TEMPORAL INHIBITION: EFFECTS OF CHANGES IN RATE OF REINFORCEMENT AND RATE OF RESPONDING¹

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Pigeons were trained to key peck on several multiple schedules in which the first of two components was always a simple fixed-interval schedule. The rate of responding at the beginning of the constant fixed-interval schedule was found to decrease with increases in the rate of reinforcement associated with the other component of the multiple schedule, but remained unchanged with decreases in the rate of responding associated with the other component. These results were interpreted as being consistent with the view that the presence and magnitude of the temporal inhibitory effects observed in a given fixed-interval schedule are a function of the properties of reinforcing stimuli, rather than of changes in the rate of responding associated with the time interval immediately preceding the fixed interval in question.

CONTENTS

- Experiment 1: Effects of reinforcement rate changes
- Experiment 2: Effects of response rate changes
- General Discussion

On a fixed-interval schedule of reinforcement (FI), the first response to occur after a specified interval of time is followed by a reinforcing stimulus. Staddon and Innis (1969) studied pigeons' pecking on an FI 2-min schedule and observed that when a brief timeout (consisting of the offset of the house- and key-lights) was substituted in lieu of reinforcement at the end of 25% of the intervals, overall response rate consistently increased during the following intervals. This increase was caused primarily by a relative decrease in the post-timeout pause (elapsed time between offset of the timeout and the next key peck). In addition, these investigators found that if the reinforcer and the timeout were both omitted at the end of an interval (the *no-event* condition), the response rate during the following interval would be higher than if a timeout had

occurred at the start of that interval. On the basis of these results, they suggested that the reinforcer, and to a lesser extent, the timeout at the end of the interval, controlled a longer pause and lower response rate than *no event* at the end of the interval. They named this rate-reducing function of the reinforcer and the timeout, temporal inhibition.

Kello (1972) demonstrated that the nature of the stimulus presented in lieu of reinforcement in the omission procedure described above is an important determinant of the magnitude of temporal inhibition. More specifically, he showed that the more similar the substituted stimulus complex is to the omitted reinforcement, the greater will be the magnitude of temporal inhibition that follows.

Finally, Staddon (1970) and Jensen and Fallon (1973) extended the analysis by demonstrating that the magnitude of temporal inhibition (that is to say, the increase in pausing at the start of an interval and/or the decrease in the overall response rate during an interval) varies directly with the duration of the reinforcer that terminates the preceding interval: the greater the duration of the reinforcer, the greater the magnitude of temporal inhibition observed in the following interval.

One parameter of reinforcement that has not been examined within the context of the phenomenon of temporal inhibition is the rate of reinforcement. The question can be raised as to whether the magnitude of temporal inhibition in a given interval is systematically

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related to the rate of reinforcement in the preceding time interval, just as it is systematically related to the other variables mentioned above. Evidence in the literature suggests that rate of reinforcement may be an important variable in determining the magnitude of temporal inhibition. As noted previously, Staddon and Innis (1969) found that the pause was longer and the response rate was lower on a given FI if a reinforcement had occurred at the end of the preceding interval than if a reinforcement had not occurred. This finding implies that systematic changes in the rate of reinforcement in a given interval may affect the magnitude of temporal inhibition in the following interval. Experiment 1 of the present study tested this possibility.

All of the published studies summarized above suggested that the presence or absence of temporal inhibition depends upon the properties of the reinforcing stimulus or of the stimuli presented in lieu of the reinforcer. Data reported by Dews (1970) raise the question of whether the rate of responding in a given fixed interval can affect the magnitude of temporal inhibition in the following fixed interval. Dews noted that there was a high probability that intervals containing many responses would be followed by intervals containing many responses. He did not, however, provide data on whether these sequential patterns in FI responding were accompanied by changes in the magnitude of temporal inhibition. Experiment 2 of the present study attempted to answer the question of whether systematic changes in the response rate preceding a given interval will systematically affect the magnitude of temporal inhibition observed in the given interval, other factors remaining equal.

