# ELICITED RESPONDING TO SIGNALS FOR REINFORCEMENT: THE EFFECTS OF OVERALL VERSUS LOCAL CHANGES IN REINFORCEMENT PROBABILITY[1]

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Pigeons were studied on a three-component multiple schedule where all reinforcement was independent of responding. Two components were cued by different keylights and were associated with different rates of reinforcement. The third was always a no-key period associated with extinction. After a few sessions, pecking was elicited by the keylights signalling the reinforcement and continued to be maintained indefinitely. The duration and sequence of the three components were varied to determine if the primary controlling variable was differences in the overall probability of reinforcement, or if it was the immediate change in reinforcement signalled by the onset and/or offset of the stimulus. Both variables were found to control behavior. When 30-sec components were used, the primary controlling variable was the overall probability of reinforcement, but when 3-min components were used, overall probability had little effect. Control by local changes in reinforcement also occurred, although the type of local control varied both across subjects and experimental conditions. Some behaviors were controlled more by the change in reinforcement signalled by the onset of the stimulus, while others were controlled more by the change signalled by the offset of the stimulus.

Key words: elicited responding, response-independent reinforcement, behavioral contrast, multiple schedules, sequential effects, autoshaping, key pecks, pigeons

A stimulus signalling a reinforcer, even in the absence of any response contingency, comes to elicit behavior (cf. Hearst and Jenkins, 1974). This phenomenon has been widely investigated, since it has implications for a large segment of behavior theory, including the operant-respondent distinction, the interpretation of schedule phenomena such as behavioral contrast, etc.

A fundamental issue is the conditions that cause a stimulus to become a signal for reinforcement. One alternative is simply that a stimulus becomes a signal for a reinforcer whenever the probability of reinforcement during the stimulus is greater than during its absence. The literature supports this interpretation, particularly from the random control procedure for classical conditioning (Rescorla, 1967, 1968). The simplicity of this answer may be deceptive, however, because it ignores a major question. Namely, what are the boundaries, temporal or otherwise, that determine the alternative conditions to which the reinforcement probability associated with a stimulus is compared?

The need to specify the basis of comparison can be seen best by considering a three-component multiple schedule. Suppose that food is delivered, independent of responding, on the average of once per minute during a red keylight, twice per minute during a green keylight, and not at all during a blue keylight. On the basis of previous findings with two-component multiple schedules (Gamzu and Schwartz, 1973), key pecking should develop because of the differential contingencies. But consider the behavior to the red keylight. While it signals a higher probability of reinforcement than the blue keylight, it signals less reinforcement than the green keylight. What then will be the basis of comparison? If the controlling variable is the differential probability, per se, without regard to the time-frame within which the probabilities are estimated, then the best predictor of red-key behavior should be the reinforcement rate during red versus the average rate during its absence. The average rate during green plus blue is one per minute, so the red keylight would not differentially signal reinforcement and key pecking should not develop. On the other

hand, if the controlling variable is the degree to which red signals an increase in reinforcement probability, the behavior to red should depend on the order in which the three components are presented. If green preceded red, no behavior should develop (since red would signal a reduction in reinforcement), whereas if blue preceded red, pecking on the red key should occur.

A major factor determining whether the average rate of reinforcement in the absence of a stimulus controls pecking to that stimulus is of course the temporal parameters of the situation. Probably only the most recent events are included in such an average, since presumably the animal does not "compare" present rates of reinforcement with those experienced months before. One issue, therefore, is the temporal parameters themselves. To date, there have been no systematic investigations of such parameters involving multiple schedules of response-independent reinforcement. Several studies have been reported involving response-dependent schedules (Shimp and Wheatley, 1971; Todorov, 1972; Silberberg and Schrot, 1974; Shimp and Menlove, 1974). They have generally agreed that interactions between components decrease rapidly as the component durations are increased from a few seconds to several minutes. Much recent discussion has emphasized the role of stimulus-reinforcer contingencies as the common basis of all interactions in multiple schedules (*cf.* Rachlin, 1973). It is of interest, therefore, to determine whether or not the temporal parameters governing response-dependent schedules govern response-independent schedules as well.

