BEHAVIORAL CONTRAST AS A FUNCTION OF THE TEMPORAL LOCATION OF REINFORCEMENT¹

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Pigeons were trained on a multiple variable-interval variable-interval schedule of reinforcement. One component was then changed to a variation of a fixed-interval schedule in which the same rate of reinforcement was obtained as previously but the location of the reinforcer was fixed within the component. The effects of different temporal locations were compared. An increase in response rate for the unchanged variable-interval component (behavioral contrast) occurred when the reinforcer was located in the middle or at the end of the FI component, but response suppression occurred when it was located at the beginning of the component. The pattern of results cannot be explained by any previous theories of contrast. The overall response rates, and the pattern of local rates within the components, were consistent with the hypothesis that the major determinant of the contrast effect was the transition to a lower reinforcement rate *following* the unchanged component.

Key words: behavioral contrast, multiple schedules, fixed-interval schedules, relative reinforcement rates, sequential effects, key pecks, pigeons

When animals are presented a multiple schedule with the same reinforcement rates in its alternating components, and then the reinforcement rate during one of the components is reduced, the response rate during the other, unchanged, component typically increases. This finding, termed behavioral contrast, has been widely studied since its first systematic investigation by Reynolds (1961a). A variety of hypotheses have been proposed as the necessary conditions for producing contrast, including the energizing effect of nonreinforced responding (Amsel, 1971; Terrace, 1966), changes in the relative rate of reinforcement (Herrnstein, 1970; Reynolds 1961b), and changes in the "signalling" properties of the component stimuli, which in turn cause "elicited" responding to be added to the baseline level (Gamzu and Schwartz, 1973; Rachlin, 1973).

In view of the diversity of the various explanations, the question posed is whether behavioral contrast is in fact a unitary phenomenon. To the extent that several different interactions are subsumed under the term

contrast, all of the above explanations may be partially true, since they may apply to at least some forms of contrast. Evidence for a dissociation of contrast into separate types of effects has recently come from analyses of local response rates. Several investigations have found that the typical pattern is an increase at the beginning of the unchanged component and then a decrease to a lower level as the component progresses (Arnett, 1973; Bernheim and Williams, 1967; Nevin and Shettleworth, 1966). More recent work (Buck, Rothstein, and Williams, 1975; Williams, 1974) has questioned the generality of this finding, however, as local response rate has been found to increase within the unchanged component, particularly with extended periods of training. An examination of individual subjects in various published investigations reveals a similar diversity, as some subjects within the same study show one pattern of local responding, and others show the alternative pattern (*e.g.*, Menlove, 1975). Such marked differences in the local pattern of behavior suggest that at least two separate variables may determine the contrast effect, and that their relative contributions may change as a function of continued training.

If contrast in fact consists of several different effects, some more molecular analysis of

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its determinants is clearly needed. One variable that appears fundamental to any molecular analysis is the temporal distribution of reinforcement. Interactions between the components of a multiple schedule are clearly determined by the duration of the components (*cf.*, Silberberg and Schrot, 1974). Perhaps, therefore, a closer examination of the effects of *particular* reinforcers occurring at different temporal locations, will enable some analysis of the underlying basis of the effect. The present study provided such an examination.

Pigeons were initially trained with alternating 90-sec components where each component was associated with a variable-interval 90-sec reinforcement schedule (VI 90-sec). One component was then changed to a variant of fixed-interval (FI), such that one reinforcer was delivered during each 90-sec component. Thus, the overall rate of reinforcement (40 reinforcers per hour) was unchanged. The variable under examination was the location of the FI reinforcer within the component. In one condition it occurred early (FI 5-sec), in another condition it occurred in the middle (FI 45-sec), and in a third it occurred near the end (FI 80-sec). The duration of the component after the reinforcer was obtained was always associated with extinction.

