*BEHAVIORAL CONTRAST IN FIXED-INTERVAL
COMPONENTS: EFFECTS OF
EXTINCTION-COMPONENT DURATION*

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Seven albino rats were exposed to a multiple schedule of reinforcement in which the two components (fixed interval and extinction) alternated such that a presentation of the extinction component followed each fixed-interval reinforcement. In baseline sessions, the duration of the extinction component was constant and always one-third of the fixed-interval value. Probe sessions contained a probe segment in which the duration of the extinction component was increased; the response rate in fixed-interval components during the probe segment was compared with the response rate in the segments preceding and following the probe. The effect of increasing the duration of the extinction component was studied under three values of fixed interval: 30 s, 120 s, and 18 s, in three successive conditions. Response rate within fixed intervals was a direct function of duration of the extinction component. Pausing at the beginning of the fixed interval decreased as extinction duration increased. These effects were larger and more consistent for the shorter fixed-interval values (18 s and 30 s). These results indicate a functional relation between relative component duration and responding. For the component providing more frequent reinforcement, this could be stated as an inverse relationship between relative component duration and response rate. This relation is similar to findings regarding the ratio of trial and intertrial duration in Pavlovian conditioning procedures, and suggests that behavioral contrast may be related to Pavlovian contingencies underlying the multiple schedule.

Key words: behavioral contrast, component duration, temporal control, Pavlovian-operant interactions, bar pressing, rats

In a multiple schedule, two or more components alternate, each one signaled by a distinct exteroceptive stimulus. When conditions in one component are changed, response rate often is altered in the unchanged components. A frequently investigated interaction of this kind is behavioral contrast, which may be defined as an inverse relation between the rate of responding in a constant component and

the conditions of reinforcement in the changed component.

Typically, behavioral contrast has been studied as a function of altering the conditions of reinforcement in the changed component. However, contrast effects may be produced without any change in reinforcement rates by altering the proportional relation among component durations. Hinson, Malone, McNally, and Rowe (1978) and Hinson and Malone (1980) studied a multiple schedule in which two variable-interval (VI) components and five extinction components, signaled by different line orientations, were presented in randomized sequences. When the duration of one VI component was shortened (from 30 to 10 s), the duration of the other component lengthened (from 30 to 50 s); with all other conditions constant, the response rate increased in the shortened component (positive contrast) and decreased in the lengthened component (negative contrast).

Manipulation of component durations in studies of multiple-schedule interactions has been accomplished in two ways (see Williams, 1983, for a review). In several studies, the proportional relation among component durations was held constant while the absolute

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component duration was varied (Charman & Davison, 1982; Shimp & Wheatley, 1971; Spealman, 1976; Todorov, 1972). In another series of studies, the proportional relation among component durations was altered by manipulating either the duration of a single component (de Rose, 1982; Taus & Hearst, 1970; Wilton & Clements, 1971) or of both components (Bernheim & Williams, 1967; Hinson & Malone, 1980; Hinson et al., 1978).

When the absolute duration of the components was manipulated and their proportional relation held constant, it was found that as component duration was decreased, relative response rate approached relative reinforcement rate (Shimp & Wheatley, 1971; Spealman, 1976; Todorov, 1972). Edmon (1978) showed that this was attributable mainly to an increase in response rate during the component providing more frequent reinforcement. However, Charman and Davison (1982) reported conflicting results when reinforcement rate was systematically varied and reversed across components (but see Williams, 1983, for a reappraisal of Charman & Davison's results).

The manipulation of the proportional relation among component durations reveals another kind of functional relation. Hinson et al. (1978) and Hinson and Malone (1980) suggest that response rate in a VI component is inversely related to relative component duration. A similar relation also exists for two-component multiple schedules alternating VI with extinction components (multiple VI EXT): Wilton and Clements (1971) and Hinson and Staddon (1981) showed that response rate in the VI component increases as the duration of the extinction component increases. Taus and Hearst (1970) obtained similar results using a blackout instead of an extinction component, and de Rose (1982) replicated those findings replacing the VI component with a fixed-interval (FI) component.

Analogous results have been obtained in other conditioning situations. Autoshaping and automaintenance results have shown that when reinforcement delivery is signaled by illumination of the operandum during a trial, a response directed to the operandum is conditioned. Also, the strength of conditioning is inversely proportional to the ratio between trial and intertrial durations (Balsam & Payne, 1979; Gibbon, Baldock, Locurto, Gold, & Terrace, 1977; Locurto, Travers, Terrace, &

Gibbon, 1980; Terrace, Gibbon, Farrell, & Baldock, 1975). A similar relation has been obtained in conditioned-suppression studies, when unavoidable shocks were delivered in the presence of a conditioned stimulus (CS). Suppression of operant behavior during the CS is inversely proportional to the ratio of CS duration to inter-CS duration (Musiello, 1972; Stein, Sidman, & Brady, 1958).

