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# TEMPORAL CONTROL ON PERIODIC SCHEDULES: SIGNAL PROPERTIES OF REINFORCEMENT AND BLACKOUT[1]

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Pigeons were exposed to periodic food-reinforcement schedules in which intervals ended with equal probability in either reinforcement or brief blackout. The effects on the pattern of key pecking of sequential probability of reinforcement, interval duration, and time to reinforcement opportunity were investigated in three experiments. The major results were: (1) at short absolute interval durations, time to reinforcement opportunity determined both postreinforcement and postblackout pause (time to first key peck within an interval); (2) at long intervals, postblackout pause was consistently shorter than postreinforcement pause, even if both events signalled the same time to the next reinforcement opportunity (omission effect); (3) when reinforcement and blackout signalled different times to the next reinforcement opportunity, within the same experiment, there was some evidence for interactions analogous to behavioral contrast.

## CONTENTS

## GENERAL INTRODUCTION

If an animal has been consistently fed at a given point in space or time, the occasional replacement of food with some other stimulus usually elevates the rate of responding after that stimulus (omission effect). This effect was first studied in the double alleyway, where rats were observed to run faster in the second alley after nonreward in the mid-goal-box than after reward (Amsel and Roussel, 1952). More recently, elevated responding after omission of reinforcement has been observed in fixed-interval (FI) schedules (*e.g.*, Scull, Davies, and Amsel, 1970; Staddon and Innis, 1966, 1969; Zeiler, 1972), in fixed-ratio (FR), and in spaced-responding (DRL) schedules (Davenport, Flaherty, and Dyrud, 1966; Davenport and Thompson, 1965).

Noting that the omission effect (higher rate and shorter pause after reinforcement omission) occurs only in situations where reinforcement has inhibitory (pause-producing) aftereffects (*i.e.*, in FI, FR, and DRL schedules, but not in VI schedules that produce a truly constant rate of responding, McMillan, 1971), Staddon (1970, p. 230) suggested that:

> The effects of reinforcement omission in a given situation depend entirely upon the aftereffects of a reinforcement in that situation. The effects on subsequent responding of a stimulus presented in lieu of reinforcement (*i.e.*, nonreward) will be of the same kind as the effects of reinforcement but generally of smaller magnitude.

This explanation, in terms of generalization decrement, implies that increasing the similarity between reinforcement and the stimulus presented in its stead will decrease the size of the omission effect, and that reinforcement omission may decrease rather than increase response rate under some conditions. Both of these implications have been confirmed. Response rate on 2-min fixed-interval schedules is higher after complete omission of all stimuli normally correlated with reinforcement than after blackout (Staddon and Innis, 1969), and higher after blackout

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alone than after blackout plus a flash from the magazine light (Kello, 1972). Further, the converse pattern of results is found with a schedule requiring a period of pecking followed by a period of no pecking (temporal go, no-go procedure) when reinforcement stimuli are omitted at the end of the "no-go" requirement (Staddon, 1970, 1972*a*).

The main problem for an account in terms of generalization decrement is that the omission effect usually persists even after the animad has had ample opportunity to learn that reinforcement and blackout signal the same time to the next reinforcement. If the pause-producing effect on reinforcement is attributable to its signal properties, as all the available evidence suggests, why does not the blackout come to have the same effect?

One possibility is that in many experiments, the conditional probabilities of reinforcement after reinforcement *versus* reinforcement after blackout are not equal. In many experiments, reinforcements have been omitted (*i.e.*, replaced by blackout) only at the end of odd-numbered intervals. Thus, intervals beginning with blackout always ended with reinforcement, but intervals beginning with reinforcement might end in either blackout or reinforcement. Perhaps the higher probability of reinforcement in intervals that begin with blackout is responsible for the shorter pause after blackout. This possibility was explored in Experiment I.

## EXPERIMENT I: EFFECTS OF RESPONSE-CONTINGENCY AND SEQUENTIAL PROBABILITY REINFORCEMENT

### METHOD

*Subjects*

Four White Carneaux pigeons, 106, 109, 58, and 110, all with experimental experience, were maintained at approximately 80% of their free-feeding weights.

*Apparatus*

All subjects worked in the same custom-made variant of the standard, single-key pigeon box. A standard Grason-Stadler in-line projector (stimulus set number 153) shone a green light onto a translucent screen behind the transparent key. Effective key pecks produced a click from a "feedback" relay. The houselight was a 10-W lamp mounted on the roof of the box. During reinforcement (3-sec access to mixed grain), the houselight and the keylights were extinguished and the grain magazine was illuminated. During blackouts, the houselight and keylights were extinguished. Pecks during both reinforcement and blackout were ineffective. White noise, the noise from the ventilating fan in the pigeon chamber, and a styrofoam-covered wooden box enclosing the pigeon chamber masked extraneous sounds. All recording and scheduling equipment was located in an adjacent room. Data were recorded on digital and printing counters and on an event recorder.