It is helpful to consider the results predicted by the theories of contrast previously mentioned. One hypothesis is that contrast is determined by changes in the relative rate of reinforcement. Accordingly, no contrast should occur for any of the conditions, since the overall relative rate of reinforcement remained unchanged. A second hypothesis is that contrast is a function of the response suppression occurring with the FI schedules. The degree of suppression for the different FI schedules is an empirical issue, but according to the hypothesis, the schedule producing the greatest suppression should also produce the greatest degree of contrast. A third hypothesis is that contrast is a function of local changes in reinforcement density. Thus, to the extent that contrast is the result of an increase in reinforcement rate signalled by the onset of a stimulus (Rachlin, 1973), the greatest contrast should occur with the FI 5-sec condition and the least with the FI 80-sec. That is, with the FI 5-sec the unchanged VI component is preceded by a long period of extinction; with the FI 80-sec it is preceded by a recent occurrence

of the FI reinforcer. To the extent that contrast is a function of the decrease in reinforcement signalled by the offset of the stimulus, just the opposite results should occur. Such a possibility, while intuitively implausible, is suggested by the previous examination of local response rates within the VI component of a multiple variable-interval extinction, which increased as the end of the component approached (Buck *et al.*, 1975).

METHOD

Subjects

Six White Carneaux pigeons were maintained at 80% of their free-feeding weights. All had extensive experimental histories.

Apparatus

A standard one-key operant pigeon chamber was used. The bird's chamber was 30.5 cm in all dimensions. The pigeon key, 1.5 cm in diameter, was illuminated by a standard 28-V 12-stimulus in-line projector and was located directly above the grain hopper. A force of at least 0.10 to 0.12 N was required for a peck to be recorded. A 28-V houselight, located on the rear wall of the chamber, was illuminated at all times during an experimental session.

Procedure

The pigeons were immediately exposed to alternating 90-sec components separated by 1-sec periods in which the keylight was turned off. During one component, the key was illuminated with a diffuse yellow light; during the second, it was illuminated with a thin 45-degree red line projected on an otherwise dark key. For the first two to three sessions, the schedules for both components were increased from VI 20-sec to VI 90-sec. Eighteen additional sessions were then presented with both components associated with the VI 90-sec. A single VI tape was used for both components and consisted of 18 intervals constructed from an exponential distribution. Sessions terminated after 60 min.

At the end of the first baseline training period, the subjects were switched to one of three conditions. The schedule during the yellow light was always VI 90-sec, but the schedule during the red line was switched to one of three variants of an FI schedule. For one, food was obtained for the first peck 5 sec after the start of the component (FI 5-sec); for another,

Table 1

Order of presentation of the experimental conditions for individual subjects. Shown is the schedule associated with the red line. The schedule associated with the yellow light was always VI 90-sec. In parentheses next to the order of presentation is the number of sessions of training. (Intervals in seconds.)

Order of Presentation	SUBJECT					
	Y-22	B-5	B-3	B-1	R-11	R-20
1. (18)	VI	VI	VI	VI	VI	VI
2. (20)	FI 5	FI 5	FI 45	FI 45	FI 80	FI 80
3. (10)	VI	VI	VI	VI	VI	VI
4. (20)	FI 45	FI 80	FI 5	FI 80	FI 45	FI 5
5. (15)	VI	VI	VI	VI	VI	VI
6. (20)	FI 80	FI 45	FI 80	FI 5	FI 5	FI 45
7. (20)	VI	VI	VI	VI	VI	VI
8. (20)	FI 5	FI 5	FI 45	FI 45	FI 80	FI 80
9. (20)	FI 45	FI 80	FI 5	FI 80	FI 45	FI 5
10. (20)	FI 80	FI 45	FI 80	FI 5	FI 5	FI 45
11. (20)	VI	VI	VI	VI	VI	VI

food was delivered for the first peck 45 sec after the start of the component; for the third, food was delivered for the first peck 80 sec after the start of the component (FI 80-sec). The keylight remained on after food was obtained on the FI schedule, so technically the schedule operating during the red line was a mixed FI EXT.

All subjects were exposed to all three conditions. The order of presentation and the number of sessions are presented in Table 1.

RESULTS

Table 2 shows the mean rate of responding to the unchanged VI component during the last five sessions of each experimental condition. Since each FI condition was presented twice, the rates shown are averages of 10 sessions. The baseline figure shown is the average of the last five sessions of all five of the baseline periods.