EXPERIMENT 1: EFFECTS OF REINFORCEMENT RATE CHANGES

The question posed in this experiment was whether the rate of reinforcement associated with a given interval would affect the magnitude of temporal inhibition occurring in the immediately following interval.

METHOD

Subjects

Three adult, male White Carneaux pigeons (numbered 4045, 6952, and 452) each of which

had previously been exposed to a variety of schedules of reinforcement, were maintained throughout the experiment at 80% of their free-feeding body weights.

Apparatus

The experiment was conducted in a standard operant conditioning chamber, which had a translucent response key, a houselight, and a grain magazine. A minimum force of 0.2 N was required to operate the key. The response key, which remained lighted during reinforcement, was transilluminated by colored lights mounted behind it. Reinforcement consisted of a 3-sec access to the illuminated grain magazine. The houselight was off throughout the experiment. Standard electromechanical scheduling and recording equipment were located in a separate room.

Procedure

A daily experimental session consisted of 11 cycles of a two-component multiple schedule. A multiple schedule consists of two or more independent schedules presented successively, each schedule being correlated with a different exteroceptive stimulus. The data from the first cycle (warmup) were not included in the analysis. Each cycle consisted of a green-key illumination (S1) followed by a red-key illumination (S2). The schedule of reinforcement in S1 was always fixed-interval 3-min (FI 3-min); the schedule in S2 was either FI 3-min, extinction (EXT), or a differential reinforcement of behavior other than key pecking (DRO). In this last schedule, the food magazine operated whenever the pigeon had not pecked the key for a specified time t . The time without responses was measured from the onset of S2 or from the last response in the presence of S2. Any time without responses that had accumulated in a given S2 component was lost when that S2 component terminated; that is, the accumulated time did not carry over to the next S2 component. Each response began a new interval requirement of non-responding. The interval was terminated by presenting a reinforcer after t sec of non-responding. In the present experiment, the value of t was either 30, 60, 90, or 180 sec.

In each cycle, when FI 3-min was scheduled in a component, S2 (or S1) remained on until the reinforced response occurred. This response was almost always emitted within 2

sec after the 3-min interval had elapsed. When EXT or DRO was scheduled in S2, S2 terminated after 3 min and S1 came on. Thus, in practice, each cycle was of approximately 6-min duration.

Each bird received 35 sessions of preliminary training with FI 3-min in both S1 and S2. Thereafter, the schedule in S2 was either EXT (baseline condition), or DRO (experimental condition). For each bird, the order of exposure to each of the experimental conditions is summarized in Table 1. Each phase consisted

Table 1

Order of exposure to the various experimental conditions in S2 for individual subjects. The reinforcement schedule in S1 was always FI 3-min. All DRO values are in seconds. Each DRO phase in S2 was preceded and followed by sessions during which EXT was correlated with S2. See text for details.

Phase Number	Bird Number		
	4045	6952	452
1	DRO 90	DRO 30	DRO 60
2	DRO 180	DRO 60	DRO 180
3	DRO 30	DRO 180	DRO 30
4	DRO 60	DRO 90	DRO 90
5	DRO 90	DRO 180	DRO 30
6	DRO 30	DRO 90	DRO 60

of exposure to EXT (initial baseline), followed by exposure to DRO (experimental condition), followed by exposure to EXT (return to baseline). Each DRO schedule was in effect for 16 sessions. The initial baseline condition and the return to baseline condition in the first phase, and the initial baseline condition in the second phase, were all in effect for 16 sessions, but all subsequent EXT conditions were in effect for only seven sessions.

For each phase, the return to baseline condition of that phase also served as the initial baseline condition for the immediately following phase.

RESULTS

Overall response rates in the presence of each stimulus were calculated by dividing the total number of responses in the presence of that stimulus by the total time that the stimulus was on, exclusive of food delivery. The response rates in S2 during EXT and DRO were at or near zero.

Fig. 1. Median normalized response rate in S1, the first component of the multiple schedule, correlated with an FI schedule of reinforcement, as a function of median reinforcements per hour in S2, the second component, correlated with various DRO schedules of reinforcement. Filled symbols are for the initial data determinations and open symbols are for the redetermined points. The abscissa is logarithmic.

