

# BEHAVIORAL CONTRAST IN A MULTIPLE AND CONCURRENT SCHEDULE OF REINFORCEMENT<sup>1</sup>

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These experiments are a study of behavioral contrast, an effect frequently produced by the stimulus-correlated alternation of reinforcement and extinction. The rate of responding under a given reinforcement schedule is higher when the schedule is interrupted by a stimulus-correlated period of extinction than when it is programmed continuously. For example, Herrick, Myers, and Korotkin (1959) and Smith and Hoy (1954) maintained lever pressing in rats under a variable-interval (VI) schedule of reinforcement in the presence of one stimulus. When this stimulus was then alternated with a second in whose presence lever pressing was not reinforced, the rate of lever pressing increased; *i.e.*, when VI was followed by mult VI ext, the VI response rate increased. Reynolds (1961) has discussed other examples of contrast, and has pointed out the generality of the effect.

In these experiments, pigeons responded on each of two keys. The conditions for contrast were programmed on one, the multiple key: a VI schedule followed by mult VI ext. Concurrent with but independent of the schedule on the multiple key, VI was always programmed on the second key. The experiments deal with two problems: (1) To what extent is contrast specific to the multiple schedule; *i.e.*, does response rate during VI increase on only the multiple key? (2) What changes in the schedule on the non-multiple key affect contrast; *i.e.*, can the manipulation of the schedule on this key be used to isolate the variables producing contrast?

One important variable is rate of reinforcement. When VI is changed to mult VI ext, reinforcement rate decreases, because no reinforcements are programmed during ext. In one procedure, mult VI ext is maintained on the multiple key; at the same time, the over-all reinforcement rate during ext is held equal to that during VI by a change in the nonmultiple-key schedule.

## METHOD

### Apparatus

The experimental chamber (*cf.* Ferster & Skinner, 1957) contained two standard 0.75-inch pigeon keys, mounted 4 inches apart and 8.5 inches above the floor. Each key required a minimum force of 10 grams for operation. Behind each key were three 6-watt lamps, one red, one green, and one yellow. The reinforcement magazine was located behind a 2-inch-square hole centered between the keys and 2 inches above the floor. Reinforcement duration was 4 seconds.

### Subjects

Six adult, male, White Carneaux pigeons, each with a reinforcement history under multiple and concurrent scheduling, were maintained at 80% of free-feeding body weight.

### Procedure

**Combined Multiple and Concurrent Scheduling.** The concurrent procedures illustrated in Fig. 1 were programmed on two keys, one either green or yellow (the multiple key) and the other always red (the non-multiple key). Procedure A is a concurrent VI 3 VI 3 schedule. For each key, a reinforcement becomes available 3 minutes (on the average) after the preceding reinforcement. During the 30 minutes shown, 10 responses are reinforced (vertical marks) on each key.

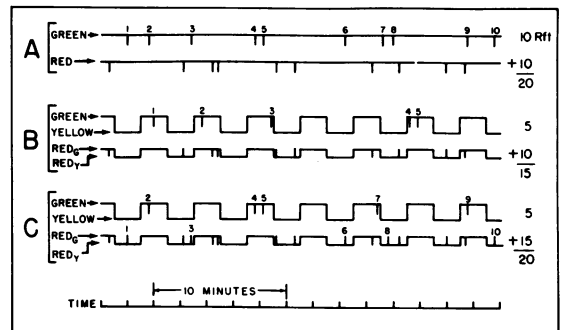


Fig. 1. Three concurrent schedules: (A) conc VI 3 VI 3; (B) mult VI 3 ext concurrent with VI 3; (C) multiple and concurrent schedule in which reinforcement rate during ext is held equal to that during VI 3. Vertical marks indicate reinforcements.

During Procedure B, mult VI 3 ext on the multiple key is concurrent with VI 3 on the other key. The multiple key is either green (VI 3) or, when the line is displaced downward, yellow (ext). While it is yellow, responses on the key are never reinforced. The second key is always red; and, as in A, reinforcement is programmed on a VI 3 schedule. During 30 minutes of B, 5 responses (numbered) are reinforced on the multiple key and 10 on the red key.

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During Procedure C, the multiple-key schedule remains mult VI 3 ext, but the reinforcement rate during yellow is held equal to that during green. Responses on the yellow key are never reinforced, but the multiple-key programmer continues to operate, programming reinforcements for responses on the red key. The numbered reinforcements in A and C occur at corresponding times; but in C, 5 are for green-key and 5 are for red-key responses. Under C, 10 responses are reinforced during the 15 minutes of yellow in Fig. 1.