Although the effects shown in Table 2 are not large, they are consistent across subjects. The order of VI response rate as a function of the FI value was FI 80-sec, FI 45-sec, and FI 5-sec. All six subjects had a greater VI rate under the FI 80-sec condition than during the baseline condition, thus demonstrating behavioral contrast. The FI 45-sec condition produced slightly more variable results, as the VI rate increased for only five of the six subjects. But perhaps the most interesting effect was that of the FI 5-sec condition, where the VI rate was lower, for all six subjects, than the baseline rate. Such an effect can be described

as induction, but an explanation in terms of generalization between the two components does not appear satisfactory. In addition to the highly discriminable stimuli cueing the two components, different patterns of behavior occurred as well. When the FI 5-sec component began, the subjects typically responded very rapidly until the reinforcer was obtained, then ceased responding for a period after the reinforcer, and then sometimes began responding again as the end of the component approached. During the VI component, as seen in Figure 2, the response rate gradually decreased as the component progressed.

The results for the individual exposures to each condition, as shown in Figure 1, were less clear. Part of the reason for this was the variability of the baseline condition. Later exposures to the *mult* VI VI condition produced higher rates of responding than during the

Table 2

Rate of responding (responses per minute) to the unchanged variable-interval component as a function of the schedule associated with the second component. The data were taken from last five sessions of each experimental condition. (Intervals in seconds.)

Subject	Schedule Associated with Red Line			
	FI 5	FI 45	FI 80	Baseline VI
Y-22	63.0	76.9	79.6	(74.3)
B-1	55.3	80.1	76.7	(73.0)
B-3	80.6	80.8	91.0	(82.7)
B-5	62.9	66.8	67.0	(64.5)
R-20	106.1	116.8	126.8	(107.4)
R-11	63.8	87.4	76.8	(69.3)
x	71.9	84.8	86.1	78.5

first exposure, indicating a general increase in responding over training. The higher response rates during later exposures to the baseline condition were not simply a failure of responding to decrease to its original level. A

frequent pattern instead was an initial decrease in responding on return to the baseline condition, followed by a prolonged increase in rate over subsequent sessions (e.g., Subject B-3). Why this increase occurred is unclear.

Fig. 1. Rate of responding to the unchanged VI component.

In spite of the variability, several consistencies emerged. In most cases, the switch to the FI 5-sec condition decreased responding that was typically evident after the first few sessions. An exception was Y-22 during its first FI 5-sec exposure. Its VI rate initially increased over the first 10 to 12 sessions and then decreased. Other exceptions were B-5, which initially showed a large drop and then recovery, and B-3, which showed little change in VI rate.

The clearest contrast effects were produced by the FI 45-sec and FI 80-sec conditions when they were presented to subjects as the first experimental condition after the initial baseline. Both B-1 and B-3, which first received the FI 45-sec, significantly increased their VI rates throughout the 20 sessions of training. R-20 and R-11, which first received the FI 80-sec, also showed a clear contrast effect. Subsequent presentation of the two conditions produced less consistent contrast effects.

Table 3

Rate of responding (responses per minute) to the variable component as a function of its schedule. The data were taken from the last five sessions of each experimental condition. (Intervals in seconds.)

Subject	Schedule Associated with Red Line			Baseline VI
	FI 5	FI 45	FI 80	
Y-22	13.7	50.1	55.4	86.2
B-1	19.8	47.2	41.6	58.1
B-3	18.3	49.0	59.3	79.1
B-5	20.9	56.6	52.4	69.8
R-20	30.0	71.0	95.4	132.2
R-11	15.9	22.3	39.7	69.4
$\bar{x}$	19.8	49.4	57.3	82.5

Of major interest is whether the degree of VI responding across conditions was a function of the degree of response-rate reduction during the FI conditions. Shown in Table 3 is the average rate during the FI components for the last five sessions of each FI condition. Once again, the two exposures to the same condition were averaged together. It is clear that the FI 5-sec condition produced the greatest suppression, and in most cases the FI 80-sec produced the least suppression. Thus, there was a negative correlation between the degree of response suppression and the response rate during the unchanged VI component.