A second and less obvious factor, one that will determine the degree of red-key responding in the above example is the nature of changes in local contingencies to which the subject is sensitive. One such local change is of course a comparison of the rate of reinforcement during red with that during the stimulus preceding it. A second possibility, usually ignored, is the comparison with the stimulus following red. This possibility is indicated by the results of Pliskoff (1961, 1963) and Wilton and Gay (1969), who demonstrated an increase in response rate during a signal preceding a change to extinction. More recently, Williams (1974) and Buck, Rothstein, and Williams (1975) have shown the same effect to operate

in simple multiple schedules themselves. That is, response rates within the unchanged variable-interval (VI) component (after a change to a multiple VI extinction) increased as the end of the component approached. This change in local response rate is just the opposite to the increase in rate often seen at the beginning of the VI component (*cf.* Menlove, 1975). The two types of "local contrast" are not necessarily in opposition, however, since the increase at the end of the component generally occurred only with extensive training. The two effects may simply indicate two different types of local effects that govern multiple schedule interactions. Of particular interest, however, is whether the second type of local interaction is operative in schedules involving response-independent reinforcement as well.

The present study investigated interactions in a three-component multiple schedule involving response-independent reinforcement. Three variables were manipulated: duration of the components of the schedule, reinforcement rates during the components, and their sequence of presentation.

## METHOD

### Subjects

Eight White Carneaux pigeons were maintained at 80% of their free-feeding body weights. Four were experimentally naive at the start of the experiment (R-1, R-9, R-18, B-19); the other four had extensive key-pecking experience (R-2, R-5, R-12, Y-91).

### Apparatus

A standard operant-conditioning chamber was constructed from a plastic picnic chest. The pigeon's chamber was approximately 30.5 cm in all dimensions. On the front panel were mounted two transparent pigeon keys, 1.9 cm in diameter, which required a force of at least 0.10 to 0.12 N for operation. The stimuli were projected on the rear of the key by standard 28-V, 12-stimulus in-line projectors. Ten centimeters below and between the keys was the window through which the birds were fed when the grain magazine was operated. Located on the rear wall of the inner chamber was a 28-V houselight, illuminated at all times during an experimental session.

## Procedure

*General procedure.* On the first day of training, the four naive subjects were trained to eat from the grain hopper by presenting the hopper for a series of 30-sec periods. All subjects were then exposed directly to one of the experimental conditions. During all conditions, a session consisted of three types of components: periods in which the left key was illuminated with a white vertical line, periods in which the right key was illuminated with a 45-degree red line, and periods in which neither key was illuminated. The two response keys were never illuminated simultaneously. Response-independent, 3-sec grain presentations occurred intermittently during the key-light illuminations but never when neither key was illuminated. Sessions terminated after 48 min.

*Experimental conditions.* Combinations of three variables defined the different experimental conditions. Component duration was one variable and was either 30 sec or 3 min. Frequency of grain presentation was the second variable. During illumination of the right key, food was presented always on the average of once per minute (variable time or VT 60-sec). During illumination of the left key, the schedule was either VT 120-sec or VT 30-sec. All three schedules consisted of 18 intervals constructed according to an exponential distribution. The third variable, the sequence of presentation for the three components, was determined by a stepping switch and was one of three possibilities: (1) no key, left key, right key, no key; (2) no key, right key, left key, no key; (3) no key, right key, no key, left key. After one full sequence was completed, the stepper recycled. Thus, when a 30-sec component duration was used there were 24 complete cycles, and when a 3-min component duration was used there were four cycles. Table 1 summarizes the different experimental conditions. Their order of presentation for individual subjects can be seen in Figures 1 and 2.

## RESULTS

### Overall Response Rates

The absolute rates for both responses are shown in Figures 1 and 2 and Table 2. Figure 1 shows the data for subjects initially trained with the 30-sec components and Figure 2 shows

### Table 1

Combinations of three variables defining the different experimental conditions. The schedule during right-key illumination was always VT 60-sec. The (—) denotes a period of extinction during which neither key was illuminated, the R denotes right-key illumination, and the L denotes left-key illumination.

| Condition | Sequence of Presentation | Component Duration | Reinforcement Schedule during Left Key |
|---|---|---|---|
| 1 | —RL— | 30 sec | VT 120-sec |
| 2 | —LR— | 30 sec | VT 120-sec |
| 3 | —R—L | 30 sec | VT 120-sec |
| 4 | —RL— | 3 min | VT 120-sec |
| 5 | —LR— | 3 min | VT 120-sec |
| 6 | —R—L | 3 min | VT 120-sec |
| 7 | —RL— | 30 sec | VT 30-sec |
| 8 | —LR— | 30 sec | VT 30-sec |
| 9 | —RL— | 3 min | VT 30-sec |
| 10 | —LR— | 3 min | VT 30-sec |

those subjects initially trained with 3-min components. In each figure are subjects that were initially naive and subjects with key-pecking experience. Except for a difference in the time required for the development of key pecking there was no consistent effect of prior experience, so that variable is ignored in the description of the results. One naive subject, R-9, did fail to maintain consistent key pecking, so its data were excluded from further analysis.