The effects of the various obtained reinforcement rates in S2 on responding in the presence of the unchanged FI schedule in S1 are summarized in Figure 1. For each bird, the median rate of responding in S1 during the last three sessions on a given DRO condition in S2 was normalized by dividing that rate by the median rate of responding in S1 during the last three sessions of the immediately preceding EXT condition in S2.² If the response rates in S1 during the DRO conditions were not different from the response rates in S1 during the EXT conditions, Figure 1 would appear, for each bird, as a straight line parallel to the X-axis and intersecting the Y-axis at 1.00. For Birds 452 and 6952, however, there is a downward slope at the start of each function, indicating a decrease in the normalized rate of responding in S1 with increasing reinforcement in S2. The response rate in S1 decreased as the reinforcement rate in S2 increased from zero to 60 reinforcements per hour, for Bird 452, and from zero to 40 reinforcements per hour, for Bird 6952. With only one exception (at 12 reinforcements per hour for Bird 4045), response rates in S1 were lower with a non-zero rate of reinforcement in S2 (DRO in S2) than with a zero rate of reinforcement in S2 (EXT

²The relevant raw data are available on request from the authors.

in S2). Each of the redetermined rates in S1 was consistently lower than the initially determined rates in S1.

Normalized response rates in the first, second, and final thirds of the FI in S1 as a function of the obtained reinforcements per hour in S2 are summarized in Figure 2, top, middle, and bottom, respectively. For each bird, the median rate of responding in a given third of the FI in S1 during the last three sessions on a given DRO condition in S2 was normalized by dividing that rate by the median rate of responding in the same third of the FI in S1 during the last three sessions of the immediately preceding baseline EXT condition in S2.²

Figure 2 (top) shows that for all birds, rate of responding generally decreased during the first third of the FI in S1 as the rate of reinforcement in S2 increased from approximately 10 to 120 reinforcements per hour. The redetermined response rates, though lower than the initially determined response rates, maintained the same ordering relative to each other as they had initially. When the reinforcement rate in S2 was approximately 40 per hour or greater, the response rate in S1 was lower than that obtained in S1 during the EXT (zero reinforcements per hour) baseline.

Figure 2 (middle) shows that for Bird 452, and to a lesser extent, Bird 6952, rate of responding decreased during the second third of the FI in S1 as the rate of reinforcement in S2 increased from zero to 120 reinforcements per hour. The redetermined response rates for Birds 452 and 6952 maintained the same ordering relative to each other as they had initially. For the same birds, when the reinforcement rate in S2 was approximately 10 reinforcements per hour or greater, the response rate in S1 was lower than that obtained in S1 during the EXT (zero reinforcements per hour) baseline.

Finally, in Figure 2 (bottom), there is some suggestion that, for the initial determination of the data points, the highest rates of responding in the final third of the FI in S1 were obtained when the highest rates of reinforcement (approximately 60 and 120 reinforcements per hour) were scheduled in S2. The redetermined points did not show the same relationships, however.

Figures 3A, B, and C show cumulative records of responding during the final session

Fig. 2. Median normalized response rate in the first third (top), second third (middle), and final third (bottom) of the FI in S1 as a function of the reinforcement rate in S2, correlated with various DRO schedules. Filled symbols are for the initial data determinations and open symbols are for the redetermined points. The abscissa is logarithmic.

of each pigeon's first exposure to the EXT, DRO 180-sec, and DRO 30-sec conditions respectively. Following an EXT component, there was almost no pause in responding at the start of S1; indeed, there were occasional bursts of responding at the start of the component as at a, b, and c. After a DRO 180-sec component, there was some pausing at the start of S1 (as at d, e, and f) if the animal had received a reinforcer at the end of the preceding S2 component, but there was almost no pausing (as at g, h, and i) if the animal had not. Following a DRO 30-sec component, there was typically considerable pausing at the beginning of S1 (as at j, k, and l). If all three conditions are compared, it can be seen that the longest pauses at the start of S1 consistently occurred after a DRO 30-sec component.