Each component of the multiple schedule lasted 2 minutes. Reinforcements available but not obtained at the end of one VI 3 component of the multiple schedule were still available at the beginning of the next VI 3 component. Each session lasted 1 hour.

The abbreviations G and Y refer to the multiple key during green and yellow, respectively; and R refers to the red key. The subscript on R indicates the condition on the multiple key. Thus, C may be described:

mult (conc VI 3<sub>G</sub> VI 3<sub>R<sub>G</sub></sub>) (conc ext<sub>Y</sub> VI 1.5<sub>R<sub>Y</sub></sub>).

Table 1 indicates the procedure sequence and the number of sessions of each procedure for each subject. All sessions indicated were included in the data

Table 1

Sequence of Procedures for Each Subject, and Number of Sessions Each Procedure was in Effect

Pigeon No.					
82	84	89	90	91	94
A 3	—	A 3	A 3	A 3	A 3
B 17	C 7	B 17	C 10	B 17	C 17
C 10	B 10	C 10	B 10	C 10	B 10
A 7	A 7	A 7	A 7	A 7	A 7
C 7	B 7	C 7	B 7	C 7	B 7
B 7	C 7	—	—	—	—
A 7	A 7	A 3	A 6	A 3	A 3
B 17	C 17	C 7	B 7	C 7	B 7
A 4	A 4	B 7	C 7	B 7	C 7
—	—	A 4	A 4	A 4	A 6

analysis.<sup>3</sup> The dashed lines indicate sessions omitted because of programming failures. Each subject was exposed to each of these sequences: AB, BC, CA, AC, CB, and BA.

*Changeover Delay.* A COD 1 second (changeover delay of 1 second; cf. Herrnstein, 1961) was used for changeovers in both directions. The COD provides that a response on one key preceded by a response on the other is never reinforced; also, if reinforcement has been programmed, it will not be available until

<sup>3</sup>Analyses of operant-conditioning data generally include only the last *n* sessions under a given procedure. The present procedures produced their effects rapidly, however; and the findings obtained were unaltered when, instead of all sessions, all except the first few or only the last several sessions under a given procedure were used.

some fixed time after the changeover. This procedure insures that responses on one key do not come under the control of the reinforcement schedule on the other key through superstitiously maintained chaining.

*Terminology.* The following terminology is used here to describe the concurrent performance. A "run" is a series of consecutive responses emitted on one key. The first response in a run is that following a response on the second key; the last, is that preceding a response on the second key. The notation run<sub>G</sub> is a run on the green key, and run<sub>R</sub> is a run on the red. The running rate, or local rate of responding during the run, is the number of responses (resp/run) divided by the duration (time/run) of the run. A changeover from the green key to the red is CO<sub>R</sub>, and a changeover from the red key to the green is CO<sub>G</sub>. The subscript indicates the key to which the subject is switching. The time from the first response of a run on one key to the beginning of the next run on that key constitutes a cycle, whose duration is the sum of the two CO-times and the two run-durations.

*Measurement.* Two timers were used to estimate time/run on each key. The timer for a given key operated after each response on the key but stopped if 2 seconds passed without a response. Because inter-response times (IRT's) during a run were generally less than 2 seconds, and runs on a key were separated by more than 2 seconds, these timers cumulated the run durations plus 2 seconds per run for each key.<sup>3</sup>

The mean time/run was given by:

mean time/run =

$$\frac{\text{timer reading} - (2 \text{ seconds} \times \text{no. of runs})}{\text{no. of runs}}$$

A second pair of timers was used to estimate the mean CO-time in each direction. One timer started with the first response on Key<sub>G</sub> and stopped with a response on Key<sub>R</sub>. It thus cumulated time/run<sub>G</sub> plus CO<sub>R</sub> time. Since time/run<sub>G</sub> was available, the mean CO<sub>R</sub>-time could be calculated:

$$\text{mean CO}_R\text{-time} = \frac{\text{timer reading}}{\text{no. of runs}} - \text{mean time/run}_G$$

Similarly, the second timer, which started with a response on Key<sub>R</sub> and stopped with a response on Key<sub>G</sub>, provided the mean CO<sub>G</sub>-time.

These measures were obtained only during green, because during yellow, few responses were made on the multiple key.

<sup>3</sup>Examination of Esterline-Angus records showed that even for the pigeon responding at the lowest rate (No. 94), less than 5% of the IRT's during runs on either key were more than 2 seconds. In most records, IRT's longer than 2 seconds made up only 1 or 2% of the total IRT's. These longer IRT's rarely exceeded 3 seconds, and sometimes never exceeded 2.5 seconds. Occasions on which the subject switched to the other key and returned in less than 2 seconds were also few, far less than 1% of the total number of changeovers.