Figure 2 shows the local response rates during the unchanged VI component divided into 18-sec bins (fifths of the component). The data came only from the second presentation of each condition because the local rates were not recorded earlier. As can be seen, the pattern of local rates differed markedly for the three FI conditions. The data were most consistent for the FI 5-sec, as all subjects showed a decrease in responding within the component. The form of the gradients was typically concave, although one subject, B-5, had a very shallow gradient, and one other, R-11, had a linear gradient. Although the overall effect of the FI 5-sec on the VI rate was clearly to suppress responding, there was also some evidence for a local enhancement of responding during the first segment of the VI component. This can be seen most clearly for Subjects B-3 and R-20, whose rates in the first VI segment were clearly above the baseline level. Apparently, therefore, two effects operated simultaneously: an excitation of responding at the beginning of the component, presumably the result of the 80 to 85-sec period of extinction before the start of the VI component, and an inhibition of responding, which gradually increased as the end of the component approached.

The gradients produced by the FI 45-sec and FI 80-sec were less consistent. Gradients from the FI 45-sec condition increased within the component for three subjects (Y-22, R-11, B-3), but decreased for two others (B-1, B-5). A similar pattern was seen for the FI 80-sec gradients. There was also some evidence for nonmonotonic gradients with the longer FI schedules, particularly the FI 80-sec. That is, the rate at the beginning of the VI component was elevated during the first segment of the component, then declined, followed by a monotonic increase for the remainder of the component (*e.g.*, B-5).

DISCUSSION

The present experiment demonstrated behavioral contrast as a result of changing a VI schedule to an FI schedule with an equivalent rate of reinforcement. Explanations of contrast in terms of changes in the relative rate of reinforcement (*e.g.*, Herrnstein, 1970) must be regarded as inadequate, therefore, or must be modified to calculate rate of reinforcement in some nonarithmetic fashion. It is unclear,

Fig. 2. Local rate of responding within the unchanged VI component. Shown separately are the local response rates produced by alternation with each of the three FI conditions.

however, what type of averaging method would predict contrast for one FI condition (FI 80-sec) but not for others (FI 5-sec).

The present results also refute explanations of contrast in terms of reductions in the rate of responding (Terrace, 1966). The failure of contrast when response rate has been reduced by response-independent reinforcement (*cf.* Halliday and Boakes, 1972) has previously challenged this interpretation, but Terrace has modified his original position to include only response reduction via "active inhibition" (Terrace, 1972). The present results challenge that hypothesis as well, since the degree of VI response-rate enhancement was inversely correlated with the amount of response-rate reduction during the FI component itself. In fact, the schedule that produced the greatest rate reduction, FI 5-sec, produced no contrast effect, but instead suppressed VI responding.

A third explanation of contrast challenged by the results is that viewing it as a function of the eliciting properties of the stimulus. Rachlin (1973) proposed that contrast results whenever the *onset* of a stimulus is associated with an increase in the rate of reinforcement. The ordering of the VI rates for the different FI conditions clearly contradicts such an expla-

nation. The longest period of extinction preceding the VI occurred with the FI 5-sec, so the VI stimulus should have signalled the greatest increase in reinforcement during that condition. With the FI 80-sec, on the other hand, the VI onset was shortly preceded by the FI reinforcer, so the VI stimulus should have signalled a decrease in the local rate of reinforcement. Nevertheless, the greatest contrast occurred with the FI 80-sec, and no contrast, but instead induction, occurred with the FI 5-sec.

The overall pattern of results leaves little doubt that the primary controlling variable was the local rate of reinforcement *following* the VI component. When that rate was low, as with the FI 80-sec, contrast occurred, but when it was high, as with the FI 5-sec, suppression occurred. The gradients of local response rates within the VI component also supported this interpretation, as they generally increased when approaching a low density of reinforcement (the FI 80-sec and FI 45-sec) and decreased when approaching a high density (FI 5-sec).

Primary control by the following period of reinforcement or nonreinforcement does not mean, of course, that the preceding condition

did not also control behavior. There was in fact some indication that both types of control occurred simultaneously. Evidence for an excitatory effect of a preceding period of nonreinforcement came from the local pattern of responding under the FI 5-sec condition, where initially the rate of VI responding was often *above* the baseline level, but then declined as the component progressed. Control by the preceding reinforcement condition might explain the relatively small magnitude of the effects shown in Table 2. Since the presentation of only one reinforcer per component necessarily entailed that the reinforcement conditions preceding and following the VI component were negatively correlated, the opposing effects of the two variables should have counteracted each other. It is also possible that the two types of control were affected differently by extended training, with different parameters across subjects, thereby causing the considerable variability across exposures to the same conditions.