Finally, the median post-reinforcement pause in S1 (the period of time that elapsed between the onset of S1 and the first key peck in S1) was a monotonically increasing function of the rate of reinforcement in S2.²

DISCUSSION

In Experiment 1, the rate of responding in S2 was essentially constant throughout. Thus, any behavioral changes in S1 are probably attributable to the major independent variable of the study: rate of reinforcement in S2.

Experiment 1 demonstrated that as the rate of reinforcement in S2 increased from approximately 10 to 120 reinforcements per hour, the rate of responding in the first third of the FI in S1 generally decreased for all birds (Figure 2, top); as the rate of reinforcement in S2 increased from zero to 120 reinforcements per hour, the rate of responding in the second third of the FI in S1 generally decreased for two of three birds (Figure 2, middle), and the magnitude of the median post-reinforcement pause increased monotonically for all three birds. Finally, for two of the three birds, the overall rate of responding in S1 decreased as the rate of reinforcement in S2 increased from zero to 40 or 60 reinforcements per hour (Figure 1).

The above observations, that reinforcement rate in S2 affected the pausing and the response rate at the start of the FI in S1, are related to Staddon's analysis of temporal inhibition. Staddon and Innis (1969) observed that the pause was longer and the response rate was lower on an FI in one component of a multiple

schedule if a reinforcement had occurred at the end of the preceding component. They suggested that the presence of a reinforcer at the end of the preceding component sets the

Fig. 3. Cumulative records of the responding of three pigeons on a sequence of multiple schedules with EXT in S2 (A), DRO 180-sec in S2 (B), and DRO 30-sec in S2 (C). The schedule in S1 was always FI 3-min. When the event marker was down, S1 was in effect; when it was up, S2 was in effect. The response pen reset at the end of S1 and S2. Reinforcements are indicated by short vertical lines on the response records.

occasion for a long pause and a low rate in the following FI component. They named this rate-reducing effect of the reinforcer, temporal inhibition. The absence of the reinforcer at the end of the preceding component results in a corresponding absence of temporal inhibition, that is to say, shorter pausing and a higher response rate in the following FI component.

The present results are similar to the findings of Staddon and Innis and extend them by showing a systematic effect of reinforcement frequency in S2 on the magnitude of temporal inhibition in S1. As was the case with Staddon's study, the temporal inhibitory effects observed in the present study were limited almost exclusively to the first third of the constant FI and, to a lesser extent, the second third of the constant FI (Figure 2, top and middle).

The observation that response rate in the final third of the FI in S1 was not systematically affected by even large changes in the reinforcement rate associated with S2 has also been made in a similar situation by Reynolds and Catania (1961).

The sample cumulative records in Figure 3 help clarify some of the effects of the reinforcement rate changes associated with S2. In particular, it is seen that high reinforcement frequencies in S2 (as in DRO 30-sec) were followed by very long pauses at the start of S1, whereas zero or low reinforcement frequencies in S2 (as in EXT or DRO 180-sec) were followed by little or no pausing at the start of S1. Thus, the pause length is again shown to be highly correlated with the response rate in the first third of the FI in S1.

The cumulative records in Figure 3 also reveal an interesting effect of the DRO 180-sec schedule in S2 on the pause length in S1. If the animal missed the reinforcement in S2, there was little or no pause and a high response rate at the start of the next S1. Similar observations have been made by Staddon and Innis (1969), Zimmerman (1971), and Zeiler (1972). If the bird got the reinforcement in S2, there was a short pause and a lower rate at the start of the next S1. Thus, for the DRO 180-sec condition, the median response rate in the first third of the FI in S1 was a composite of the above two effects. These observations are also related to those made by other investigators who studied pigeons' behavior on multiple variable-interval differential-reinforce-

ment-of-other-behavior schedules (*mult* VI DRO). (On a variable-interval schedule, a response is reinforced after a period of time that varies from reinforcement to reinforcement; the mean interreinforcement interval is, however, fixed). Reynolds (1961), for example, found that on a *mult* VI 3-min DRO 50-sec schedule, a bird would peck at a higher rate at the start of a VI component that followed a DRO component in which no reinforcements were received than after a DRO component in which one or more reinforcements were received. Nevin (1968) also found that on a *mult* VI 3-min DRO 3-min response rate increased at the start of the VI component for those birds that had received only about half of the possible reinforcements available on the DRO schedule (and thus presumably these birds were exposed to some DRO components in which no reinforcement occurred). It seems plausible that the increased rates noted by Reynolds and Nevin were an effect of those DRO components that contained no reinforcement, an interpretation strengthened by the present results.