### Table 2

Responses per minute to the left and right keys during the last 10 sessions of each of the first six experimental conditions. Data in parentheses represent replications of the same experimental condition.

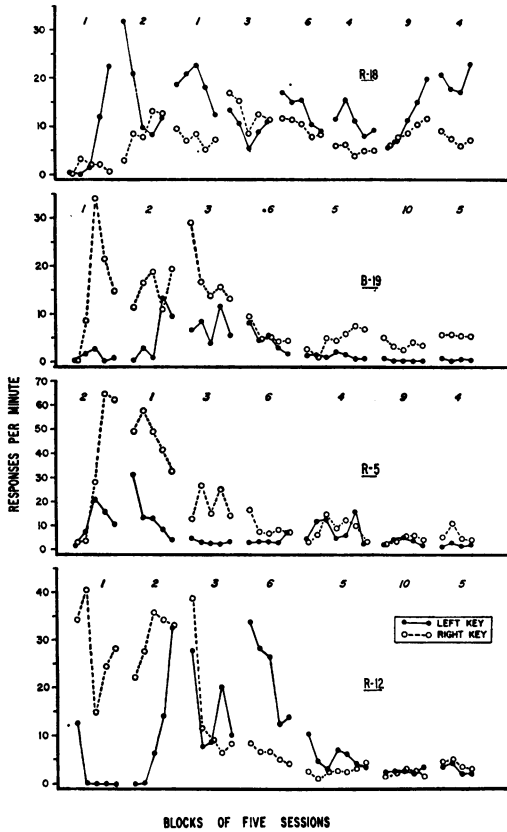| Subject | | Experimental Condition | | | | | |
| | | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| R-18 | L | 17.2 (15.2) | 10.0 | 10.0 | 8.6 | — | 9.7 |
| | R | 1.3 ( 6.1) | 13.0 | 11.9 | 5.0 | — | 8.1 |
| B-19 | L | 0.5 | 11.4 | 8.6 | — | .7 | 2.2 |
| | R | 18.1 | 15.2 | 14.3 | — | 7.0 | 4.2 |
| R-5 | L | 6.2 | 13.4 | 2.7 | 9.1 | — | 4.9 |
| | R | 37.1 | 63.4 | 19.5 | 6.4 | — | 7.7 |
| R-12 | L | 0 | 23.4 | 17.6 | — | 3.8 | 13.3 |
| | R | 26.2 | 33.6 | 7.3 | — | 3.7 | 4.6 |
| R-1 | L | 12.1 | — | 9.7 | 24.8 | 5.0 | 23.7 |
| | R | 24.4 | — | 44.8 | 21.4 | 27.1 | 35.3 |
| R-2 | L | 8.2 | — | 3.1 | 8.0 | 5.5 | 3.8 |
| | R | 31.7 | — | 25.6 | 20.5 | 19.5 | 23.4 |
| Y-91 | L | — | 6.1 | 1.4 | 5.1 | 8.1 | 9.1 |
| | R | — | 24.9 | 15.1 | 4.2 | 1.1 | 3.9 |
| Median | L | 7.2 | 11.4 | 8.6 | 8.6 | 5.0 | 9.1 |
| | R | 25.3 | 24.9 | 15.1 | 6.4 | 7.0 | 7.7 |

Fig. 1. Absolute rates of pecking for the left and right keys across all experimental conditions for pigeons initially trained with 30-sec components. Numbers above the curves refer to conditions given in Table 1.
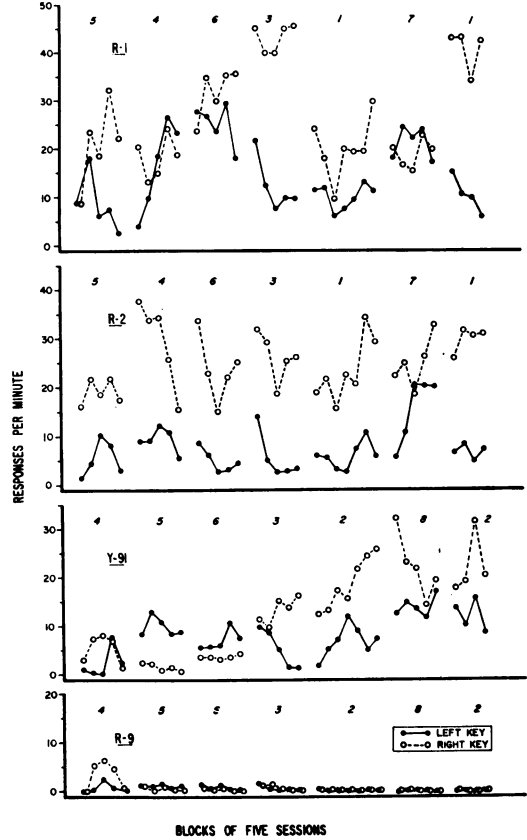