Exceptions have been observed in multiple-schedule investigations, however. For example, Bernheim and Williams (1967) examined rats' wheel running in a two-component multiple schedule, with reinforcement frequencies unequal between components. Increasing the duration of the component providing more frequent reinforcement decreased running in the unchanged component. However, increasing the duration of the component providing less frequent reinforcement did not affect responding in the alternative component. Also, Ettinger and Staddon (1982), studying a multiple schedule with two unequal VI components, found that reducing the duration of the component yielding less frequent reinforcement did not affect response rate in the alternative component.

Discrepant results in studies varying component duration in multiple schedules may be due to differences in the methods used to manipulate them. Bernheim and Williams (1967) and Hinson and Staddon (1981) presented several component durations during a single session. This may have decreased the discriminability of component duration and could have allowed carry-over of effects across successive component presentations. Wilton and Clements (1971) avoided this by using a single extinction-component presentation in each session, followed by a single presentation of the VI component; this method probably reduced sensitivity to behavioral contrast by reducing alternation, which is a condition that has been shown to increase interaction in multiple schedules. Taus and Hearst (1970), using a group design, exposed each group to only one duration of blackout (the negative component), although across-subject effects of this variable may not be exactly comparable to within-subject effects. Even the more standard free-operant steady-state design, which allows performance to stabilize under a single component duration, could allow contrast effects to partially dissipate with continued testing in each different condition.

The present study introduced a new procedure to manipulate relative component duration, attempting to maximize sensitivity to this variable. Component duration was manipulated in probes presented in one segment of selected sessions. There was an ABA design within each probe session, with the segments preceding and following each probe functioning as baseline (A), with a manipulation condition (B) inserted between them. This study also assessed the generality of component-duration effects in behavioral-contrast situations. Whereas most contrast studies are restricted to pigeons and measure contrast effects only in VI components (with the exception of Bernheim & Williams, 1967, who used rats as subjects and found conflicting results), the present study was conducted with rats and measured contrast effects in FI components. The use of an FI component also permits assessment of how the occurrence of behavioral contrast alters the temporal distribution of responding within the FI component (e.g., Carr & Reynolds, 1974; Reynolds & Catania, 1961).

METHOD

Subjects

Seven experimentally naive male albino rats, of the Wistar strain, less than a year old at the onset of the experiment, served as subjects. Their body weights were controlled by water deprivation: Dry food was always available in the home cages, but water was available only for a few minutes after each daily experimental session. The period of access to water was determined as a function of the subject's weight at the end of the session, in order to keep each rat at 85% of its ad-lib weight. Subjects J-23, J-24, and J-25 were used throughout the experiment. Subjects J-27 and J-28 became ill in the early stages of the second condition (FI 120 s) and were replaced by Subjects J-29 and J-33 at the beginning of the third condition (FI 18 s). Therefore, the first and third conditions (FI 30 s and FI 18 s) were conducted with 5 subjects each, and the second condition (FI 120 s) was conducted with 3 subjects.

Apparatus

A Grason-Stadler Model 1111-L operant-conditioning chamber, enclosed in a picnic icebox equipped with a ventilating fan, was

used. The chamber contained two horizontal bars, 5 cm wide, 7.2 cm apart, and located 9.4 cm above the grid floor. Only the left bar was operative, requiring a force of 0.38 N to activate a microswitch. A solenoid-operated dipper allowed presentations of 0.1 cc of condensed milk; the dipper remained elevated for 3 s and produced a characteristic noise when moving up and down. The dipper was presented through a hole in the front panel, 1.5 cm above the floor and centered between the bars. The 2-W 6-V houselight was located at the top left corner of the front panel.

Electromechanical equipment controlled the experiment from an adjoining room. A Gerbrands Model C-3 cumulative recorder provided records of all sessions during the conditions of FI 30 s and 120 s, but from only sample probe sessions during the condition of FI 18 s, due to equipment limitations in the lab.

Procedure

Shaping and preliminary training. The bar-press response was shaped manually. Shaping was followed by a session in which each bar press was reinforced. A multiple fixed-interval extinction schedule (multiple FI EXT) then was introduced; the FI value was increased progressively from 3 to 30 s, and the duration of the extinction component (S^A) was increased progressively from 1 to 10 s. This preliminary training lasted six sessions. In this and all subsequent conditions, the two components of the multiple schedule alternated, with the extinction component presented after each fixed-interval reinforcement. During FI components the houselight was on; during extinction components it was off.