The fact that in S1 the redetermined response rates (Figures 1 and the top and middle sections of 2) were lower is probably the result of prolonged exposure to the constant FI. Cumming and Schoenfeld (1958), for example, found that pigeons develop an essentially pause-and-break pattern of responding on an FI after many sessions of training. This increase in pause length as a function of length of training probably accounts for the decreases observed in the redetermined values of the present study. However, it should be reemphasized that the relationships between the various redetermined data points were generally the same as those occurring between the initially determined data points.

EXPERIMENT 2: EFFECTS OF RESPONSE RATE CHANGES

Experiment 1 demonstrated that when rate of responding in S2, the second component of the multiple schedule, was held constant, changes in the rate of reinforcement in S2 affected the temporal distribution of responses in the FI correlated with S1 (the constant FI). It may be asked whether the response distribution in the FI correlated with S1 would also change if the rate of responding in S2 were

varied while the rate of reinforcement in S2 were held constant. Experiment 2 attempted to answer this question.

METHOD

Subjects

Five adult, male White Carneaux pigeons (4207, 4037, 4247, 4077, and 4116) each of which had been exposed to a variety of schedules of reinforcement, were maintained at 80% of their free-feeding body weights.

Apparatus

As in Experiment 1.

Procedure

A daily experimental session consisted of eight cycles of a two-component multiple schedule. The data from the first cycle (warmup) were not included in the analysis. Each cycle consisted of a red-key illumination (S1) followed by a green-key illumination (S2). The schedule of reinforcement in S1 was always FI 4.5-min, whereas the schedule in S2 was either FI 4.5-min or a modified FI 4.5-min. The keylight color did not change until the reinforced response occurred. This response was almost always emitted within 2 sec after the 4.5-min interval had elapsed. Thus, in practice, each cycle was of approximately 9-min duration.

For each bird, the order of exposure to each of the experimental conditions in S2 is summarized in Table 2. Each phase consisted of exposure to a simple FI 4.5-min schedule (initial baseline), followed by exposure to a modified FI 4.5-min schedule (experimental condition), followed by a simple FI 4.5-min schedule (return to baseline).

During a simple FI 4.5-min schedule, the houselight was always off and only the keylight was on; this was true in both S1 and S2. During a modified FI 4.5-min schedule, which occurred only in S2, the keylight was on and at various times, depending on the experimental condition, the houselight came on. Thus, if the experimental condition in S2 was "1st", the houselight would come on during the first third of the FI 4.5-min schedule in S2, that is to say, it would be on during the first 1.5 min of S2. Likewise, if the experimental condition in S2 was "2nd and 3rd", the houselight would come on during the second and final thirds of the FI 4.5-min schedule in S2, but

Table 2

Order of exposure to the various experimental conditions (modified FI 4.5-min schedule) in S2 for individual subjects. The condition labelled '3rd' means that the houselight came on during the third third of the FI 4.5-min schedule but was off at all other times. The explanation is similar for the other experimental conditions. The reinforcement schedule in S1 was always FI 4.5-min.

Phase Number	Bird Number				
	4207	4247	4037	4077	4116
1	3rd	3rd	3rd	1st	1st
2	1st	2nd+3rd	2nd+3rd	2nd	2nd
3	2nd	1st	1st	3rd	3rd
4	2nd+3rd	2nd	2nd	2nd+3rd	2nd+3rd

would be off during the first third of the FI. Once the interval terminated, the houselight went off again.