Fig. 2. Absolute rates of pecking for the left and right keys across all experimental conditions for pigeons initially trained with 3-min components. Numbers above the curves refer to conditions given in Table 1.

*Effects of component duration.* The most direct assessment of the effects of component duration comes from the comparison of Conditions 3 and 6, where each stimulus was preceded and followed by a period of extinction, and where the subjects were transferred between the two conditions without other conditions intervening. From Table 2 it is evident that component duration interacted with the density of the reinforcement schedule. For the higher-density schedule (the right key), the rate of responding was higher under the 30-sec components (Condition 3) for all seven subjects. For the lower-density schedule (left key), component duration had little consistent effect. A similar pattern occurred for the comparisons of Condition 1 *versus* Condition 4, and Condition 2 *versus* Condition 5 (which received the same sequence of component

presentation), as only responding to the right key was systematically affected.

*Effects of sequence of presentation.* For the subjects trained with the 30-sec components, an examination of Conditions 1 and 2 shows that, with one exception, all subjects responded more to the right key in both conditions, even during Condition 2 where the left key occurred first in the sequence. The one deviant subject, R-18, was first trained with Condition 1, where the right key occurred first in the sequence. It nevertheless developed pecking almost entirely to the left key. Thus, its behavior was counter that predicted both by the overall rate of reinforcement and by the local increase at the start of the components. The behavior cannot be accounted for by a simple stimulus preference, since a switch to Condition 2 reversed the behavior,

and the switch back to Condition 1 once again produced greater responding to the left key (see Figure 1). The most feasible interpretation is that R-18's behavior was controlled primarily by the change to a lower probability of reinforcement at the offset of the stimulus.

In addition to the control by the overall probability of reinforcement, Table 2 provides some evidence for greater responding to the stimulus that occurred first in the sequence. This was indicated mainly by the responding to the left key, which was greater during Condition 2 than Condition 1 (−LR− *versus* −RL−). Because of the variability across subjects, the difference between the relative rate of responding to the left key for Condition 2 *versus* Condition 1 was subjected to a *t* test. Because all subjects were not run on both conditions, each relative rate was treated as an independent event. Also, the data of R-18 were excluded from the analysis because its behavior clearly was controlled by different variables. The results of the test were not statistically significant ($t = 1.77$, 7 $df$, $p > 0.05$).

A different pattern of sequential effects occurred for the conditions with the 3-min components (Conditions 4 and 5). There, the median rate of responding was higher for the component that occurred last in the sequence. This effect was tested statistically by once again converting the absolute rates to relative rates of responding to the left key and treating each score as an independent event. The results of the test showed that the difference between Conditions 4 and 5 in relative rate to the left key was not statistically significant ($t = 0.92$, 8 $df$, $p > 0.05$).

## Distribution of Responses Within Components

*Effects of component duration.* Table 3 shows the proportion of responses that occurred in the first half of each component during the last 10 sessions of each condition. A comparison of Conditions 3 and 6 once again provides the most direct assessment of the main effect. There was considerable variability across subjects, but in general, the 3-min component (Condition 6) produced relatively more responding in the first half of the component. A similar pattern occurred for the comparison of Condition 1 with 4 and Condition 2 with 5, where the same pattern of proportions occurred, but the 3-min con-

Table 3

Proportion of pecks in the first half of the left- and right-key components (total pecks in the first half/total pecks in both halves) for the last 10 sessions of each of the first six experimental conditions.