The major theoretical question raised by the results is the mechanism by which control by the following component was mediated. Since the most reliable effect was the suppression of responding by the following FI 5-sec component, it is appropriate to consider its case first. Some insight into the phenomenon perhaps can be gained by considering its similarity to previous work on the inhibition of responding by reinforcement. Catania (1969, 1971, 1973) has argued cogently that contrast effects seen in concurrent schedules can be understood by the assumption that each reinforcer has two effects: strengthening the response on which it is contingent and inhibiting all responding in the same situation. He has further argued that the function relating the response rate to reinforcement rate with simple VI schedules can be similarly understood. A modification of Catania's hypothesis also appears appropriate for the present results. Namely, the inhibitory effects of a reinforcer on responding occurs primarily as a function of that reinforcer *following* the reinforcer maintaining the response. To the extent that the second reinforcer follows the contingent reinforcer closely in time, the strengthening effects of the contingent reinforcer will be reduced.

The hypothesis can best be elucidated by first considering the inhibitory effects of the

reinforcer during the baseline condition of *mult* VI VI. There, the strengthening effect of particular reinforcers was attenuated by some fraction because of the occasional subsequent reinforcers that followed closely in time. There was no differential attenuation as a function of time within the component, however, as the probability of the following reinforcer was independent of that time. When the VI schedule associated with the following component was changed to an FI 5-sec, however, those VI reinforcers occurring near the end of the component were followed on all occasions by the FI reinforcer. Consequently, responding toward the end of the VI component was suppressed because the functional value of the reinforcers occurring during that time had been reduced.

A similar analysis explains the enhancement of rate that occurred with the FI 80-sec condition. There, the probability of a reinforcer following reinforcers near the end of the unchanged VI component was decreased when the following component was changed from a VI to the long FI. Thus, the inhibition of reinforcement that occurred during the baseline condition was partially removed, so the response rate to the unchanged VI increased. The explanation also accounts for the enhancement of response rate occurring in the typical contrast procedure (multiple VI VI changed to multiple VI EXT), since there the reinforcers following the unchanged VI component are removed. In support of the analysis is the recent finding (Buck *et al.*, 1975) that the local response rates within the unchanged VI component do in fact increase as the end of the component approaches.

It should be noted that the gradients of local response rate are not a necessary feature of the above analysis. The only assumption is that the effectiveness of a reinforcer is a function of the time following it that is not filled with other reinforcers. To the extent that the strengthening effects of a reinforcer are only associated with the exteroceptive stimulus, the enhancement (or suppression) could occur without the differential local rate gradients. To the extent that the animal is also sensitive to temporal cues, however, the gradients of local responding should emerge. Variability among subjects in sensitivity to temporal cues thus provides an explanation for the failure to obtain the expected gradients for some sub-

jects in the present study. Such variability may also explain the different patterns of local responding among different subjects in other contrast studies (e.g., Menlove, 1975; Williams, 1974).

A final question to be considered is whether inhibition-by-reinforcement can itself be reduced to some more fundamental process. The most obvious possibility for such reduction is that involving the memory concept of consolidation. Since at least the work of Mueller and Pilzecker (1900), many investigators have argued that learning experiences produce greater effects on behavior if the subject is not interrupted during the temporal period following the experience. Such a concept of course plays a major role in recent theorizing regarding human memory, under the guise of the concept of rehearsal. That it may be relevant to the understanding of animal learning is suggested not only by the present data, but also by recent work on the blocking effect in classical conditioning. Wagner, Rudy, and Whitlow (1973) provided strong evidence that classical conditioning is greatly reduced when the CS-US pairing is followed by "surprising" events, with the magnitude of the disruption a direct function of the temporal separation. Whether their effect has the same underlying basis as the present effect is unclear. At the very least, however, the two effects demonstrate that the temporal distribution of learning events is a major variable in determining the extent of conditioning.

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