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# THE EFFECT OF FIXED AND VARIABLE BLACKOUTS OF DIFFERENT DURATIONS ON RESPONDING IN FIXED INTERVAL SCHEDULES

by

Jean L. Hatten

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Approved by

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# APPROVAL PAGE

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When the probability of reinforcement varies systematically with elapsed time since some event, rate of responding often varies in a corresponding way. The present experiment investigated whether stimulus events which make equally good predictions of the time to food result in equal average pause durations. For one group of pigeons a fixed-duration blackout was interpolated after each fixed-interval food delivery and the blackout was varied systematically. It was found that the probability of terminating the pause increased early in the fixed interval as the duration of the blackout was increased. The probability of terminating the latency at different times in the 2-min fixed interval on fixed-duration blackout conditions corresponded to that observed during an equivalent portion of a food-initiated fixed interval equal to the sum of the fixed interval and blackout durations. This finding is consistent with the proposal that initiation of the terminal period was under the control of time since food. The comparisons also revealed some control over key-pecking by the key-light onset, with the degree of such control increasing with blackout duration. A second group of pigeons was used to investigate the effects of making the blackout periods variable in duration. The mean blackout duration was varied systematically. It was found that the probability of pause termination over the 2-min fixed interval differed only slightly from that observed when food initiated each fixed interval. This finding is consistent with the proposal that the key-light onset exercises a greater degree of temporal control when fixed intervals are separated by blackouts of variable duration. Several mechanisms are discussed as possible explanations for the different pause-producing effectiveness of the key-light onset when fixed- and variable-duration blackouts separate successive fixed intervals. It was concluded that the extent to which a given event exercises temporal control depends on whether such control enhances the net reward value.

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# CHAPTER I

## INTRODUCTION

When the probability of reinforcement varies systematically with elapsed time since some event, rate of responding often varies in a corresponding way. Schedules of reinforcement differ with respect to the relation between the probability of reinforcement and time since food. The random interval schedule and constant probability variable-interval schedules are examples of schedules on which the probability of reinforcement does not change systematically with time since food. While such schedules produce little pausing, performance on arithmetic variable-interval schedules is characterized by significant pausing after food delivery (Cantania & Reynolds, 1968; Staddon, 1977).

In the simplest case all time-markers bearing the same temporal relationship to reinforcement would possess equal pause-producing effectiveness If the occurrence of the reinforcer and the occurrence of some less salient stimulus event, such as a brief darkening of the response key, are both associated with identical periods of non-reinforcement, then it might be expected that with extended training an equivalent average pause duration would follow each type of time-marker. A relative finding, however, is that pauses following a non-food stimulus are considerably shorter than those following a reinforcer presentation when the predictive significance of the two time-markers is identical (Kello, 1972; Staddon, 1972, 1974; Staddon & Innis, 1969; Stubbs, Vautin, Reid, & Delehanty, 1978; Zeiler, 1972. Apparently, the degree of temporal control exerted by a time-marker depends upon variables in addition to predictiveness.

A number of different accounts of the limited pause-producing effectiveness of non-food time-markers are considered. These may be grouped into two general classes of account. The first of these proposes that the different pause-producing capacity of different time-markers results from the differential stimulus control exerted by the different events. A number of mechanisms which might result in differential stimulus control by different events will be discussed. First, it could be that the shorter pauses observed to follow non-food events are a result of a stimulus generalization decrement. A second possibility is that the shorter pauses observed to follow non-food time-markers result from the overshadowing of non-food time-markers by food delivery. Yet another possibility considered is that the degree of stimulus control exerted by a given time-marker depends upon whether such control enhances the net reward value in a situation. The second class of account is exemplified by a proposal advanced by Gibbon (1977). These accounts explain the shorter pauses observed to follow non-food time-markers in motivational terms. The specific proposal considered is that the shorter pauses observed to follow non-food events result from a local contrast effect, with the average amount of reward representing a relative improvement in conditions in intervals initiated by a non-food event.

Each of the above alternatives will be evaluated, and it will be concluded that the available data are best explained by proposing that the degree of stimulus control exerted by a particular time-marker depends upon the extent to which control by that event enhances net reward value.

## Stimulus Control Accounts

It may be that the pause-producing effect of non-food stimuli is related to their similarity to the reinforcer: the more similar such stimuli are, the more the pause they control will be like the pause the food time-marker controls. This stimulus generalization account receives some support from the finding that the pause following such a stimulus is an increasing function of the number of dimensions of the reinforcing event that were incorporated into it (Kello, 1972). Staddon and Innis (1969) found, however, that the pause following a blackout presented in lieu of reinforcement increased as a function of the duration of the blackout. Because blackouts longer than food were presumably less like food than shorter blackouts, this finding is a problem for a stimulus generalization account.