| Subject | | Experimental Condition | | | | | |
|---------|---|------|------|------|------|------|------|
| | | 1 | 2 | 3 | 4 | 5 | 6 |
| R-18 | L | 0.49 | 0.66 | 0.37 | 0.51 | — | 0.47 |
| | R | 0.54 | 0.47 | 0.58 | 0.53 | — | 0.52 |
| B-19 | L | 0.44 | 0.63 | 0.45 | — | 0.73 | 0.54 |
| | R | 0.51 | 0.42 | 0.31 | — | 0.55 | 0.47 |
| R-5 | L | 0.40 | 0.55 | 0.39 | 0.53 | — | 0.58 |
| | R | 0.36 | 0.38 | 0.19 | 0.53 | — | 0.57 |
| R-12 | L | — | 0.55 | 0.47 | — | 0.68 | 0.46 |
| | R | 0.47 | 0.43 | 0.45 | — | 0.42 | 0.45 |
| R-1 | L | 0.35 | — | 0.46 | 0.47 | 0.71 | 0.38 |
| | R | 0.61 | — | 0.49 | 0.48 | 0.50 | 0.43 |
| R-2 | L | 0.40 | — | 0.44 | 0.57 | 0.80 | 0.54 |
| | R | 0.47 | — | 0.42 | 0.58 | 0.58 | 0.52 |
| Y-91 | L | — | 0.45 | 0.37 | 0.50 | 0.64 | 0.49 |
| | R | — | 0.42 | 0.32 | 0.72 | 0.65 | 0.67 |
| Median | L | 0.40 | 0.55 | 0.44 | 0.51 | 0.71 | 0.49 |
| | R | 0.49 | 0.42 | 0.42 | 0.53 | 0.55 | 0.52 |

ditions (4 and 5) produced relatively more responses in the first half. To test the effect statistically, all of the proportions for conditions using 30-sec components were averaged for each subject and compared with the average of the proportions for conditions using 3-min components. The mean difference was statistically significant ($t = 2.89$, 6 $df$, $p < 0.05$).

*Effects of sequence of presentation.* The median response rates shown in Table 3 also indicate that the distribution of responses within the component was affected by the sequence of presentation. Whereas the distributions of responses for the left and right keys were similar for the −R−L sequence of Conditions 3 and 6, they differed for the sequences −RL− and −LR−. In both cases, the median proportion of responses in the first half of the component was greater for the component that occurred first in the sequence. To test this effect statistically, the proportions for different component durations but the same sequence of presentation were averaged for each subject. A difference score (left-key proportion minus right-key proportion) was taken for each sequence of presentation and the difference between the two difference scores was subjected to a t-test. R-12 was excluded from the analysis because it did not respond to the left key during the −RL− condition. The

mean difference between the differences was statistically significant ($t = 9.46$, 5 $df$, $p < 0.05$).

### Behavioral Contrast

The results described so far have concerned only the first six conditions shown in Table 1, where the schedule of reinforcement associated with the left key was VT 120-sec, and the schedule for the right key was VT 60-sec. For Conditions 7 to 10, the schedule associated with the left key was changed to VT 30-sec, while that for the right key was unchanged. The last three segments of Figures 1 and 2 show the overall rates to the two keys for the conditions before, during, and after the change.

Since the change in reinforcement was analogous to procedures used in studies of behavioral contrast, the expected results were an increase in rate to the left key but a decrease in rate to the right key. The increase in left-key responding was the less reliable effect and apparently interacted with the component duration. All three subjects trained with the 30-sec components (Figure 2) showed a large increase in left-key responding, but this was not true for subjects trained with 3-min components (Figure 1). Right-key responding, on the other hand, decreased for six of the seven subjects, the one exception being R-18 (Figure 1), which exhibited strong induction effects.

Of major interest was the change in distribution of responding within the right-key component. If the overall rate of reinforcement during the left-key component was the only controlling variable, a reduction in right-key responding, but no change in the pattern of responding, would be expected. On the other hand, if right-key behavior was controlled by the just preceding rate of reinforcement (or by the following rate of reinforcement), changes in the pattern of right-key behavior should occur, but depend on the sequence of component presentation. Table 4 shows the effects of the increase in left-key reinforcement for the first and second halves of the right-key component. The ratios were calculated by treating the two halves of the component separately and dividing the rate after the change in left-key reinforcement by the rate before the change. The individual subjects are grouped according to the sequence of component presentation. Subjects trained with the

## Table 4

Rate of right-key responding during the last 10 sessions of the contrast manipulation, divided into the first half and second half of the component, and normalized relative to the same rates during the last 10 sessions of the condition before the contrast manipulation. Subjects are divided into those trained with the sequence —RL— and those trained with the sequence —LR—.

| Sequence | Subject | First Half | Second Half |
|----------|---------|-----------|-------------|
| —LR— | Y-91 | 0.58 | 0.79 |
|  | B-19 | 0.35 | 0.72 |
|  | R-12 | 0.38 | 0.67 |
| —RL— | R-2 | 1.08 | 0.79 |
|  | R-1 | 1.02 | 0.63 |
|  | R-18 | 2.26 | 2.17 |
|  | R-5 | 1.07 | 0.43 |

—LR— sequence were generally more affected, with a greater reduction in the first half of the right-key component. Responding also decreased for subjects receiving the —RL— sequence (with the exception of R-18), but only in the second half of the component. A generalization, therefore, is that the part of the right-key component closest to the left-key component, whether preceding or following, was most affected by the change in left-key reinforcement.