*Procedure*

There were four experimental conditions. The basic schedule in the first three was FI 5-sec. Approximately half the intervals ended in response-contingent food delivery (reinforcement), half in blackout of the same duration (3 sec). The first two conditions (Min 4-C and Min 4-NC) allowed a comparison between response-contingent (fixed interval) *versus* response-independent (fixed time) blackout presentations. The last three of the four conditions looked at the effects of the minimum blackout run length (*i.e.*, minimum number of blackouts between two successive reinforcements), and time to the next reinforcement opportunity. Conditions were changed when performance appeared stable, as estimated from daily plots of the relevant dependent variables (peck rates and postevent pauses). Sessions ended after 65 food deliveries. The conditions were as follows (see Table 1):

Table 1

Sequence of conditions, mean number of sessions, and rate (responses per minute) after food and blackout for each condition in Experiment I.

| Condition | Mean Number of Sessions | Rate After | |
|---|---|---|---|
| | | Food | Blkt |
| Min 4-C | 26 | 87.53 | 91.18 |
| Min 4-NC | 25 | 62.14 | 81.70 |
| Min 1-NC | 25 | 86.89 | 97.80 |
| 1-NC | 28 | 71.71 | 92.19 |

*Min 4-C:* food and blackout were response contingent (hence, "C"). The probability of blackout (N) at the end of an interval beginning with blackout was approximately 0.9 ($P(N|N) = 0.9$), and the probability of food (R) at the end of an interval that began with food was also 0.9 ($P(R|R) = 0.9$). Thus, $P(N|R) = P(R|N) = 0.1$. The actual sequence of intervals received by each bird varied from day to day, but the minimum number of consecutive intervals ending in the same event (N or R) was four (hence, "Min 4"); the maximum run length was 14.

*Min 4-NC:* this was the same as the first condition, except that the blackouts were presented independently of key pecking (noncontingent), *i.e.,* on FT 5-sec; food deliveries were response-contingent (FI 5-sec), as before.

*Min 1-NC:* this was the same as the preceding condition, except that the minimum blackout run length was reduced from four to one; the maximum run length was 15.

*1-NC:* this condition was a modification of the preceding one, designed to test the hypothesis that performance in the first three conditions was a function of minimum time to the next reinforcement opportunity. In the first three conditions, some event, N or R, occurred every 5 sec. In this condition, however, although the distribution of interreinforcement intervals (exclusive of blackout time) was the same as in the preceding condition, blackouts after the first in a run were omitted. For example, consider the following sequence of intervals ending in reinforcement (R) and blackout (N) presented in Condition Min 1-NC (each dash stands for 5 sec): -R-N-N-N-R-R-R-R-N-N-N-N-N-N-R-N-R. In Condition 1-NC, the sequence became -R-N *(15 sec)* R-R-R-R-N *(30 sec)* R-N-R.

## RESULTS

Figure 1 presents data for the last five days of all four experimental conditions. The top panel of each graph in Figure 1 shows the five-day average probability of reinforcement given that the $i^{th}$ blackout in a run just occurred *i.e.,* $P(R|N_i)$ and the five-day average probability of a blackout given that the $i^{th}$ reinforcement in a run just occurred *i.e.,* $P(N|R_i)$. The bottom panel in each graph shows the pause after the $i^{th}$ blackout or reinforcement in a run.

In Condition Min 4-C, pausing after food was the same at varying positions within a run of intervals ending in food. The birds did not pause longer after food as the probability of a blackout increased. However, the length of pausing after blackout did depend on the position of the blackout within a run. The average pause after the first blackout in a run was 10.98 sec, much longer than the pause after other blackouts. Also, pausing after the first three blackouts in a run (when the probability of food was zero) was longer than pausing after later blackouts and longer than pausing after food. As the probability of reinforcement increased above zero, pausing after blackout decreased. Pausing after the fourth and all subsequent blackouts in a run was shorter than pausing after food.

The data from Condition Min 4-NC, in which there was no response contingency for blackouts, but the conditional probabilities were the same as in Condition Min 4-C, are similar to those of Condition Min 4-C. The upper unfilled symbols for position 1 in a run show these data for individual birds; the large filled circle bisected by a dashed line indicates the average for all birds. Pausing after food was the same at varying positions within a run. Pausing after the fourth and all subsequent blackouts in a run was shorter than pausing after food. Further, pausing after the initial blackout in each run was very similar to pausing after the initial blackout in Condition Min 4-C. In Condition Min 4-NC, the maximum interval duration, and thus the maximum pause per interval, was 5 sec. However, when pause to first response is calculated, summing across intervals if necessary but excluding blackout duration, average pause after the initial blackout was 10.75 sec *versus* 10.98 sec in the previous condition.

In Condition Min 1-NC, the probability that food would follow the first few blackouts in a run remained very low (but not zero). However, the minimum length of a run was reduced to one; thus, the minimum blackout-to-food interval was 5 sec. This procedure abolished the very long pause after the initial blackout in Conditions Min 4-C and Min 4-NC. Pausing after the first three or four blackouts in a run was still longer than pausing after later blackouts in a run and longer than pausing after food.

