remaining responses (as in the present experiments), all responses will have the same percentage increase in time allocation (the matching law models of Deluty, 1976, and de Villiers, 1981, both make this prediction if the target is eliminated completely by punishment). The present results do not support this rule, because percentage change varied considerably across nontarget responses. Dunham (1978) also found that constant proportions were not maintained following punishment of one response with gerbils.

A weaker version of this rule is that, although exact proportions may vary, the rank order of time allocated remains constant (Tversky, 1972). The results from the present Experiment 1 do not support this constant rank rule; if anything there was a slight inverse relationship between the ranks during baseline and the restriction or response cost phase. For Experiment 2, however, 4 subjects had constant ranks (H06, H08, H11, and H13), and 2 others approximated this (H09 and H12); only 1 subject (H07) did not show this pattern. It is not obvious why the subjects in Experiment 2 had constant ranks whereas those in Experiment 1 did not. Future researchers might profitably investigate whether this rule applies only with effortful responses.

In addition to providing new data to test time allocation rules, the present results may also provide new evidence for behavioral momentum (Nevin, 1988; Nevin, Mandell, & Atak, 1983). According to this proposition, the greater the frequency of reinforcement, the less responding will change when some external force is applied (e.g., extinction, prefeeding, and punishment). In the present Experiment 2, Location 1 had the lowest reinforcement frequency during baseline plus the greatest percentage change in response duration for all subjects (see Table 3). Furthermore, Location 4 had the greatest reinforcer frequency for all subjects, and for 5 of the 7 subjects this location had the smallest percentage change. Because locations also differed in response force requirement and time allocation, it is not clear that there is a functional relationship between reinforcer frequency and change in time allocation. Nonetheless, behavioral momentum has excellent theoretical credentials, and this possibility deserves experimental consideration.

Future Directions

Several improvements could be made to the present procedures. Subjects had the largest increases for the top location and the smallest increases for the bottom location. It is therefore possible that the present results were produced by a position preference. To eliminate such a possibility, subjects could respond at only one location with a different color correlated with each set of contingencies, and select the next condition by pressing a changeover key (Findley, 1958).

Another recommendation is the use of milder response cost so that target responding is not completely eliminated. With leaner VI schedules (e.g., VI 3 min) reinforcer frequency would be relatively unaffected, and changes in unpunished responses could be attributed to punishment and not to the reduction of total reinforcement.

Finally, the conditions to be presented in the concurrent schedule should first be presented separately in a multiple schedule, and subjects should told explicitly that the conditions are independent. This is likely to produce better matching between contingencies and time allocation (Takahashi & Iwamoto, 1986).

It is a difficult technical challenge to study time redistribution in humans following changes to one response in a free-operant repertoire. The present experiments have shown one way that this can be achieved, and illustrate the possibilities offered by being able to manipulate the number of responses in the repertoire, response effort, reinforcer magnitude and frequency, punishment magnitude and frequency, and response topography. Future studies might consider increasing the number of responses in a repertoire after baseline or increasing the time allocated to a response (e.g., by increasing reinforcer frequency for that response) to determine whether the present findings form part of a continuum or are unique to removal of a response. With appropriate technology and free-operant responses, there are endless possibilities for exploring time redistribution with humans.

REFERENCES

Azrin, N. H., & Holz, W. C. (1966). Punishment. In W. K. Honig (Ed.), *Operant behavior: Areas of research and application* (pp. 380–447). New York: Appleton-Century-Crofts.

Barlow, D. H., Hayes, S. C., & Nelson, R. O. (1984). *The scientist practitioner: Research and accountability in clinical and educational settings.* New York: Pergamon Press.

Bernstein, D. J., & Ebbesen, E. B. (1978). Reinforcement and substitution in humans: A multiple-response analysis. *Journal of the Experimental Analysis of Behavior,* **30,** 243–253.

Bradshaw, C. M., Szabadi, E., & Bevan, P. (1979). The effect of punishment on free-operant choice behavior in humans. *Journal of the Experimental Analysis of Behavior,* **31,** 71–81.

Brethower, D. M., & Reynolds, G. S. (1962). A facilitative effect of punishment on unpunished behavior. *Journal of the Experimental Analysis of Behavior,* **5,** 191–199.

Catania, A. C., & Reynolds, G. S. (1968). A quantitative analysis of the responding maintained by interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior,* **11,** 327–383.

Crosbie, J. (1988). *The behavioural side-effects of human punishment.* Unpublished doctoral dissertation, Flinders University of South Australia, Adelaide.