The rationale for the modified FI 4.5-min schedule (experimental condition) can be stated as follows. Since the houselight was never paired with food, it would soon come to control a very low rate of responding. Thus, if the houselight came on during the first third of the FI in S2 (where there is normally a low response rate anyway), a small reduction in the overall rate of responding on the FI would occur. If, however, the houselight came on during the final third of the FI in S2 (where most of the responding normally occurs), a great reduction in the overall rate of responding on the FI would occur. Thus, by having the houselight come on during different thirds of the fixed interval, it would be possible to modulate the overall rate of responding in S2.

Each modified FI 4.5-min schedule (experimental condition) was in effect for 16 sessions. The baseline FI 4.5-min condition in the first phase was in effect for 35 sessions, but all subsequent baseline conditions were in effect for only seven sessions.

For each phase, the return to baseline condition of that phase also served as the initial baseline condition for the immediately following phase.

RESULTS

Overall rates were calculated as in Experiment 1. The response rates in S2 were lower during the experimental conditions than during the corresponding baseline conditions.² In particular, there was a small reduction in S2

response rate during the "1st" houselight and "2nd" houselight conditions and a great reduction, almost to a zero response rate, in the "3rd" and the "2nd and 3rd" houselight conditions.

The effects of the various response rates in the experimental S2 condition on the rate of responding in the presence of the unchanged FI schedule in S1 are summarized in Figure 4. For each bird, the median rate of responding in S1 during the last three sessions of a given S2 experimental condition was normalized by dividing that rate by the median rate of responding in S1 during the immediately preceding S2 baseline condition. The overall rate of responding in S1 did not change systematically with changes in the overall rate of responding in S2.

Response rates in the first, second, and final thirds of the FI in S1 did not vary systematically as a function of the various conditions in S2. Hence, these data are not presented.

DISCUSSION

Experiment 2 showed that when reinforcement rate in S2 is held constant, and response rate is varied, there are no systematic behav-

Fig. 4. Median normalized response rate in S1, correlated with an FI 4.5-min schedule of reinforcement, as a function of median responses per minute in S2, correlated with various modified FI 4.5-min schedules of reinforcement.

ioral changes in S1: this fact is evident from Figure 4. Such a finding seems to be at variance with that of Ferster and Skinner (1957), who noted that on a simple FI 4-min schedule, the post-reinforcement pause would be shorter and the acceleration to the terminal rate more rapid if the response rate in the preceding interval were very low. Their observations were casual, however, and they made no attempt to manipulate directly the response rate in one interval to see what effect such a rate change would have on the response rate in the following interval. The present study shows that when such a manipulation is made, there is no effect on either the overall rate or the distribution of responses in the following interval.

GENERAL DISCUSSION

Experiment 2 demonstrated that changes in the rate of responding associated with a given interval do not affect the magnitude of temporal inhibition in the following fixed interval. This finding is consistent with the view that the presence or absence of temporal inhibition depends upon properties of the reinforcing stimulus (or properties of the stimuli presented in lieu of the reinforcer), rather than upon changes in the rate of responding.

Experiment 1 demonstrated that increases in the rate of reinforcement associated with a given time interval systematically increase the magnitude of temporal inhibition. Thus, duration of reinforcement, similarity (of a given substituted stimulus) to the unconditioned reinforcer, and rate of reinforcement are functionally similar, in that systematic increases in each of these variables produce systematic increases in the magnitude of temporal inhibition.

A final question concerns the mode of operation of the rate of reinforcement variable. All of the published literature cited above has considered the effects of a single stimulus at the end of a given interval upon the magnitude of temporal inhibition present in the following fixed interval. In the present study, however, reinforcement in the DRO 30-, 60-, or 90-sec conditions occurred not only at the end of the DRO component but also earlier in the component; yet, systematic effects were observed. This observation must mean that reinforcers occurring long before the start of the fixed-interval component in question affect the

magnitude of temporal inhibition as well as the reinforcer occurring immediately before the onset of the fixed-interval component in question. Thus, one possible area for future research concerning the phenomenon of temporal inhibition should pertain to the analysis of the long-term effects of the reinforcing stimulus.

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