In Condition 1-NC, all blackouts except the initial one in each run were eliminated to assess the effect of subsequent blackouts on the pause after initial blackouts. As in all other

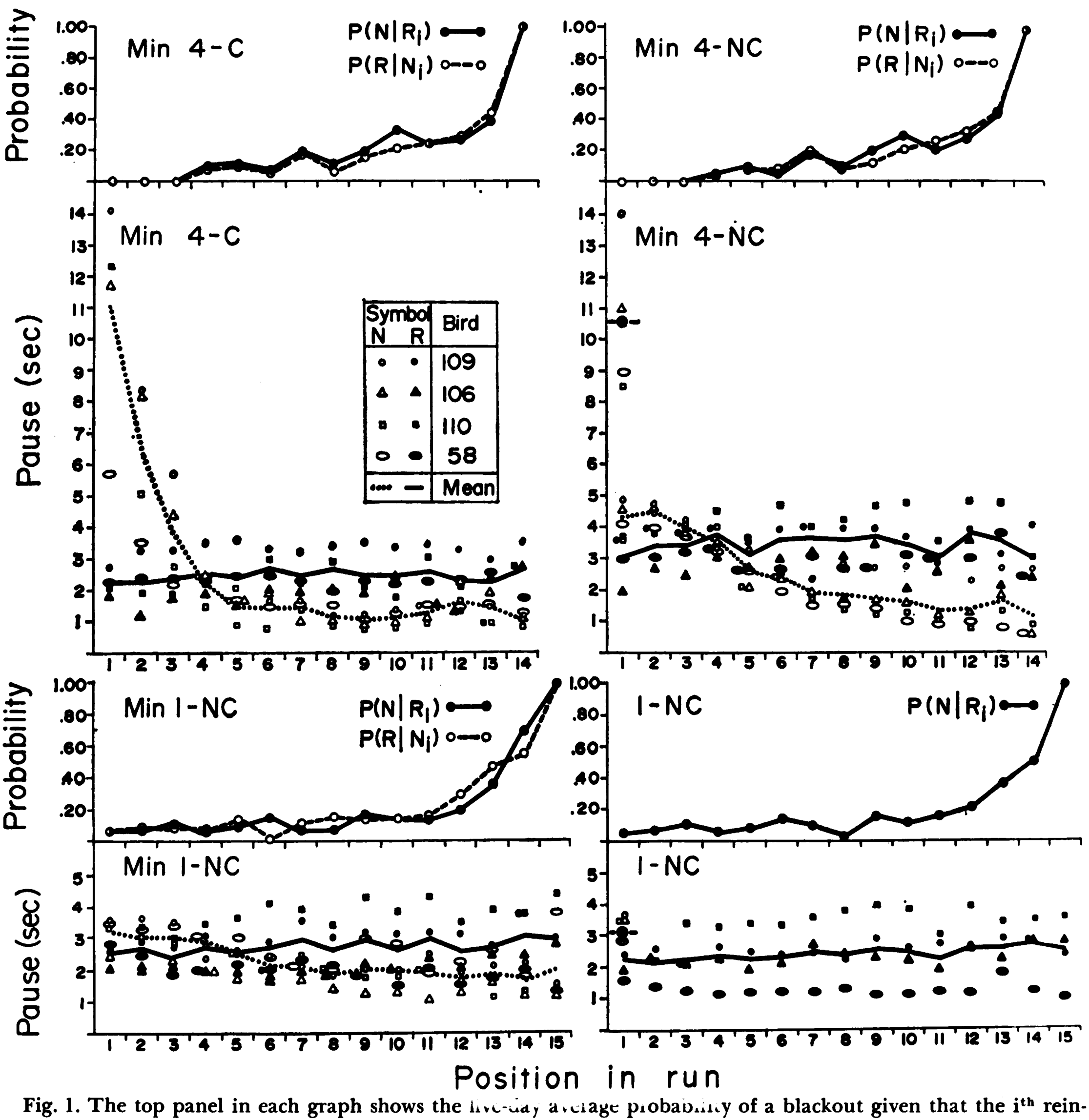

Fig. 1. The top panel in each graph shows the five-day average probability of a blackout given that the i$^{th}$ reinforcement in a run has occurred and the probability of reinforcement given that the i$^{th}$ blackout in a run has occurred. The bottom panel of each graph shows mean pause after reinforcement (filled symbols) and after blackout (unfilled symbols) for each bird. The solid line in each bottom panel indicates pause after reinforcement averaged across all birds. The dashed line indicates the average for intervals after blackout. See text for further explanation of graphs for Conditions Min 4-NC and 1-NC.

conditions, pause after food was the same at all positions within a run. There was little difference in pausing after the initial blackout in Condition 1-NC (3.13 sec average, large filled circle on dashed line at position 1 in a run), and in Condition Min 1-NC (3.23 sec average).

## DISCUSSION

The similar results from Conditions Min 4-C and Min 4-NC show that the pause-producing effect of blackout did not depend on whether blackout was response dependent.

Pause after the first blackout in a run was much longer in Condition Min 4-NC than in Condition Min 1-NC. Since the next reinforcement was at least 20 sec (excluding blackout time) away from the first blackout in the former condition, but could occur after only 5 sec in the latter, *time to the next rereinforcement opportunity* may be the main variable controlling postblackout (and postreinforcement) pause in this situation. Condition 1-NC was a test of this idea, since it retained the same temporal relation between blackout and reinforcement opportunity as in the preceding condition, but eliminated blackouts other than the first in each run. Postblackout pause was similar in both conditions, confirming the dominant role of time to reinforcement opportunity as the main determiner of pause.