Crosbie, J. (1990a). The effects of punishment on unpunished behaviour. *Behaviour Change,* **7,** 25–34.

Crosbie, J. (1990b). The Microsoft mouse as a multipurpose response device for the IBM PC/XT/AT. *Behavior Research Methods, Instruments, & Computers,* **22,** 305–316.

Crosbie, J. (1990c). Some effects of response cost on a free-operant multiple-response repertoire with humans. *Psychological Record,* **40,** 517–539.

Crosbie, J. (1991). The effects of punishment on unpunished reinforced free-operant responses. *Australian Journal of Psychology,* **43,** 1–5.

Crosbie, J., & Sharpley, C. F. (1989). DMITSA: A simplified interrupted time-series analysis program. *Behavior Research Methods, Instruments, & Computers,* **21,** 639–642.

Deluty, M. Z. (1976). Choice and the rate of punishment in concurrent schedules. *Journal of the Experimental Analysis of Behavior,* **25,** 75–80.

de Villiers, P. A. (1977). Choice in concurrent schedules and a quantitative formulation of the law of effect. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 233-287). Englewood Cliffs, NJ: Prentice-Hall.

de Villiers, P. A. (1981). Quantitative studies of punishment: The negative law of effect revisited. In C. M. Bradshaw, E. Szabadi, & C. F. Lowe (Eds.), *Quantification of steady-state operant behaviour* (pp. 139–151). Amsterdam: Elsevier/North-Holland Biomedical Press.

Dunham, P. J. (1971). Punishment: Method and theory. *Psychological Review,* **78,** 58–70.

Dunham, P. J. (1972). Some effects of punishment upon unpunished responding. *Journal of the Experimental Analysis of Behavior,* **17,** 443–450.

Dunham, P. J. (1978). Changes in unpunished responding during response-contingent punishment. *Animal Learning & Behavior,* **6,** 174–180.

Dunham, P. J., Cornwall, A., & Hurshman, A. (1986). Structural features in multiple response repertoires: Effects of response restriction. *Canadian Journal of Psychology,* **40,** 12–28.

Dunham, P. J., & Grantmyre, J. (1982). Changes in a multiple-response repertoire during response-contingent punishment and response restriction: Sequential relationships. *Journal of the Experimental Analysis of Behavior,* **37,** 123–133.

Elsmore, T. F. (1971). Effects of response effort on discrimination performance. *Psychological Record,* **21,** 17–24.

Ferster, C. B., & Skinner, B. F. (1957). *Schedules of reinforcement.* New York: Appleton-Century-Crofts.

Findley, J. D. (1958). Preference and switching under concurrent scheduling. *Journal of the Experimental Analysis of Behavior,* **1,** 123–144.

Gellermann, L. W. (1933). Chance orders of alternating stimuli in visual discrimination experiments. *Journal of Genetic Psychology,* **42,** 206–208.

Herrnstein, R. J. (1970). On the law of effect. *Journal of the Experimental Analysis of Behavior,* **13,** 243–266.

Herrnstein, R. J. (1974). Formal properties of the matching law. *Journal of the Experimental Analysis of Behavior,* **21,** 159–164.

Killeen, P. R. (1978). Stability criteria. *Journal of the Experimental Analysis of Behavior,* **29,** 17–25.

Luce, R. D. (1959). *Individual choice behavior: A theoretical analysis.* New York: Wiley.

Nevin, J. A. (1988). Behavioral momentum and the partial reinforcement effect. *Psychological Bulletin,* **103,** 44–56.

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

Premack, D. (1965). Reinforcement theory. In D. Levine (Ed.), *Nebraska symposium on motivation* (Vol. 13, pp. 123–180). Lincoln: University of Nebraska Press.

Reynolds, G. S. (1961). Behavioral contrast. *Journal of the Experimental Analysis of Behavior,* **4,** 57–71.

Sidman, M. (1960). *Tactics of scientific research: Evaluating experimental data in psychology.* New York: Basic Books.

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

Takahashi, M., & Iwamoto, T. (1986). Human concurrent performances: The effects of experience, instructions, and schedule-correlated stimuli. *Journal of the Experimental Analysis of Behavior,* **45,** 257–267.

Tversky, A. (1972). Elimination by aspects: A theory of choice. *Psychological Review,* **79,** 281–299.

Ulman, J. D., & Sulzer-Azaroff, B. (1975). Multielement baseline design in educational research. In E. Ramp & G. Sempio (Eds.), *Behavior analysis: Areas of research and application* (pp. 377–391). Englewood Cliffs, NJ: Prentice-Hall.

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