A check on reliability was possible because two independent measures of cycle duration were available: (1) the sum of the temporal measures, and (2) the reciprocal of the rate of changeover. (For example, if the subject switched to one key six times per minute, cycle length was 10 seconds.) Cycle lengths calculated in these two ways were in good agreement.

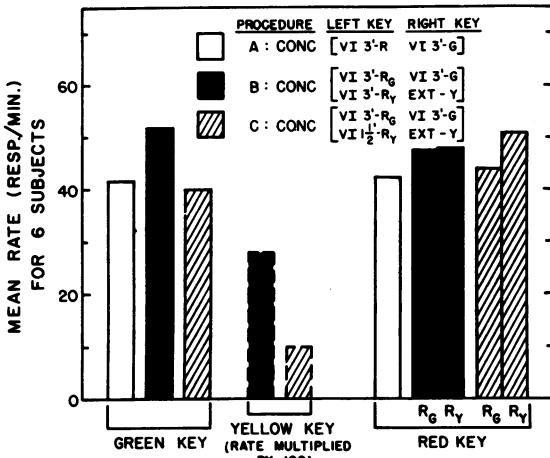


Fig. 2. Mean rate of responding (six subjects) on each key and under each procedure and stimulus condition. Response rate on the yellow key has been multiplied by 100.

RESULTS

Rate of Responding

Figure 2 summarizes the response rates on each key and under each procedure and stimulus condition. The rates on the green and on the red key are mean

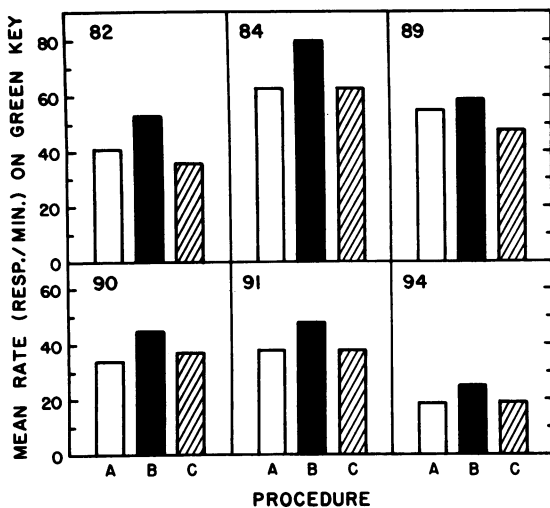


Fig. 3. Mean rate of responding on the green key under each procedure for individual subjects.

rates across the individual-subject data in Fig. 3 and 4. The rates on the yellow key were multiplied by 100, and are also mean rates across subjects.

Several rate comparisons are of interest. Under A, the rates on the green and on the red key were about equal (as were the schedules, VI 3, on each). Under B, the rates on each key were higher than those under A, but the rate increase relative to A was greater for the green than for the red key. The red-key rates during green and during yellow ( $R_G$  and  $R_Y$ ) were about equal. Under C, response rates on the green key and on the red key during green ( $R_G$ ) were about equal to those under A. The rate on  $R_Y$  (VI 1.5) was higher than that on  $R_G$  (VI 3).

Response rates on the yellow key were low throughout; the rates in Fig. 2 represent only 3 to 8 responses per session.

Figures 3 and 4 present the mean rates of responding on the two keys for individual subjects. The mean rate was computed over each series of consecutive sessions under a given procedure. Because subjects were exposed to a given procedure on as many as four different occasions (Table 1), the separate series under a given procedure were equally weighted and averaged in order to simplify data presentation. The data are in good agreement with the average rates in Fig. 3.

The data indicate that relative to A, B consistently produced an increase in rate on the green key whereas C did not. In other words, multiple scheduling produced contrast only when the rate of reinforcement during the ext component decreased (B), but not when it was held equal to that during the VI 3 component (C). The rate on  $R_G$  also increased under B and not under C, although the increase was not so large as that on the green key.