Superimposed on this large effect of time to reinforcement opportunity was a much smaller effect of reinforcement probability. For example, in Condition Min 1-NC, the effect of probability of reinforcement on pause can be seen only in a slight decline in postblackout pause as the conditional probability of reinforcement increases. Also, even though the probability of reinforcement after blackout was only 0.1 *versus* 0.9 after reinforcement), postblackout pause overall was slightly shorter than postreinforcement pause (2.24 *versus* 2.66 sec). Thus, differences in conditional probability of reinforcement can be excluded as an explanation for the persistent omission effect (longer pause after reinforcement than after blackout) found on longer FI schedules. This conclusion is also consistent with reports of relatively persistent omission effects on schedules with symmetrical conditional probabilities (*e.g.*, Scull *et al.*, 1970).

In Condition Min 1-NC, when time to the next reinforcement opportunity was the same after reinforcement and blackout, overall average response rate and postevent pause were similar following the two events (*i.e.*, there was no omission effect, see Figure 1, Table 1). This contrasts with the much higher response rate after blackout reported in comparable experiments with longer interval values, and suggests that the omission effect depends on interval value.

## EXPERIMENT II: EFFECT OF INTERVAL DURATION WHEN REINFORCEMENT AND BLACKOUT SIGNAL THE SAME TIME TO REINFORCEMENT

Staddon and Innis (1969), using 2-min fixed intervals, found that pigeons emitted almost 100% more key pecks following blackout than following reinforcement, largely due to much shorter pause after blackout. However, Chung and Neuringer (1967) and Neuringer and Chung (1967) using response-initiated intervals (*e.g.*, tandem FR 1 FI 5-sec), apparently found only small differences in pausing after reinforcement and after blackout in intervals of 30 and 5 sec, although the magnitude of the effect cannot be accurately estimated from their figures. Taken together with the results of Experiment I, these data strongly suggest that the omission effect depends on interval duration. The present experiment investigated the effect of interval duration directly.

### METHOD

### *Subjects*

Eight White Carneaux pigeons, all with considerable experimental experience, were maintained at approximately 80% of their free-feeding weights. Pigeons 28, 84, 26, and 105 were used in Conditions 1 and 3. Pigeons 38, 46, 56, and 106 were used in Condition 2.

### *Apparatus*

The apparatus was the same as in Experiment I.

### *Procedure*

In all conditions, the basic schedule was fixed interval. Intervals ended, with equal probability, either in response-contingent reinforcement (3-sec access to food) or response-independent 3-sec blackout. The keylight was green throughout and the other procedural details were as in the previous experiment. Sessions ended after 65 reinforcements (Conditions 1 and 2) or 30 reinforcements (Condition 3). Data were gathered only after performance appeared to be stable, as indicated by daily plots of response rates and postevent pauses.

Three interval values, 5, 10, and 60 sec, were studied successively (see Table 2).

Table 2

Interval duration, mean number of sessions, and rate (responses per minute) after food and after blackout for each condition in Experiment II.

| *Condition* | *Interval Duration (sec)* | *Mean Number of Sessions* | *Rate After* | |
|---|---|---|---|---|
| | | | *Food* | *Blkt* |
| 1 | 5 | 25 | 135.32 | 140.30 |
| 2 | 10 | 28 | 78.93 | 76.91 |
| 3 | 60 | 30 | 34.90 | 45.71 |

## Results

The upper graph in Figure 2 shows the mean pause (time to the first response in the interval) after food and after blackout for each bird for the last five sessions of each condition. In both the 5- and 10-sec interval conditions, there was virtually no difference in pausing after food and after blackout, *i.e.,* no omission effect. In the 5-sec condition, the difference in pausing after food and after blackout ranged from 3% to 5% of the interval duration. Two birds (26 and 105) paused slightly longer after blackout than after food; the other two (28 and 84) paused slightly longer after food. Similarly, the differences in pausing after food and after blackout in the 10-sec condition ranged from 1% to 6% of the interval duration. Three of the four birds paused somewhat longer after food than after blackout; the other paused slightly longer after blackout.