Staddon (1972, 1977) has proposed an alternative explanation for these effects. In this account events that have been associated with a relatively low probability or long time to the next scheduled reinforcer induce activity that is controlled by unscheduled reinforcers and that is incompatible with the measured, required response. Because no event has been associated with a longer time until the next reinforcer than food delivery, food delivery should induce more of the "interim" activity than any other event. As time elapses in the interval, the relative strength of the factors responsible for interim activities decays and the relative strength of the factors responsible for terminal responding increases. During the intermediate portions of longer interval durations neither the causal factors for interim nor those for terminal behavior will be sufficient to evoke the appropriate activity. At these times "facultative" activities predominate. These are activities which are not directly related to the schedule but rather serve to fill "temporal gaps" between the offset of interim activities and the onset of terminal activities. Only when the relative strength of the causal factors responsible for terminal responding is greater than that responsible for interim activity will terminal responding be evoked.

Staddon (1972, 1974) explains the limited effectiveness of non-food time-markers on percentage schedules by proposing that highly salient time-markers such as food delivery may easily "overshadow" some less salient stimulus such as a brief blackout. That is, the relative salience of food impairs selectively the temporal control by a blackout. If the effectiveness of a salient time-marker extends beyond the interval it initiates, then in those intervals initiated by the less salient of two time-markers there will be two durations either of which might come to control responding. One of these durations is timed from the last occurrence of the salient time-marker, the other from the last occurrence of the less salient stimulus. The overshadowing idea predicts that, when blackouts and food both serve as time-markers within a session, responding will more likely be controlled by time elapsed since the last food delivery even if the most recent time-marker has been a blackout. Because responding would then increase with elapsed time since the beginning of the interfood interval, the short pauses following very brief blackouts presented in lieu of reinforcement suggest that, on at least some percentage schedules, the functional interval duration is the period between food deliveries.

If food delivery alone served as the time-marker, then food delivery alone would instigate interim activities. If so, the relative strength of the factors responsible for terminal activity would begin to increase following food delivery and continue to rise until the next food delivery. Presenting a blackout at the end of an interval would not interrupt terminal behavior and so the pauses would be very short after blackouts.

Alternatively, if the blackout also served as a time-marker, its presentation should reinstate the initial strength of the factors responsible for interim activity, and the duration of the pauses following blackouts would be similar to those following a food delivery. Although some evidence has been reported that adjunctive drinking will occur following a non-food time-marker (Porter & Kenshalo, 1974; Rosenblith, 1970), later studies have failed to demonstrate that drinking reliably occurs following non-food time-markers on percentage reinforcement schedules (Allen, Porter, & Arazie, 1975; Porter, Arazie, Holbrook, Cheek, & Allen, 1975). These findings are consistent with the proposal that non-food events are less effective than a food delivery in initiating the interim period.

Staddon (1974) has reported data showing that the effectiveness of non-food time-markers in controlling pausing depends on the nature of the exteroceptive stimuli present during a fixed interval. In one experiment, 50 percent of the fixed intervals in a session were terminated by a brief blackout, but the balance of the intervals ended with the presentation of food. If the blackout had ended the interval, the key light was illuminated red throughout the next interval; if food had ended the interval, the key light was illuminated green throughout the next interval. Inasmuch as the event to end the next interval was determined randomly, the key colors were not differentially associated with the forthcoming event, but only with whether the last event was a blackout or food. Because the two stimuli were selectively associated with the differing events which initiated different intervals, it might be expected that the red key light would enhance the temporal control exerted by the blackout, perhaps by increasing its functional salience. Staddon (1974) found that the average pause in intervals initiated by a blackout was comparable to that observed in intervals initiated by a reinforcer delivery. Because presenting a blackout in lieu of reinforcement did not result in shortened pauses and enhanced response rates in Staddon's experiment, his data suggest that under some circumstances performance will reliably be controlled by a non-food time-marker.