Response rate on the red key was not affected by the multiple-schedule component; *i.e.*, under B, the rates on  $R_G$  and  $R_Y$  were about equal. (Under C, the rate on  $R_G$  was lower than that on  $R_Y$ , but the VI 3

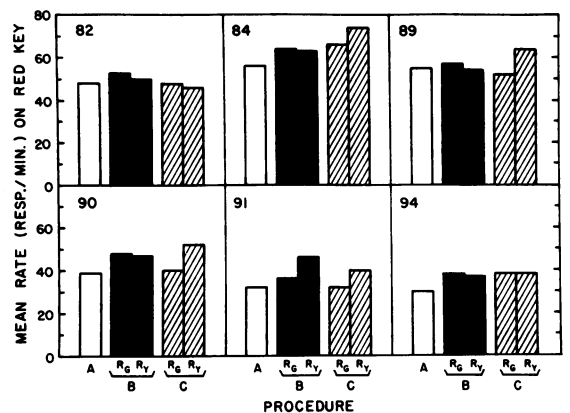


Fig. 4. Mean rate of responding on the red key under each procedure and during each multiple-schedule component ( $R_G$  and  $R_Y$ ), for individual subjects.

schedule on  $R_G$  provided less frequent reinforcement than the VI 1.5 schedule on  $R_Y$ .)

#### Characteristics of the Concurrent Performance

The data in Fig. 5 describe the performance during green under each procedure, and are means across the individual-subject data in Fig. 6. For both keys, the CO time or time to change over (I) was shorter under B than under either A or C.

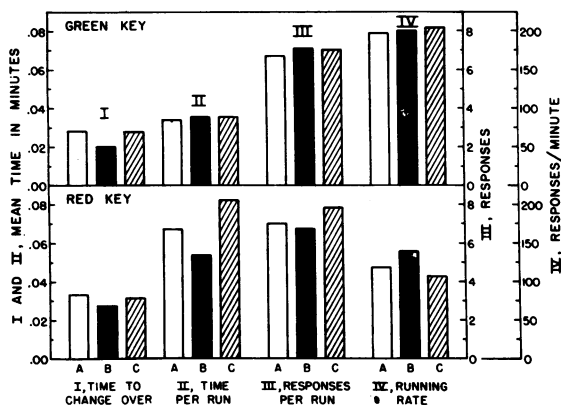


Fig. 5. Concurrent performance during green under each procedure (six subjects). Data for each key are: I, mean time to change over from the other key; II, mean time/run; III, mean resp/run; IV, mean running rate.

On the green key, the performance during runs, time/run (II), resp/run (III), and the running rate (IV) differed only slightly from one procedure to another. On the red key, marked differences were noted; time/run $_R$  and resp/run $_R$  were lowest under B and highest under C, and running rate $_R$  was highest under B and lowest under C.<sup>4</sup>

The data for individual subjects in Fig. 6 (calculated in the same way as in Fig. 3 and 4) are in general agreement with the grouped data in Fig. 5.

The mean time/run on both keys was well above the 1 second (0.017 minute) required by the COD. For each subject, however, time/run $_G$  was consistently shorter than time/run $_R$ . (Note the different ordi-

ates.) This was probably the result of the occasional programming of VI 1.5 on the red key ( $R_Y$  under C). This assumption is borne out by a comparison of data for individual subjects, which shows that the difference between time/run $_G$  and time/run $_R$  was largest for

<sup>4</sup>Note that given time/run and resp/run, running rate is determined:  $\frac{\text{resp/run}}{\text{time/run}} = \frac{\text{resp}}{\text{time}} = \text{running rate}$ . If CO time is also known, response rate is determined as well, and may be calculated by replacing time/run by time/cycle.

Birds 82 and 94. Discriminative control of red-key responding by the stimuli on the multiple key was never well established for these birds. The programming of VI 1.5 on  $R_Y$  (both in the reported sessions and in previous experiments) increased the time the subjects spent responding on  $R_G$  before switching. This effect was apparently long lasting, since it was evident throughout A and B as well as under C.

#### SUPPLEMENTARY PROCEDURES

##### Method

Throughout the sessions in Table 1, the multiple key was on the right. Following these sessions, and after several sessions under A, the key on the right was always green (VI 3) and the key on the left alternated between red (VI 3) and yellow (ext) for 21 sessions. This procedure is the same as that under B except that green and red have been reversed:

mult (conc VI 3 $_G$  VI 3 $_R$ ) (conc VI 3 $_G$  ext $_Y$ )

Procedure C was then programmed with colors changed for 10 (Birds 82, 89, and 91) or 15 (Birds 84, 90, and 94) sessions:

mult (conc VI 3 $_G$  VI 3 $_R$ ) (conc VI 1.5 $_G$  ext $_Y$ )

In earlier experiments, successive components of the multiple schedule varied in duration, lasting either 1, 2, or 3 minutes; and the conditions on the keys alternated between the right and the left key every 2 minutes. Thus, a red key was always available on either the right or the left, and the remaining key was always green (A) or either green or yellow (B and C). The side and component changes were arranged so that the key which was green changed to yellow (and the other key remained red) as frequently as the key which was red changed to yellow (and the other key became red). This procedure differs from that described previously in that either key could change to yellow while the subject was responding on it. In the earlier procedure, only the green key could change color while the subject responded on it; the other key was always red. The multiple and concurrent scheduling was otherwise unaltered.