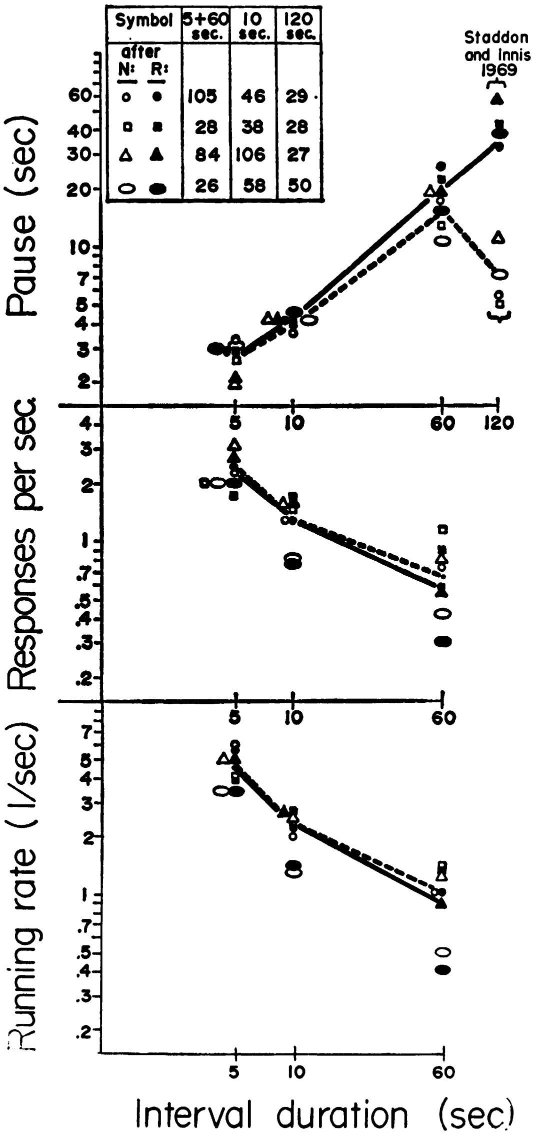

Fig. 2. Mean pause, response rate, and running rate after reinforcement (R; filled symbols) and after blackout (N; unfilled symbols) for each bird in each condition of Experiment II. The data for the 120-sec interval are from Staddon and Innis (1969). The data plotted on logarithmic scales. The solid line in each graph indicates data, averaged across all subjects in each condition, from intervals after reinforcement. The dashed line indicates the average for intervals after blackout.

In the 60-sec condition, three of the four birds showed a moderate omission effect. The difference in pausing after food and after blackout ranged from 8% to 14% of interval duration. Bird 105 paused, on average, 8.4 sec longer after food than after blackout, Bird 28 paused 7.2 sec longer after food, and Bird 26 paused 4.9 sec longer after food. The fourth bird, 84 showed a variable level of pausing across sessions, but within each session it paused approximately the same length of time after food and blackout.

The data for all conditions are presented in the middle and lower graphs in Figure 2. The middle graph shows the response rate after food and after blackout for each bird in each condition. The lower graph shows running rate (*i.e.,* response rate after the first response in an interval). An omission effect is indicated in response data by a higher response rate after blackout than after food; typically, the running rates after blackout and after food are similar. In the 5- and 10-sec interval conditions, both response rate and running rate were very similar after food and after blackout. As with the pause data, there was little indication of an omission effect. In the 60-sec condition, all four birds showed an omission effect; that is, they all responded at a higher rate after blackout than after food. Two of the four birds (105 and 28) displayed similar running rates after blackout and after food. The other two (84 and 26) showed a higher running rate after blackout than after food. Response rate and running rate declined after both blackout and food as the duration of intervals was increased.

### Discussion

The results of this experiment confirm the suggestion from other data that the omission effect depends on interval values. At short intervals (5, 10 sec), there is little difference between postblackout and postreinforcement pause, whereas at longer (>60 sec) intervals, the difference is substantial. Figure 2 also shows data reported from Staddon and Innis (1969), who studied the effects of reinforcement omission with 120-sec fixed intervals. These results are representative of numerous experiments in our laboratory and others, and show a substantial difference between postblackout and postreinforcement pause at this value, with postblackout pause even shorter than on FI 60-sec.

Experiment I showed that postblackout pause was unaffected by whether or not blackout was response contingent. In a number of unpublished experiments with longer interval values, we have found only small and unreliable effects of response contingency on the pause measure. Marr and Zeiler (1974, Figure 3) also showed only small differences between response-independent and response-dependent brief stimuli in terms of a measure related to pause. Hence, it is unlikely that the main conclusion of Experiment II, that the omission effect is directly related to interval value, depends on whether blackout presentation is response-independent or response-dependent.

The lack of omission effect with short intervals cannot be put down to a floor effect. For example, postblackout pause was longer here than in some conditions of Experiment I (see Figure 1); and postblackout pause at the 10-sec interval value was consistently longer than at the 5-sec value, yet the omission effect was negligible in both cases. In a tracking experiment, Innis and Staddon (1971) found that postreinforcement pause was directly related to interval value down to 4 sec, showing that even at this short duration, pause is sensitive to schedule variables.

## EXPERIMENT III: EFFECT OF ASSIGNING BLACKOUT AND REINFORCEMENT DIFFERENT PROXIMITIES TO THE NEXT OPPORTUNITY FOR REINFORCEMENT

In Experiment I, time to the next reinforcement opportunity was the main variable determining pause after both reinforcement and blackout. However, Experiment II showed that this simple relation breaks down at longer interval values, when postblackout pause is shorter than postreinforcement pause even if both events signal the same time to reinforcement. The third experiment was a systematic replication of the first two. We here studied the joint effects of time to reinforcement opportunity and interval value. The following predictions were explored:

(1) When interval duration is short and blackout signals more time to the next reinforcement opportunity than does reinforcement, pausing after blackout should be longer than pausing after reinforcement.

(2) When the intervals are long, pausing after blackout should be shorter than pausing after reinforcement, even if blackout signals that the next reinforcement opportunity is more distant.

(3) When reinforcement indicates a longer time to the next reinforcement opportunity than does blackout, pausing after reinforcement should be longer than pausing after blackout.

### Method

*Subjects*

Four experienced White Carneaux pigeons, 106, 109, 110, and 58, were maintained at approximately 80% of their free-feeding weights.

*Procedure*

As in the previous experiment, blackout and reinforcement occurred with equal frequency, and reinforcement was response contingent, whereas blackout was response independent. However, in this experiment the interval value depended on the event, blackout or reinforcement, with which the interval began. For example, in Condition R5-N10, intervals beginning with blackout were 10 sec long and intervals that began with reinforcement were 5 sec. All intervals ended, with equal probability, in either reinforcement or blackout. This basic procedure is diagrammed in Figure 3. Sessions ended after 65 reinforcements. Other details were as in the preceding experiment. There were four experimental conditions (see Table 3): R5-N10, R5-N20, R30-N120, and R20-N5.