Design of probe sessions. To investigate the effects of the extinction-component (S^A) duration on the performance maintained by the fixed-interval component of the multiple schedule, probe sessions were interspersed between baseline sessions; the S^A duration was manipulated within probe sessions. The procedure in a probe session was as follows: The session was divided into four segments, each containing the same number of schedule cycles. Segment 1, with the same parameters as the preceding baseline sessions, was discarded as warm-up; Segment 2, labeled preprobe, was the same as Segment 1 and provided the baseline against which probe effects were assessed; Segment 3 was the probe, in which an S^A

Table 1

Number of baseline sessions prior to the first probe session (Init.), total number of baseline sessions, and number of probe sessions with each S^a value, for each FI condition.

Rat	FI 18 s								FI 30 s								FI 120 s							
	Baseline		S ^a durations						Baseline		S ^a durations						Baseline		S ^a durations					
	Init.	Total	12	20	40	80	Init.	Total	30	60	90	120	Init.	Total	100	200	400							
J-23	14	38	2	4	4	5	73	140	6	6	6	4	7	54	5	6	6							
J-24	16	54	5	5	5	5	78	131	6	6	6	4	38	59	4	4	3							
J-25	15	55	5	5	5	6	71	148	7	6	6	4	7	52	7	6	6							
J-27	—	—	—	—	—	—	16	73	6	6	6	—	—	—	—	—	—							
J-28	—	—	—	—	—	—	17	75	6	6	6	—	—	—	—	—	—							
J-29	14	43	2	4	5	2	—	—	—	—	—	—	—	—	—	—	—							
J-33	14	55	5	5	5	5	—	—	—	—	—	—	—	—	—	—	—							

duration greater than that in the baseline was introduced; in Segment 4 or postprobe, the baseline S^a duration was reinstated.

Thus, each probe session reproduced an ABA design, beginning with baseline S^a duration during the preprobe segment, followed by an increased S^a duration that was repeated throughout the probe segment, and returning to the baseline S^a value in the postprobe segment.

Baseline conditions. Fixed-interval durations were parametrically manipulated in this study and constituted three experimental conditions; for each of these conditions, the duration of S^a presentations in baseline sessions was always one-third of the fixed-interval value. Thus, the baseline conditions were: multiple FI 18 s S^a 6 s, multiple FI 30 s S^a 10 s, and multiple FI 120 s S^a 40 s. They will be called FI conditions to facilitate description. The FI 30-s condition was conducted first, followed by the FI 120-s condition, and then by the FI 18-s condition.

Table 1 presents the number of baseline sessions conducted before the first probe session, the total number of probe sessions with each S^a duration, and the total number of baseline sessions for each subject in each condition. The experiment began with a multiple 30-s EXT schedule, in which the duration of the extinction component (S^a) in baseline sessions was 10 s. After an initial series of baseline sessions (see Table 1 for the exact number of sessions for each subject), probe sessions were introduced, interspersed with baseline sessions. To minimize the possibility of carry-over effects from one probe session to the following, a maximum of two probe sessions were

scheduled each week, with at least one baseline session occurring between them. The S^a probe duration was 30 s in the first six probe sessions (seven for Subject J-25), 60 s in the following six sessions, 90 s in the next six, and 120 s in the last four probe sessions (omitted for J-27 and J-28).

The FI value then was increased to 120 s, with baseline S^a duration correspondingly increased to 40 s. The concentration of the condensed milk solution was doubled to minimize a decline in baseline FI responding. Probe durations of S^a were 100 s, 200 s, and 400 s. In an attempt to balance the effects of any cyclic changes in baseline FI responding, S^a durations were studied in a semirandom order. This probe procedure did not appear to cause carry-over effects across probe sessions, so the only restriction was that no more than two probe sessions be conducted on consecutive days.

The last experimental condition employed a multiple FI 18-s extinction schedule in which the extinction component duration was 6 s. Concentration of the milk solution returned to the value prevailing in the FI 30-s condition. Probe S^a durations were 12 s, 20 s, 40 s, and 80 s, studied in a semirandom order. Probe sessions were randomly interspersed among baseline sessions, with the restriction that no more than three probe sessions be conducted on consecutive days.

Experimental sessions in the FI 18-s and 30-s conditions ended after the 60th milk presentation; in the FI 120-s condition, sessions ended after the 20th milk presentation. Sessions were conducted 6 days a week.