During these sessions, COD 0.5 second was used, and session length was determined by number of reinforcements (40 per session). Three subjects were exposed to each procedure for five sessions in the sequence ABACA, and three in the sequence ACABA.

The schedules were then repeated with VI 1.5, VI 6, or ext rather than VI 3 on the nonmultiple (red) key. With VI 1.5 (Birds 84 and 94) and VI 6 (Birds 89 and 90), seven sessions of A preceded sessions of B and C. With ext (Birds 82 and 91), 14 sessions of A preceded. The schedules are described in Table 2.

##### Results

Part I of Fig. 7 shows data obtained when the multiple schedule in B and C was programmed on the

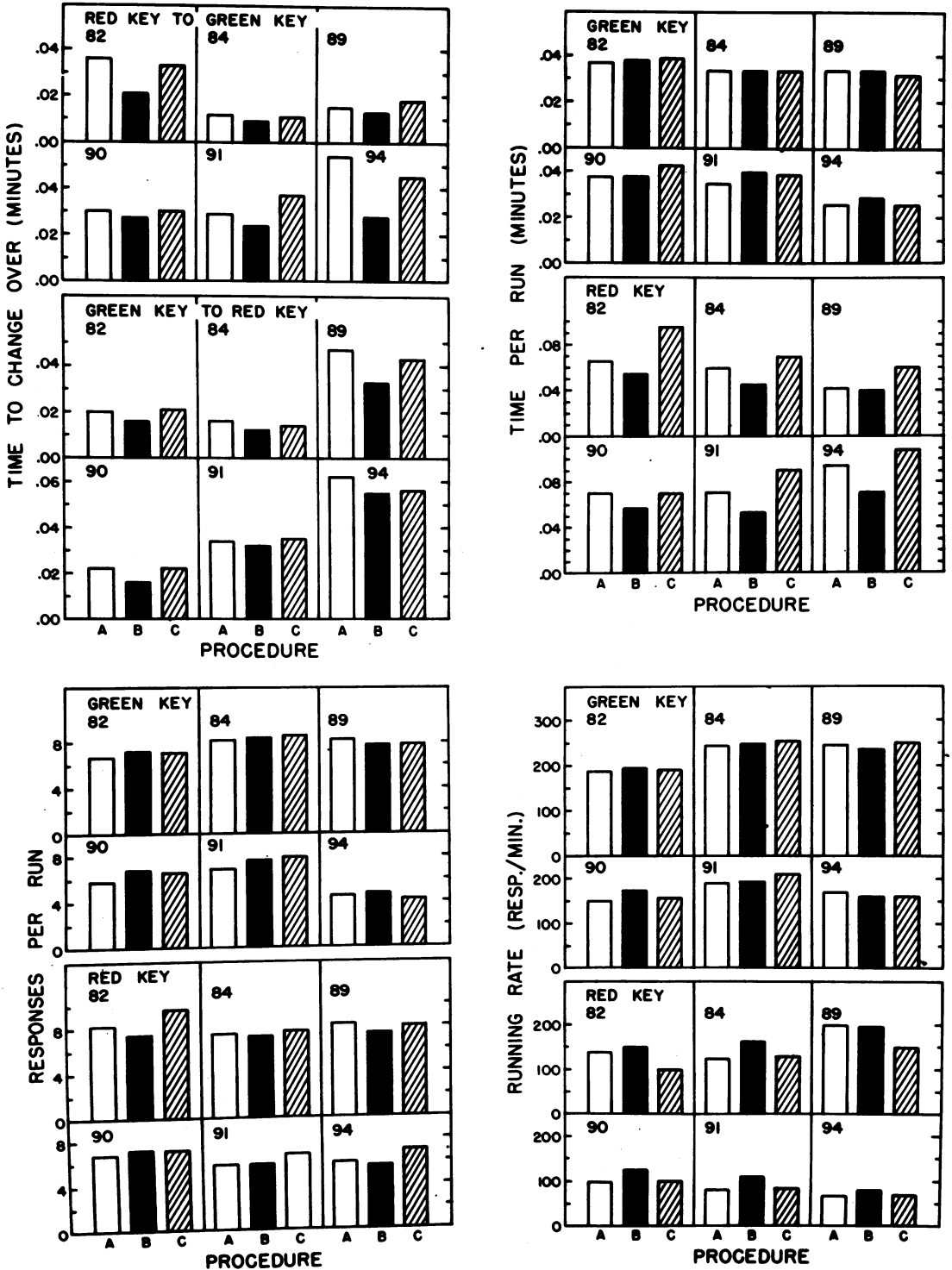


Fig. 6. Concurrent performance during green under each procedure for individual subjects. Data are: mean time to change over (upper left); mean time/run (upper right); mean resp/run (lower left); mean running rate (lower right).