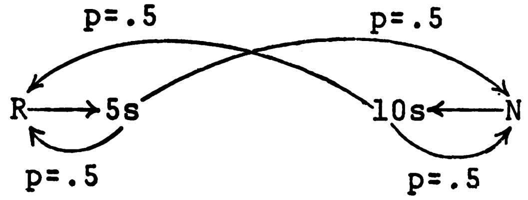

Fig. 3. Procedure used in Experiment III. The interval values shown are those used in Condition R5-N10. All other conditions were similarly programmed; only the interval durations were different.

Table 3

Sequence of conditions, mean number of sessions, and rate (responses per minute) after food and blackout for each condition in Experiment III.

| *Condition* | *Mean Number of Sessions* | *Rate After* | |
|---|---|---|---|
| | | *Food* | *Blkt* |
| R5-N20 | 24 | 57.81 | 59.79 |
| R30-N120 | 26 | 39.60 | 66.87 |
| R5-N10 | 21 | 52.22 | 49.10 |
| R20-N5 | 28 | 57.96 | 153.58 |

## RESULTS

Table 4 shows postblackout and postreinforcement pause in seconds for each bird in each condition of Experiment II. Group averages are also shown for pause in seconds and for proportional pause (*i.e.,* the fraction of the interval paused). When food signalled a longer interval than blackout, all animals paused longer after food than blackout. When blackout signalled a longer interval than food, all birds paused longer after blackout in the conditions using short intervals. Three of the four birds also paused longer after blackout in the long interval condition (R30-N120). However, proportional pause after blackout was substantially shorter than proportional pause after food in the R30-N120 condition.

If, for both blackout and reinforcement, pause is proportional to interval duration (*cf.* Schneider, 1969), then the ratio of postblackout pause ($P_N$) to postreinforcement ($P_R$) pause will be linearly related to the ratio of the intervals ($I_N/I_R$) signalled by these two events, thus:

Assume $P_N = k_1 I_N$ and $P_R = k_2 I_R$, then

$$\frac{P_N}{P_R} = \frac{I_N}{I_R} \cdot \frac{k_1}{k_2},$$

where $k_1$ and $k_2$ are constants.

Thus, a plot of $P_N/P_R$ *versus* $I_N/I_R$ can show whether reinforcement and blackout differ quantitatively in their temporal effects, or whether the large omission effect at long interval values represents a breakdown of temporal control by blackout, as the data from Experiment II suggest.

Figure 4 shows a plot of $P_N/P_R$ *versus* $I_N/I_R$ for the four conditions of Experiment III. The size of the symbols indicates the absolute size of the intervals. Thus, Conditions R5-N20 and R30-N120 are plotted at the same abscissa value (because the ratio $I_N/I_R$ is the same for both), but both the mean (filled circle and bar) and individual data are shown by larger symbols in the R30-N120 case. The line through the origin is the locus of matching between $P_N/P_R$ *versus* $I_N/I_R$ *i.e.,* points falling on this line show that postblackout and postreinforcement pause were the same fraction of their respective intervals.

The mean data clearly showed that the R30-N120 condition is the only one that deviates substantially from the matching line. For all the other conditions (*i.e.,* those with absolute interval durations of 20 sec or less), $P_N/P_R$ ap-

Table 4

Pause after Blackout and Reinforcement for Each Condition in Experiment I

| *Bird* | *106* | | *109* | | *110* | | *58* | | *Mean Pause (sec)* | | *Mean Proportional Pause* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P_N$ | $P_R$ | $P_N$ | $P_R$ | $P_N$ | $P_R$ | $P_N$ | $P_R$ | $P_N$ | $P_R$ | $P_N/I_N$ | $P_R/I_R$ |
| R5-N10 | 3.9 | 2.3 | 4.7 | 3.1 | 4.9 | 3.5 | 5.8 | 2.2 | 4.8 | 2.8 | 0.48 | 0.56 |
| R5-N20 | 7.1 | 2.1 | 6.2 | 2.5 | 5.4 | 3.2 | 10.2 | 1.9 | 7.2 | 2.4 | 0.36 | 0.49 |
| R30-N120 | 33.6 | 12.3 | 18.3 | 8.1 | 3.9 | 6.7 | 15.6 | 10.8 | 17.9 | 9.5 | 0.15 | 0.32 |
| R20-N5 | 1.4 | 9.6 | 1.7 | 8.2 | 1.2 | 7.0 | 1.6 | 10.2 | 1.5 | 8.8 | 0.30 | 0.44 |