In the second phase of Staddon's (1974) experiment, a red key light was presented only during intervals which were initiated by a blackout. A green key light was presented during intervals which might have been initiated by either a reinforcer delivery or a blackout. Again, the two stimuli had no differential predictive significance as to which event would terminate a given interval. Staddon found the pause in the red-key intervals to be comparable to the pause following a food delivery in the ambiguous green-key intervals. In the green-key intervals following the presentation of a blackout, however, the pause was shorter. These data provide further evidence that the temporal control exerted by a non-food time-marker may be increased by presenting a stimulus during the fixed interval which is selectively associated with the prior occurrence of that time-marker. In situations where the key color is not correlated with the event which initiates the interval, temporal control by non-food time-markers is selectively impaired. Thus, the overshadowing mechanism proposed by Staddon suggests an associative function of the stimuli present during the fixed intervals of his experiment which may serve to increase the functional salience of blackouts.

It seems possible, however, to provide a discriminative interpretation of Staddon's (1974) findings. If it is assumed that fixed-interval performance is jointly determined by the conditional stimulus control of the time-marker (reinforcer or blackout) in combination with the stimuli associated with each, then the results of Staddon's (1974) experiment might be explained in the following way. In those intervals in which performance is controlled by the compound "reinforcer + green," post-ingestion stimuli are associated with long times to food, while the absence of post-ingestion stimuli is reliably associated with short times to food. In those intervals in which performance is controlled by the compound "blackout + red," however, the absence of post-ingestion stimuli is equally associated with long and short times to food. In these intervals temporal control must be by some other dimension, such as time since the onset of the red key light. When the green key light was made ambiguous by beginning green intervals with either a food delivery or a blackout, the pigeons could have come under the control of the dimension of post-ingestion stimuli. Because the absence of post-ingestion stimuli is associated with long and short times to food, this stimulus dimension is not a completely valid predictor of time to food. Consequently, one cost of such control would be an increased amount of work per reinforcer in green intervals initiated by a blackout.

Alternatively, the pigeons could have come under the control of some other dimension, such as time since the occurrence of a blackout. Although this stimulus dimension would be a more valid predictor of time to food, it might also be a considerably less salient stimulus dimension. If it is difficult for pigeons to discriminate different times since a non-food time-marker, then one potential cost of such control would be the increased effort expended in attending to the non-salient dimension. If emitting additional unreinforced key pecks reduces net reward value less than attending to a non-salient stimulus dimension, then pigeons would be expected to come under the control of the more salient dimension of post-ingestion stimuli, even though that dimension is less valid. In those intervals initiated with the compound "blackout + red," however, the absence of post-ingestion stimuli is equally associated with short and long times to food. In red intervals, therefore, the post-ingestion stimulus dimension has no predictive validity with respect to time to food. Time since the onset of the red key light is a valid predictor of time to food in such intervals, however. The fact that the pigeons came under the control of non-food time-markers only under such conditions strongly suggests that there is an inherent cost associated with control by non-food time-markers. In summary, this analysis suggests that the likelihood that a particular stimulus event will exert temporal control depends on the net reward value associated with coming under the control of that event as a time-marker.

The suggestion just expressed receives support from an experiment on simple human reaction time conducted by Snodgrass, Luce, and Galanter (1967). In one of a series of experiments, a warning signal preceded the reaction signal by a fixed period of time (approximately 2 sec). Under such procedures, subjects will anticipate the onset of the reaction signal with the result that some recorded reaction times appear to be unusually short. In order to improve the estimate of the "true" reaction time it would be helpful to eliminate such anticipations. Snodgrass et al. sought to eliminate anticipations by giving money for latencies occurring within a 20 msec "payoff" band. Latencies longer or shorter than the specified target band were punished. The target band was then varied from times shorter than the apparent "true" reaction time to considerably longer times. In all, the subjects were exposed to six different payoff bands.

There were three strategies that a subject could adopt in order to maximize net reward value. The subject could estimate elapsed time from the warning stimulus, estimate time from the reaction signal, or ignore both of these time-markers and simply react to the reaction signal. Snodgrass et al. had determined in a previous experiment the variability of ordinary time estimates for these subjects when payoffs and feedback were used. They found that the standard deviation of estimates was a constant proportion of the mean estimate. The standard deviation of time estimates relative to the mean estimate also exceeded that of "true" reaction times, which are presumed to involve no time estimation. Snodgrass et al. reasoned that if these relationships also held for the reaction time experiment, then the strategy the subject employed should depend upon the temporal location of the payoff band. When the payoff band was shorter than the "true" reaction time, the subject had to estimate the time since the warning stimulus or be incorrect most of the time. The subjects would also be forced to estimate elapsed time when the payoff band is considerably longer than the "true" reaction time. Although the subjects could estimate time from either the warning stimulus or the reaction signal, reward should be maximal if time is estimated from the reaction signal. Because the variability of estimates is a constant proportion of the interval being estimated, the variability of estimates would be less if the shorter duration were estimated. Finally, because the relative variability of reactions is less than the variability of time estimates, the least variable and, hence, most successful strategy would be simply to react to the reaction signal when most of the reaction time distribution falls within the payoff band. Snodgrass et al. found that the mean reaction time closely tracked the payoff band. Consistent with the idea that whether an event will serve as a time-marker is determined by the costs and benefits associated with its use, Snodgrass et al. found that the ratio of the standard deviation to the mean reaction time was greatest when the payoff band was shorter than the "true" reaction time. This ratio was smallest when simply reacting to the reaction signal resulted in the highest percentage of rewarded trials. The ratio was intermediate and constant for all conditions in which the target band was longer than the "true" reaction time. Thus, the subjects appear to have used all of the response strategies discussed above.