Recording of temporal distribution of re-

spending. Responses in the FI component were recorded by six different counters that were operative during successive sixths of the fixed interval. During probe sessions these counters were read and reset after the end of each segment, providing independent temporal distributions of responding for the preprobe, probe, and postprobe segments. During the first FI condition (30 s), this reset was not done in all sessions; therefore, for some subjects, temporal distributions of FI responses are lacking for some probe S^A values. During the subsequent FI conditions, temporal distributions of responding were obtained for all probe sessions.

RESULTS

The performance measures presented here were obtained in the probe sessions; all probe sessions were used for the calculations of means. Performance measures are presented for each S^A duration used in probes, in each FI condition.

As S^A duration increased, performance during the unchanged fixed-interval component varied systematically. The main features of these effects are depicted in Tables 2 and 3. Table 2 shows mean response rate in the FI component for each S^A duration used in probe sessions. Parenthetical values represent the mean rates in the preprobe and postprobe segments, which are the segments that served as baseline. The most consistent effect is seen by comparing each value obtained in probes with corresponding baseline values. Increasing S^A duration during the probe segment increased FI response rates in 45 of 47 cases; the two exceptions occurred with the lowest S^A values (S^A 12 s for Subject J-29 with FI 18 s, and S^A 30 s for Subject J-28 with FI 30 s).

There were some differences in the pattern of rate increases through the three FI conditions. With FI 18 s, rate increases were small for the lowest S^A value (12 s); larger rate increases were obtained with S^A 20 s, and the largest rate increases occurred with S^A 40 s and 80 s, when the rate in the probes generally attained values two to three times larger than the rate of the preprobe. With FI 30 s, large rate increases were obtained from the smallest S^A value in the probes (30 s) except for J-28. The largest rate increases were obtained with S^A 60 s and 90 s (twofold or threefold increases usually were recorded). With

FI 120 s, response rate also tended to increase in probe segments, but these increases were smaller compared with the former FI conditions and were less consistent across individual sessions.

The values for the postprobe segment presented in Table 2 suggest a posteffect (negative contrast) of the experimental manipulation. In the postprobe segment, when the S^A duration was returned to baseline value, response rate in the FI component decreased, attaining values even smaller than in the preprobe segment (40 of 47 cases).

Another dependent variable measured throughout probe sessions was the pause at the beginning of the fixed interval (strictly speaking, it is not a postreinforcement pause, because an S^A presentation always intervened between reinforcement and the beginning of the following interval). Table 3 shows mean pause for each S^A duration in probe sessions. Each entry is the average of pause durations in the probe segment. The mean pauses in the preprobe and postprobe segments are presented in parentheses. Table 3 shows that variations in pause approximately mirrored the variations in response rate presented in Table 2. Large decreases in pause occurred in the probe segment as S^A duration increased. In the postprobe segment pauses returned again to near baseline values, and in many cases pauses in the postprobe segment exceeded those in the preprobe baseline.

In order to compare the FI performances during the probe segment with the preprobe segment, each measure obtained in the probe was expressed as a value relative to its corresponding preprobe value (the value in the probe segment was divided by the sum of the values in the preprobe and probe segments). Thus, relative values of less than 0.50 indicate lower measures during the probe than during the preprobe segment, and relative values greater than 0.50 indicate higher measures during the probe than during the preprobe. These calculations were made for the values of response rate, pause, and S^A duration.

Figure 1 shows relative response rate during the FI component (Panel A) and relative pause at the beginning of the FI (Panel B), as a function of relative S^A duration. Figure 1A shows that mean relative response rate was above 0.50 for all subjects, in all conditions, with three exceptions. Mean pause duration

Table 2

Mean rate of responding (responses per minute) in the FI component at each duration of S^a studied in probes. Data are presented for the three FI conditions; each entry is the mean for probe segments of all probe sessions with the labeled S^a durations. The values presented within parentheses are the means for preprobe and postprobe segments (baseline), respectively.

Rat	FI 18 s				FI 30 s
	12	20	40	80	30
J-23	12 (10, 8)	15 (11, 7)	19 (9, 5)	22 (9, 9)	38 (16, 8)
J-24	17 (16, 7)	26 (14, 11)	26 (19, 11)	26 (13, 12)	28 (22, 14)
J-25	8 (5, 4)	13 (5, 4)	14 (5, 5)	14 (3, 3)	8 (3, 3)
J-27	—	—	—	—	12 (7, 4)
J-28	—	—	—	—	16 (17, 12)
J-29	37 (37, 19)	47 (35, 19)	47 (35, 20)	48 (31, 21)	—
J-33	11 (9, 7)	11 (8, 5)	23 (8, 5)	22 (7, 4)	—

was below 0.50 with one exception. The general trend was an increase in relative rate and a decrease in pause duration as relative S^a length increased. However, there were some differences in the functions obtained for the three FI conditions. Effects were larger for functions obtained with lower FI values; with FI 120 s the effects were smaller. The curves for response rate show a generally increasing trend, whereas the functions for pause show a symmetrically decreasing trend. There are, however, some points in which these trends are reversed. This is especially noticeable in the FI 30-s condition, for the higher relative S^a duration used for J-23, J-24, and J-28; thus, the functions for these subjects are bent in the right extreme, downward for response rate and upward for pause.