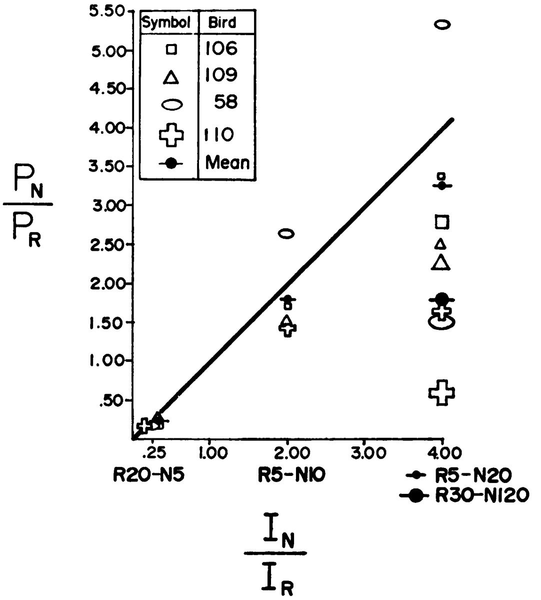

Fig. 4. The ratio of the pause in seconds after blackout (N), and after reinforcement (R) for each bird (unfilled symbols) and averaged across all birds (filled circles) is shown as a function of the ratio of postblackout and postreinforcement interval durations in the four conditions of the experiment. As $I_N/I_R = 4.00$ for both R5-N20 and R30-N120, data from R30-N120 (longer intervals) are indicated by larger symbols. The solid line indicates the line along which the data would fall if $P_N/P_R = I_N/I_R$, *i.e.*, if postfood and postblackout pause increased in the same proportion as postfood and postblackout interval duration. The data shown are from the last five days of each condition.

proximately matched $I_N/I_R$. Thus, as in Experiment II, the linear relation between interval size and postblackout pause broke down at long interval values.

Comparisons of proportional pause suggested that there may have been schedule interactions, thus:

(1) The postreinforcement pause in the 5-sec interval was shorter in Condition R5-N20 (when blackout signalled reinforcement only after 20 sec) than in Condition R5-N10 (when blackout signalled food in 10 sec).

(2) Although birds paused a similar fraction of the interval at both 5- and 10-sec interval values in Experiment II, here they paused relatively less after blackout in Condition R20-N5 than in Condition R5-N10 (0.36 *versus* 0.48); this difference is presumably attributable to the difference in R-interval duration. (3) Postreinforcement pause was on the average proportionally longer in Condition R20-N5 than in Condition R30-N120 (0.44 *versus* 0.32).

## Discussion

These data confirmed the conclusion from the first two experiments: that postblackout pause is determined principally by time to the next reinforcement opportunity, providing the absolute times involved are short (<20 sec). However, the data also showed that when blackout and reinforcement signalled different times to reinforcement in the same experiment, interactions analogous to behavioral contrast may occur. For example, even at short intervals, the birds paused for a smaller fraction of the interval if the other interval was long than if it was short (compare postreinforcement pauses in Conditions R5-N20 *versus* R5-N10, or postblackout pauses in Conditions R20-N5 *versus* R5-N10). Similarly, Staddon and Innis (1969), using a condition equivalent to R120-N120 in the present terminology, found an average postblackout pause of only 8.2 sec, yet postblackout pause was 17.9 sec in Condition R30-N120 of the present experiment. Thus, although proximity to reinforcement (as signalled by reinforcement or blackout) is the main determiner of pause, relative proximity also has an effect when different proximities are signalled by the two events. This is analogous to the effect of relative reinforcement rate on response rate in multiple variable-interval schedules (Herrnstein, 1970; Staddon, 1974*a*).

## GENERAL DISCUSSION

A discriminative stimulus may acquire control over behavior in its presence (synchronous control) or over behavior following its onset or offset (temporal control). Synchronous control is not very sensitive to the properties of the discriminative stimuli. Providing they are discriminable, in the psychophysical sense, the magnitude of the differences among stimuli makes little difference to their effectiveness in controlling differential responding, at least in the conventional food-reinforcement situation with key pecking as the instrumental response. The present series of experiments showed that this equivalence among discriminative stimuli is not as true of temporal as it is of synchronous control: postblackout pause was proportional to time to reinforcement opportunity only at short absolute times, whereas postreinforcement pause remained proportional to time to reinforcement even at long times. Thus, blackout is not as effective a temporal (trace) stimulus as is food delivery.

This dependence of temporal control on absolute time goes some way towards explaining the puzzling discrepancy between the data of Chung and Neuringer (1967) and Neuringer and Chung (1967) on so-called "quasi reinforcement", and the omission effect. Using a 5-sec response-initiated fixed-interval schedule, Neuringer and Chung found that brief stimuli, scheduled in the same way as food reinforcement, had similar effects on the rate and pattern of key pecking. Conversely, experiments with longer fixed intervals (*e.g.*, Scull *et al.*, 1970; Staddon and Innis, 1966, 1969) have uniformly found a shorter pause and higher rate after blackout when reinforcement and blackout are scheduled similarly (omission effect). The Neuringer and Chung result is attributable to the fact that when blackout and reinforcement have similar signal properties, in terms of time to reinforcement, they come to control similar behavior; the omission effect is attributable to the fact that temporal control by a "neutral" stimulus intercalated with reinforcement breaks down at long times.

Why is blackout less effective than food in producing long pauses? More generally, why is temporal control more dependent than synchronous control on discriminative stimulus properties? Staddon, 1972*b*, 1974*b* suggested that this is because temporal control places more demands on memory than does synchronous control. Consequently, variables that effect memorability are likely to affect temporal control more than synchronous control. The *value* (positive or negative) of a stimulus has been proposed as one such variable, and since food delivery is to a hungry pigeon clearly more valuable, less neutral, than a brief blackout, the better temporal control by food can be attributed to its greater memorability.