## DISCUSSION

The results demonstrated that the differential association of response-independent reinforcement with different stimuli is a sufficient condition for initiating and maintaining key pecking in pigeons. The results further indicated that the notion of differential probability of reinforcement cannot be understood adequately unless both the overall probability of reinforcement and local changes in reinforcement are considered. When shorter component durations (30 sec) were used, the overall probability of reinforcement was the primary determinant of behavior, as subjects responded most to the component associated with the higher rate of reinforcement, regardless of whether it followed a period of extinction or a second reinforcement schedule. When longer component durations (3 min) were used, there was no consistent effect of overall reinforcement probability.

It is not surprising that longer component durations should eliminate control by overall probability since, presumably, the effects of

alternative reinforcement decrease with their removal in time. More surprising was the failure to replace the control by overall probability with control by local increases in probability. According to several recent accounts of elicited behavior (Gamzu and Schwartz, 1973; Rachlin, 1973) the stimuli that followed the period of extinction (L of the −LR− sequence and R of the −RL− sequence) should have elicited the greatest amount of responding, particularly with the longer component durations. In fact, however, there was no systematic difference in the degree of overall responding as a function of the sequence of presentation. This was particularly surprising for the left-key component that was associated with the intermediate level of reinforcement. According to the above accounts, it should have elicited considerable pecking with the −LR− sequence, since it signalled an increase in reinforcement probability, but no responding with the −RL− sequence, since there it signalled a decrease in reinforcement. In fact, however, the median rate of responding to the left key with the 3-min components was slightly higher when it occurred in the −RL− sequence. One subject in particular (R-1 of Figure 2) clearly changed its behavior in a pattern exactly opposite to that predicted by the signal properties of the left key's onset.

The failure to find consistent effects of sequence of presentation on overall rate of responding should not be taken as evidence against that variable as a determinant of behavior. Instead, there was evidence that two separate effects of local changes in reinforcement operated simultaneously. That is, responding during a component was enhanced both when that component followed a period of extinction and when it preceded extinction. Evidence for the latter effect came from three sources. First, some subjects clearly responded more in the component that occurred last in the sequence (Conditions 1 and 2 of R-18, Figure 1; Conditions 4 and 5 of R-1, Figure 2). Second, from the distribution of responding within the components shown in Table 3, relatively more responding occurred in the second half of the component when it was presented last in the sequence (*e.g.,* component L of −RL−). Finally, the effects of the contrast manipulation shown in Table 4 were primarily on the segment of the unchanged right-key component that was closest to the left key.

Of major importance were the results of subjects trained with the −RL− sequence, where behavior was unaffected for the first half of the right-key component but reduced in the second half. Such an effect can only be interpreted as showing that right-key behavior was influenced by the rate of reinforcement in the following left-key component.

It appears, therefore, that onset and offset transitions in probability of reinforcement produce symmetrical effects on the degree of elicited responding. It remains unclear, however, whether the two effects share a common underlying basis. Interactions due to the preceding reinforcement condition appear straightforward, since they apparently can be subsumed under transitory motivational effects dependent on increases or decreases in reward (*e.g.,* elation/depression effects). Control by "events to come" presents quite a different problem because it implies a comparison by the subject of its immediate situation with events in the future. Clearly, some mechanism of mediating future events must be found for such a comparison to be theoretically meaningful. The present data offer little clue to the nature of those mechanisms.

The importance of the control exerted by "events to come" is nonetheless emphasized by the fact that similar results have been obtained in multiple schedules of response-dependent reinforcement. Several studies (Buck, Rothstein, and Williams, 1975; Pliskoff, 1961, 1963; Williams, 1974; and Wilton and Gay, 1969) have demonstrated an enhancement of response rate during a signal that itself did not predict an increase in reinforcement but did predict an impending decrease of reinforcement at its offset. Apparently, the role of reinforcement conditions following a stimulus is of widespread importance in understanding multiple schedule interactions.

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