Table 2

Multiple and Concurrent Schedules, with VI 1.5, VI 3, VI 6, or ext Programmed on the Nonmultiple Key  
(Rates of Reinforcement Are Indicated)

Procedure A		Procedure B		Procedure C	
Schedule (Key R) (Key G)		Schedule (Key R <sub>G</sub> ) (Key G) (Key R <sub>Y</sub> ) (Key Y)		Schedule (Key R <sub>G</sub> ) (Key G) (Key R <sub>Y</sub> ) (Key Y)	
rft/hr	conc VI 1.5 VI 3 60	mult (conc VI 1.5 VI 3) (conc VI 1.5 ext)	60 40	mult (conc VI 1.5 VI 3) (conc VI 1 ext)	60 60
rft/hr	conc VI 3 VI 3 40	mult (conc VI 3 VI 3) (conc VI 3 ext)	40 20	mult (conc VI 3 VI 3) (conc VI 1.5 ext)	40 40
rft/hr	conc VI 6 VI 3 30	mult (conc VI 6 VI 3) (conc VI 6 ext)	30 10	mult (conc VI 6 VI 3) (conc VI 2 ext)	30 30
rft/hr	conc ext VI 3 20	mult (conc ext VI 3) (conc ext ext)	20 0	mult (conc ext VI 3) (conc VI 3 ext)	20 20

red rather than on the green key. The data resemble those in Fig. 2, indicating that the differences in time/run<sub>G</sub> and time/run<sub>R<sub>G</sub></sub> discussed above did not play

an important role in determining the observed changes in response rate. The data are mean rates across subjects over the four sessions of A preceding sessions under B and the last five sessions of both B and C. The results also demonstrate that contrast is an effect which lasts, apparently undiminished, for as many as 21 successive sessions.

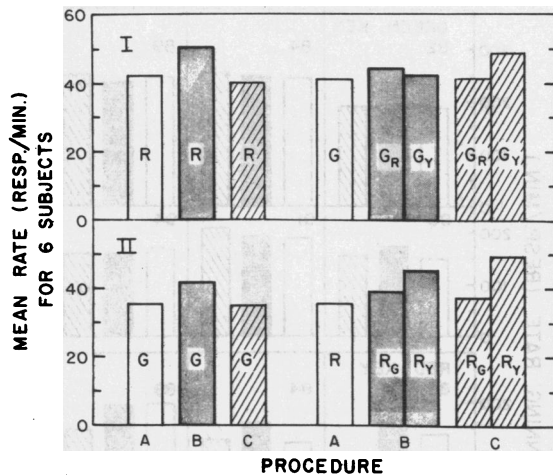


Fig. 7. Mean rate of responding (six subjects) on each key and under each procedure and stimulus condition. In I, the multiple schedule was programmed on the red rather than on the green key. In II, the conditions on the keys alternated from one side to the other every 2 minutes.

Part II of Fig. 7 presents the data obtained when the conditions on the keys changed sides every 2 minutes, and the multiple-schedule components changed after 1, 2, or 3 minutes. These data are mean rates across subjects for five sessions of both B and C. The

data for A represent three sessions preceding B and three preceding C. Except for the rates on R<sub>Y</sub>, the effects again resemble those in Fig. 2. High rates on R<sub>Y</sub> were observed during early sessions of combined multiple and concurrent scheduling. These rates of responding decreased and stabilized during subsequent sessions of multiple and concurrent scheduling. The data are representative of those for the individual subjects.

Figure 8 shows the effects of different schedules programmed on the nonmultiple key. The data are mean rates for two subjects over six sessions of A (three preceding B and three preceding C), five of B, and five of C.

The relative magnitude of the rate increase on the green key under B (contrast) varied with the nonmultiple-key schedule as shown in Fig. 9, which presents the increase in response rate (relative to the rate under A) as a function of the decrease in reinforcement rate during the VI 3 component (cf. Table 2). In all cases, Procedure C eliminated contrast.