Figure 2 shows local response rates, in responses per minute, for consecutive sixths of the fixed interval for each S^a duration, with FI 18 s (Panel A), FI 30 s (Panel B), and FI 120 s (Panel C). In each graph, the heavy line corresponds to baseline values obtained dur-

ing sessions when the different S^a durations were imposed during the probes. For some subjects, with FI 30 s (Panel B), local response rates were obtained for only some S^a durations. The main feature of the results was an increase in local rates for intermediate segments (2 to 5) at all S^a durations used within the probes. For some subjects there were smaller increases also in the local rate for the sixth segment. The concavity of the curves tends to be reduced for larger S^a durations, indicating that increasing S^a durations resulted in deteriorated temporal control over FI responding.

The effects of the experimental manipulations are illustrated also in Figure 3, which shows representative cumulative records for probe sessions with FI 18 s (Panel A), FI 30 s (Panel B), and FI 120 s (Panel C). For better visualization of FI responding, the cumulative recorder was stopped during all S^a periods. Responses during S^a, which rarely occurred, moved up the response pen and also were recorded as event pen deflections. All

Table 3

Mean pause (in seconds) at the beginning of the FI at each duration of S^a studied in probes. Data are presented for the three FI conditions; each entry is the mean for probe segments of all probe sessions with the labeled S^a durations. The values presented within parentheses are the means for preprobe and postprobe segments (baseline), respectively.

Rat	FI 18 s				FI 30 s
	12	20	40	80	30
J-23	16 (18, 17)	15 (16, 18)	12 (17, 19)	11 (16, 16)	18 (25, 29)
J-24	14 (14, 19)	12 (15, 16)	12 (13, 16)	10 (15, 15)	19 (22, 24)
J-25	16 (18, 19)	12 (18, 19)	10 (18, 17)	9 (18, 17)	23 (31, 32)
J-27	—	—	—	—	22 (26, 28)
J-28	—	—	—	—	17 (16, 19)
J-29	11 (11, 14)	8 (12, 14)	9 (11, 13)	6 (12, 12)	—
J-33	14 (16, 16)	14 (16, 18)	8 (15, 18)	7 (16, 19)	—

Table 2
(Extended)

FI 30 s			FI 120 s		
60	90	120	100	200	400
43 (16, 11)	40 (15, 15)	32 (15, 12)	15 (11, 7)	15 (9, 8)	18 (10, 8)
40 (25, 20)	28 (18, 14)	27 (18, 16)	14 (12, 11)	16 (12, 8)	15 (11, 6)
12 (5, 3)	13 (5, 4)	14 (4, 3)	7 (4, 5)	7 (5, 4)	6 (4, 4)
22 (8, 5)	26 (8, 4)	—	—	—	—
23 (14, 10)	20 (13, 10)	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—

records show, successively, the segments of preprobe, probe, and postprobe, separated by the reset of the response pen; warm-up segments were omitted. Panel A shows records of two probe sessions with FI 18 s and S^A of 80 s during the probe, corresponding to one session with J-24 (left) and one session with J-25 (right). During the probe segment, in which S^A duration was increased from 6 to 80 s, response rate increased and pause decreased; these effects occurred immediately after the experimental manipulations, and baseline responding recovered quickly when the baseline S^A value was reinstated in the postprobe segment. Bursts of S^A responding occurred in some sessions with large S^A durations, as shown in the session for J-25. S^A responding did not occur in all sessions with large S^A values in the probe and had no noticeable effect on FI responding, as seen by comparing the two records shown in Panel A.

Panel B of Figure 3 shows two records with FI 30 s—one for J-23 (left) with S^A 30 s in the probe and another for J-25 (right) with

S^A 60 s in the probe. These records show that data with FI 30 s replicated the main features obtained with FI 18 s. Subjects J-23 and J-25 differed widely in baseline response rate; nevertheless, both showed a proportional increase in response rate during probes. Panel C shows two records for Subject J-25 in the FI 120 s condition, with S^A values of 100 s (left) and 200 s (right) in the probes. This subject showed the lowest rate of responding across the three FI conditions. The records presented in Panel C illustrate the main features that occurred in probe sessions with FI 120 s: Response rate in the probes showed trends similar to those occurring under lower values of FI, but effects were less systematic and of smaller magnitude.