The effects of the pairing operation, in experiments on conditioned reinforcement with second-order schedules, can also be explained in this way by assuming that pairing a brief stimulus with food enhances its memorability. It is noteworthy that most of the experiments that have found an effect of pairing have used long (>60 sec) intervals Byrd and Marr, 1969; deLorge, 1967, 1969, 1971) whereas in those that have failed to find an effect, the interreinforcement intervals have been shorter (*e.g.*, Stubbs, 1971, 1972). Since temporal control by brief stimuli is only impaired (relative to food reinforcement) at long intervals, there is room for improvement in memorability (and thus for an effect of pairing) only at long intervals, as seems to be the case.

## REFERENCES

Amsel, A. and Roussel, J. Motivational properties of frustration: I. Effect on a running response of the addition of frustration to the motivational complex. *Journal of Experimental Psychology*, 1952, **43**, 363-368.

Byrd, L. D. and Marr, M. J. Relations between patterns of responding and the presentation of stimuli under second-order schedules. *Journal of the Experimental Analysis of Behavior*, 1969, **12**, 713-722.

Chung, S. H. and Neuringer, A. J. Control of responding by a percentage reinforcement schedule. *Psychonomic Science*, 1967, **8**, 25-26.

Davenport, J. W., Flaherty, C. F., and Dyrud, J. P. Temporal persistence of frustration effects in monkeys and rats. *Psychonomic Science*, 1966, **6**, 411-412.

Davenport, J. W. and Thompson, C. I. The Amsel frustration effect in monkeys. *Psychonomic Science*, 1965, **3**, 481-482.

de Lorge, J. Fixed-interval behavior maintained by conditioned reinforcement. *Journal of the Experimental Analysis of Behavior*, 1968, **10**, 271-276.

de Lorge, J. The influence of pairing with primary reinforcement on the maintenance of conditioned reinforcement in second-order schedules. In D. P. Hendry (Ed.), *Conditioned reinforcement*. Homewood, Ill.: The Dorsey Press, 1969. Pp. 61-76.

de Lorge, J. The effects of brief stimuli presented under a multiple schedule of second-order schedules. *Journal of the Experimental Analysis of Behavior*, 1971, **15**, 19-25.

Herrnstein, R. J. On the law of effect. *Journal of the Experimental Analysis of Behavior*, 1970, **13**, 243-266.

Innis, N. K. and Staddon, J. E. R. Temporal tracking on cyclic-interval reinforcement schedules. *Journal of the Experimental Analysis of Behavior*, 1971, **16**, 411-423.

Kello, J. E. The reinforcement-omission effect on fixed-interval schedules: Frustration or inhibition? *Learning and Motivation*, 1972, **3**, 138-147.

Marr, M. J. and Zeiler, M. D. Schedules of response-independent conditioned reinforcement. *Journal of the Experimental Analysis of Behavior*, 1974, **21**, 433-444.

McMillan, J. C. Percentage reinforcement of fixed-ratio and variable-interval performance. *Journal of the Experimental Analysis of Behavior*, 1971, **15**, 297-302.

Neuringer, A. J. and Chung, S. H. Quasi-reinforcement: control of responding by a percentage reinforcement schedule. *Journal of the Experimental Analysis of Behavior,* 1967, **10,** 45-54.

Schneider, B. A. A two-state analysis of fixed interval responding in the pigeon. *Journal of the Experimental Analysis of Behavior,* 1969, **12,** 677-687.

Scull, J., Davies, K., and Amsel, A. Behavioral contrast and frustration effect in multiple and mixed fixed-interval schedules in the rat. *Journal of Comparative and Physiological Psychology,* 1970, **71,** 478-483.

Staddon, J. E. R. Temporal effects of reinforcement: A negative "frustration" effect. *Learning and Motivation,* 1970, **1,** 227-247.

Staddon, J. E. R. Reinforcement omission on temporal go—no-go schedules. *Journal of the Experimental Analysis of Behavior,* 1972, **18,** 223-229. (*a*)

Staddon, J. E. R. Temporal control and the theory of reinforcement schedules. In R. M. Gilbert and J. R. Millenson (Eds.), *Reinforcement: behavior analysis.* New York: Academic Press, 1972. Pp. 209-262. (*b*)

Staddon, J. E. R. A note on behavioral contrast and frustration. *Quarterly Journal of Experimental Psychology,* 1974, **26,** 285-292. (*a*)

Staddon, J. E. R. Temporal control, attention and memory. *Psychological Review,* 1974, *in press.* (*b*)

Staddon, J. E. R. and Innis, N. K. An effect analogous to "frustration" on interval reinforcement schedules. *Psychonomic Science,* 1966, **4,** 287-288.

Staddon, J. E. R. and Innis, N. K. Reinforcement omission on fixed-interval schedules. *Journal of the Experimental Analysis of Behavior,* 1969, **12,** 689-700.

Stubbs, D. A. Second-order schedules and the problem of conditioned reinforcement. *Journal of the Experimental Analysis of Behavior,* 1971, **16,** 289-313.

Stubbs, D. A. and Cohen, S. L. Second-order schedules: comparison of different procedures for scheduling paired and nonpaired brief stimuli. *Journal of the Experimental Analysis of Behavior,* 1972, **18,** 403-413.

Zeiler, M. D. Fixed-interval behavior: effects of percentage reinforcement. *Journal of the Experimental Analysis of Behavior,* 1972, **17,** 177-189.

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