#### DISCUSSION

The data have shown that contrast occurs in a mult VI ext schedule when the reinforcement rate during ext becomes less than that during VI. It does not occur when the reinforcement rate during ext is held equal to that during VI.

The data obtained when the schedule on the nonmultiple key was varied indicate that the magnitude of the contrast effect is a function of relative rather than absolute decreases in reinforcement rate (Fig. 9). The largest response-rate increase was obtained with ext programmed on the nonmultiple key, and the smallest with VI 1.5 programmed. In both cases, the absolute decrease in the reinforcement rate in the ext component was 20 rft/hour. With ext programmed on the nonmultiple key, however, the relative decrease in reinforcement during ext was 100%, whereas with VI 1.5 programmed on the nonmultiple key, it was

33%. Under C, the rate of reinforcement did not decrease in the ext component, and response rate did not increase.

A decrease in the rate of reinforcement appears to be a necessary condition for contrast, and it is of interest to consider how this decrease produces its effect.

One interpretation is that a decrease in reinforcement rate has emotional consequences, producing an increase in the general level of activity and therefore

contrast was observed only under B. The interpretation also does not account for the rapidity of the effect (contrast occurs within a single session).

A similar argument may be made in terms of differential punishment of IRT's. Ferster (1958) has shown that the interruption of a VI schedule may be punishing. When the schedule is interrupted periodically, the probability that a given long IRT will be punished is greater than the probability that a shorter

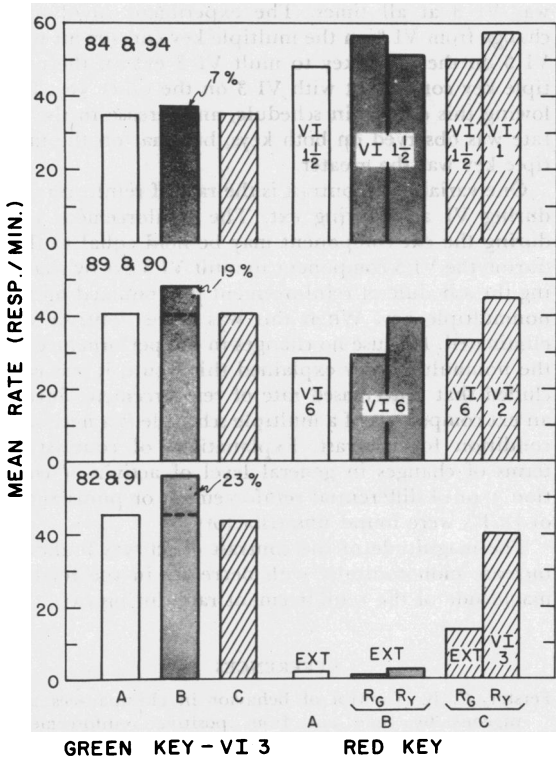


Fig. 8. Mean rate of responding when VI 1.5, VI 6, or ext were programmed on the red key, rather than VI 3, for two subjects under each condition.

in response rate. Emotional effects, however, may be expected to decrease with time, whereas contrast was observed for as long as 21 sessions under B. Second, the magnitude of the rate increase was not the same on both keys; that on the multiple key was greater. Contrast was, at least to some extent, specific to the multiple key.

Another interpretation of contrast is in terms of differential reinforcement of IRT's. When a VI schedule is interrupted periodically, the likelihood of an interruption is greater after longer pauses than after shorter ones. Long IRT's will therefore be reinforced relatively less frequently than when the VI schedule is uninterrupted. This is effectively differential reinforcement of high rates (cf. Ferster, 1958). The mult VI 3 ext schedule programmed on the multiple key remained constant under B and C, however, whereas

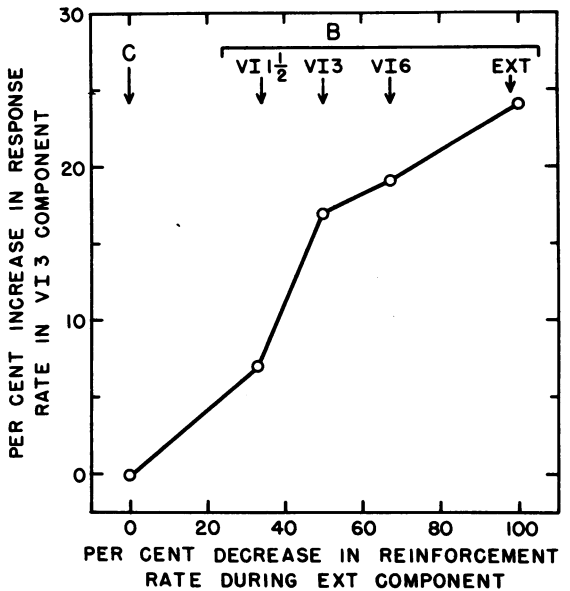


Fig. 9. Contrast (rate increase relative to A) in VI 3 component as a function of the relative decrease in reinforcement rate during the ext component. Schedule on the nonmultiple (red) key and procedure are indicated for the plotted points.