DISCUSSION

The following results were obtained: (a) Response rate in the FI component was a direct function and pause was an inverse func-

Table 3
(Extended)

FI 30 s			FI 120 s		
60	90	120	100	200	400
14 (26, 27)	17 (27, 26)	15 (26, 26)	51 (61, 53)	29 (54, 56)	30 (59, 51)
16 (20, 21)	16 (23, 24)	18 (24, 24)	71 (79, 75)	68 (80, 89)	58 (82, 85)
17 (28, 30)	19 (29, 28)	14 (29, 29)	57 (66, 72)	38 (54, 63)	34 (63, 57)
18 (26, 33)	16 (28, 32)	—	—	—	—
16 (23, 25)	19 (24, 26)	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—

Fig. 1. Mean relative response rate in the fixed-interval component (Panel A) and mean relative pause duration (Panel B), as functions of relative S^{Δ} duration. All probe sessions with each S^{Δ} value were used for the averages. The data shown in each row (Panels A and B) were derived from the schedule identified in the label inside the Panel B axes of the row.

tion of S^{Δ} duration; (b) these effects were attenuated for a high FI value; (c) as the baseline value of S^{Δ} duration was reimposed in the post-probe segment, baseline performance recovered quickly; however, response rates were slightly lower than in the preprobe segment, and pauses tended to be slightly longer, suggesting a posteffect (negative contrast) of the experimental manipulation; (d) the distribution of local rates along the fixed interval became flatter as S^{Δ} duration increased, resulting from the larger increase in local rates in the middle of the interval; thus, as S^{Δ} duration increased, the temporal control exerted by FI contingencies diminished.

The probe procedure used in the present study avoided the difficulties encountered by earlier researchers by assessing the effect of several component durations within a session, and it proved to be sensitive to the effects of the experimental variable. The use of a within-session ABA design allowed the use of relative performance measures such that probes could be repeated with different S^{Δ} values with minimal interference from the variability typical of long exposure to FI schedules. Moreover, only one S^{Δ} value was probed in each session, free of carry-over effects from different S^{Δ} values. Thus, each probe session was a systematic replication, increasing the validity of the

Fig. 2. Local rates of responding (responses per minute) for successive sixths of the fixed interval. Solid lines correspond to local rates for baseline S^{Δ} length obtained during preprobe segments, and broken lines correspond to local rates in probe segments. Columns A through C present graphs from FI 18 s, FI 30 s, and FI 120 s conditions, respectively.

results. One limitation of the method was the inability to confirm if contrast effects were transitory or more permanent, as probe segments do not allow performance to stabilize under modified conditions.

Nevertheless, it must be considered that performance measures in this study were conservative, because responding under FI schedules is differentially sensitive to several variables: Responding at the end of the interval appears to be less sensitive than responding in

the middle or initial segments of the interval (e.g., Blough, 1975; Carr & Reynolds, 1974; Reynolds & Catania, 1961). The present results show that responding in the middle of the interval is largely affected by the experimental variable, but responding at the end of the interval is almost unaffected by this variable. However, in this report response rate was averaged along the entire interval. Larger rate increases would be reported here if the end of the interval were excluded from the

Fig. 3. Selected cumulative records obtained during probe sessions in the conditions of FI 18 s (Panel A), 30 s (Panel B), and 120 s (Panel C). The S^A duration within the probe for each session is printed above the event line. Segments of preprobe, probe, and postprobe, respectively, are separated by the reset of the response pen. The recorder was stopped during S^A for easier visualization of FI performance; responses during the S^A moved up the response pen and were also recorded as deflections in the event line. Deflections of the response pen indicate reinforcer deliveries.

rate calculations (as in Blough's report, in which rate measures were computed only for the first half of the interval).

This differential sensitivity of responding during the interval can account for the decreasing temporal control over responding as S^A duration was increased. Inasmuch as effects are stronger in the middle of the interval, any variable that increases response rate should flatten the distribution of local response rates along the fixed interval.

The ancillary procedural variations effected in the course of the study apparently did not affect the results; the only possible exception is the increase in the concentration of the milk reinforcer in the FI 120 s condition. The results obtained in this condition were in the same direction but of smaller magnitude than

those obtained with smaller FI values. One could argue that this attenuation of effects could result from an interaction between the increase in the value of the FI and the increase in the concentration of the reinforcer. This possibility cannot be ruled out. Lowe, Davey, and Harzem (1974) found that increases in the concentration of a milk reinforcer affected rats' FI performance, producing longer post-reinforcement pauses and higher local response rates; they suggested that increases in magnitude of reinforcement can enhance the inhibitory and discriminative functions of the reinforcement in an FI schedule. Therefore, an increase in the magnitude of reinforcement could increase the temporal control by FI contingencies (see also Jensen & Fallon, 1973; Staddon, 1970). It is possible that a stronger

temporal control exerted by the FI contingencies decreases the sensitivity of FI responding to variations in an alternative component. Although logically possible, this seems unlikely to have occurred in the present study. Indeed, the FI 18-s and FI 30-s conditions exerted a larger degree of temporal control in the baseline than did the FI 120-s condition, because the former conditions produced steeper local rate distributions along the interval (see Figure 2). Also, in other contexts, amount of reinforcement does not seem to be a potent determinant of behavioral contrast, at least for pigeons (Shettleworth & Nevin, 1965).

The present data support the statement of a functional relation holding for two-component multiple schedules containing an extinction component: Response rate in the component in which reinforcement is delivered is inversely proportional to the relative duration of this component. Thus, response rate in a VI or FI component should increase when the duration of this component is reduced or when the duration of an alternative extinction component is increased. Previous results with multiple VI EXT schedules using pigeons as subjects have consistently verified this relation (Hinson & Staddon, 1981; Taus & Hearst, 1970; Wilton & Clements, 1971), and the present results extend these findings to multiple FI EXT schedules and to rats as subjects. This functional relation may hold also for several-component multiple schedules, as suggested by the results of Hinson et al. (1978) and Hinson and Malone (1980), and for multiple schedules comprising VI components of unequal value, although results of studies using unequal VI components have been somewhat conflicting (Bernheim & Williams, 1967; Ettinger & Staddon, 1982).

The functional relation depicted above may be compared with data obtained under other conditioning situations that involve Pavlovian-operant interactions. Several studies of autoshaping have shown that key-peck responding is acquired more rapidly and is maintained at a higher rate for a given trial (T) duration when the intertrial interval (ITI) increases, or when the ratio of trial to intertrial duration decreases (Balsam & Payne, 1979; Gibbon et al., 1977; Locurto et al., 1980; Terrace et al., 1975). Also, in studies of conditioned suppression, the degree of suppression of operant responding increased as the

relative duration of the stimuli signaling unavoidable shock was decreased (Musiello, 1972; Stein, Sidman, & Brady, 1958).

This similarity may be viewed as evidence for a classical-conditioning basis for behavioral contrast. Indeed, the operations that produce behavioral contrast can affect the strength of Pavlovian (stimulus-reinforcer) contingencies. Contrast is produced when the relative reinforcement rate delivered in the presence of one stimulus is increased, or when the relative duration of a stimulus in which reinforcement is more frequent is decreased. These are the same operations that increase the strength of stimulus-reinforcer contingencies (e.g., Staddon, 1975).

The most accepted Pavlovian theory of behavioral contrast has been the additivity theory, which holds that multiple schedules can maintain two kinds of contingencies: a response-reinforcer contingency and a stimulus-reinforcer contingency. According to this view, behavioral contrast arises when the classes of responses maintained by these two contingencies overlap. In this case, when the multiple schedule provides differential reinforcement across components, a positive stimulus-reinforcer contingency exists; its effects are measured as an increase in the operant response, which is maintained by the response-reinforcer contingency. If there is no overlap among the response classes maintained by the two contingencies, the additivity theory predicts the absence of contrast, because the increase in strength of the stimulus-reinforcer contingency cannot sum up to the rate of the operant response. There are two conditions in which these two response classes are not supposed to overlap: when stimuli signaling the multiple schedule components are presented away from the manipulandum, or when the operant response is topographically different from the consummatory response elicited by the reinforcer. Inasmuch as these conditions were present in this study, it is not likely that these results could be explained by the additivity theory. Moreover, this theory has not been favored by recent evidence (e.g., Bradshaw, Szabadi, & Bevan, 1978; McSweeney, 1983; Williams, 1983; Williams & Heyneman, 1981).

The present data suggest, however, that Pavlovian contingencies can increase the rate of operant responding even when the Pavlov-

ian contingency is not supposed to elicit responses topographically similar to the operant response class. Results consistent with this suggestion were presented by Buzzard and Hake (1984), who found that a Pavlovian contingency increased the amount of general activity; they also suggested that in certain conditions this general activity can be directed to the operandum producing an increase in response rate. This could produce behavioral contrast even when the additivity theory does not predict it.