IRT will be punished, and the resulting differential punishment may produce an increase in response rate. The different effects of B and C would then simply indicate that the yellow ext stimulus is not punishing when the over-all rate of reinforcement during yellow is equal to that during green. But there is another difficulty. Since contrast is to some extent specific to the multiple key, the assumption must be made that the effect of the punishing stimulus (the yellow key) is greatest when it appears on the key on which the subject is responding. Yet, the specificity remains even when the conditions on the two keys change sides in such a way that the red key changes to yellow as frequently as the green key changes to yellow.

It could be argued that contrast was not observed under C only because changes in the performance on the nonmultiple key prevented a rate increase. The rate of responding on R<sub>G</sub> was lower under C than under B, however, and the changeover and run measures for the multiple key under C were not altered (relative to A) by the red-key performance.

The increase in response rate under B may be stated in terms of changes in the local characteristics of the performance. When subjects responded on the green key under B, they responded at about the same running rate, emitted about the same resp/run, and took about the same time/run as they did when responding under A. Nevertheless, under B, the over-all response rate on the green key increased. The reason is that although  $\text{time/run}_G$  remained unchanged, the CO times for both keys and  $\text{time/run}_R$  decreased.

The duration of a cycle under B was consequently shorter than that under A. This means that when the subject reached the green key, it responded as it did under A; but it reached the green key more often and therefore emitted more responses in a given amount of time.

This may imply that B produces contrast primarily through an effect on changeover responses. But, it may also imply that the part of the performance which changed under the contrast-producing procedure was that which had the fewest constraints on it. The COD imposed a lower limit on time/run because runs of less than 1 second were never reinforced, and on resp/run because at least 2 responses were required for reinforcement. Constraints on running rate may have resulted from contingencies in the VI scheduling which affected IRT's. Since, in addition, any two of these characteristics of runs determine the third, the total effect of such constraints may be considerable.

An unpublished experiment performed in the Harvard Psychological Laboratories by D. M. Trask and N. Peterson is relevant here. Pigeons were reinforced on a conc VI VI schedule on two keys. Trask and Peterson found that with both conc VI 3 VI 3 and conc VI 4.5 VI 2.25, changes in the distance between the keys (from 1 inch to 9 inches), which presumably changed CO times, had no systematic effect on the response rates on each of the keys. Under conc VI 4.5 VI 2.25, the introduction of a barrier between the keys increased CO times and reduced the frequency of changeovers, but again had no systematic effect on response rates.

Another relevant finding is that under B the response rate on the nonmultiple key was independent of the schedule and performance on the multiple key. During both green and yellow, responding on the red key was reinforced on a VI 3 schedule. The response rates during each component were about equal, although during green the subject emitted brief runs of responses emitted at a high rate and separated by periods of responding on the green key, whereas during yellow, responding was relatively continuous and rarely interrupted by periods of responding on the

yellow key. This suggests that the schedules did not control rate of responding directly through control of local characteristics of the performance.

#### SUMMARY

Pigeons could respond to either of two keys. On one, the multiple key, the schedule of reinforcement was either VI 3 or mult VI 3 ext. On the second, it was VI 3 at all times. The experiment involved a change from VI 3 on the multiple key concurrent with VI 3 on the other key to mult VI 3 ext on the multiple key concurrent with VI 3 on the other key. Following this change in schedule, an increase in the VI rate was observed on both keys, but that on the multiple key was the greater.

One variable in contrast is the rate of reinforcement during VI and during ext. The reinforcement rate during the ext component may be held equal to that during the VI 3 component in mult VI 3 ext by changing the schedule of reinforcement programmed on the nonmultiple key. When this was done, contrast was eliminated. Because no changes in the performance on the nonmultiple key explained this result, it was concluded that a decreased rate of reinforcement during an ext component of a multiple schedule is a necessary condition for contrast. Explanations of contrast in terms of changes in general level of activity ("emotion") or of differential reinforcement or punishment of IRT's were found unsatisfactory.

The magnitude of the contrast effect was found to increase monotonically with decreases in the relative magnitude of the reinforcement rate during ext.

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