Another way to account for the data would be to suppose that a Pavlovian contingency adds to the strength of the operant contingency, as was also suggested by Gutman (1977) and Gutman and Maier (1978). Gutman and Maier (Experiment 2B) exposed rats to a multiple VT EXT schedule and then superimposed the VT cue on an operant baseline, showing that the rate of operant responding increased. As the stimuli were diffuse, the increase could not have resulted from responses explicitly elicited by the signal adding to the operant responses. In fact, Gutman and Maier observed that the signal actually evoked responses that should compete with ongoing operant behavior, but nevertheless response rate increased. They explained their results in terms of a centrally mediated algebraic summation of Pavlovian and operant contingencies.

One difficulty with this interpretation arises from studies superimposing a stimulus that precedes a positive reinforcer on an operant baseline. In these cases, as the stimulus signals the delivery of a reinforcer independently of the subject's behavior, there is a positive stimulus-reinforcer contingency in its presence. However, this procedure may produce suppression rather than enhancement of positively reinforced operant responding, especially when the stimulus duration is short (e.g., Azrin & Hake, 1969; Meltzer & Brahlek, 1970). These data seem to contradict a Pavlovian interpretation of behavioral contrast, showing that a positive stimulus-reinforcer contingency can produce a decrease in operant response rate. However, a study by Lovibond (1983) attempted to control for the occurrence of competing responses evoked by the presentation of the CS. In that study, a short stimulus (10-s duration) that consistently preceded the delivery of sucrose directly to the

subject's mouth produced significant enhancement of positively reinforced behavior in rabbits. Lovibond suggested that in the previous studies, suppression of operant behavior may have been produced by the interference of approach to the magazine evoked by the CS or of sign-tracking responses directed to a localized CS.

Whether the interaction of Pavlovian and operant contingencies is peripheral, as suggested by Buzzard and Hake (1984), or central, as suggested by Gutman and Maier (1978), remains to be experimentally determined. However, the available data suggest that Pavlovian-operant interactions underlie the occurrence of behavioral contrast.

Although most data relating contrast to component duration suggest a role of stimulus-reinforcer contingencies, the present data also are compatible with the behavioral-competition hypothesis (Hinson & Staddon, 1978). This hypothesis assumes that interval schedules maintain interim and terminal (operant) behavior. As reinforcement rate is decreased in one component, interim behavior could move to this component and leave more time available for the operant response to be emitted in the unchanged component. When the duration of an extinction component is lengthened, more interim behavior could be allocated in it, leaving more time available for response rate to increase in the alternative component. The observed patterns of local rate increases across the fixed interval also are compatible with the response-competition hypothesis, in that response rate increased more in the middle of the interval, which is the segment of the interval in which higher rates of interim behavior have been reported (Killeen, 1975; Staddon & Simmelhag, 1971).

However, it seems that, more than endorsing a particular theory of behavioral contrast, the available data point to the complexity of multiple-schedule interactions and to the bulk of different effects that take place when a multiple-schedule component is changed. To review briefly, alterations in multiple schedules can alter the strength of Pavlovian contingencies (Gutman & Maier, 1978), alter response topography (Williams & Heyneman, 1981), produce negative induction concurrently with behavioral contrast (as suggested by Williams, 1983), produce inhibitory rebound effects (Mackintosh, 1974; Terrace,

1972), make stimuli in the multiple schedule become signals for the impending reinforcement conditions (Hinson et al., 1978; Williams, 1981; Wilton & Gay, 1969), release inhibition from reinforcement (Catania, 1973), and change the balance in response competition among components (Hinson & Staddon, 1978).

Most theoretical efforts addressing multiple-schedule interactions have pursued a single major determinant of behavioral contrast, although the suggestion that behavioral contrast could be a blending of several independent effects has sometimes been advanced. However, most evidence suggests that a majority of the phenomena listed above can occur in certain situations. The understanding of multiple-schedule interactions is complicated by the fact that these phenomena may have different temporal patterns and different functional relations to independent variables. For instance, inhibitory rebound effects are more likely in the beginning of training, while signaling of the impending reinforcement conditions is more likely after protracted training. Some effects seem to be dependent on the similarity of the stimuli signaling multiple schedules, while other effects have not shown this dependency (cf. Williams, 1983).

Given these complications, further research is needed to isolate these effects and to investigate their functional relation to independent variables. That information would make it easier to understand how these effects interact in a complex situation such as a multiple schedule.

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