Additional support for the idea that subjects are sensitive to the costs and benefits of coming under the control of different time-markers comes from a study by Heinz and Eckerman (1974), who investigated the performance of pigeons on a discrete-trial analogue of the fixed-interval schedule. The key light was on throughout each interval and periods during which the house light was darkened alternated with periods in which the house light was lighted. The number of trials and the duration of the fixed interval were varied independently and jointly. Many of the data were consistent with the proposal that the time since the reinforcer controlled response latencies when the number of trials was held contant at 15 and the fixed interval was varied. Latencies tended to decrease and response frequency increased as a function of the relative time elapsed since a reinforcer. When the fixed interval was held constant at 2 min and the number of trials was varied, response frequencies on the early trials decreased as the number of trials was increased. When the number of trials in the 2-min interval was eight, response frequencies were greatly increased on the early trials and showed little evidence of control by time since food. One possibility is that control was by the probability of reinforcement on a trial rather than by time since food delivery. For example, if it is assumed that terminal activity occupies about one-half of the interval, and that, when control is by the food time-marker, terminal activity is initiated and maintained without regard to the presence of the trial stimuli, then for inter-food intervals containing a small number of trials, the average work time per interval might be less if the birds simply entered the terminal state for the duration of each trial. If increasing the average work time per reinforcer reduces net reward value, then control would be expected by the time-marker which resulted in the least work time per reinforcer.

A related result has been reported by Fifer (1977). He investigated the temporal patterning of pigeons' responses on a discrete-trials fixed-time schedule in which no response dependency was employed. The number of trials was held constant at seven, and the interreinforcement interval was varied. The rate of response was found to increase on early trials with increases in the interreinforcement interval duration. This finding, in conjunction with the findings of Heinz and Eckerman (1974), led Fifer (1977) to suggest that pigeons are sensitive to the costs and benefits associated with control by different time-markers.

Thus, it appears that the extent to which a given event will exert temporal control may be modifiable. Whether or not the event will come to exert temporal control appears to depend not merely on its salience but on the relative costs and benefits of coming under the control of that event as a time-marker, as well.

Additional evidence that the cost of control by a non-food time-marker is greater than the cost of control by food comes from an experiment by Dews (1965) on the effect of interrupting a fixed interval with a single period of signalled extinction. The discriminative stimulus was present during the first and last 1200 sec of the fixed interval, while a 600-sec period of signalled extinction occupied the middle of each fixed interval. Because the onset of the final discriminative stimulus period was reliably associated with a fixed time to food, it might be expected that temporal control would be by the onset of the final discriminative stimulus period. If the birds were under the control of the food time-marker, in contrast, the average work time per reinforcer would be considerably greater than if control were by the offset of the extinction signal, the more proximal predictor of time to food. The results, however, did not confirm this expectation. The rate of responding at the beginning of the final discriminative stimulus period was comparable to rates observed at that time in uninterrupted fixed intervals. Moreover, the result could not have been due to a failure to attend to stimulus changes; the extinction signal suppressed responding relative to rates normally observed in the middle of a fixed interval. This finding provides additional evidence that there is an intrinsic cost of substantial magnitude associated with coming under the temporal control of a non-food time-marker. Thus, the degree of temporal control exerted by a given stimulus event may depend on how such control affects overall net reward value.

## A Motivational Account

The phenomenon just described is that pauses following a blackout occasionally presented in lieu of reinforcement are considerably shorter than those following food delivery. As just described, this may be so because emitting extra pecks is less costly to pigeons than coming under the control of a non-food time-marker. Gibbon, however, has proposed an account of interval performance which suggests that, on percentage-reinforcement schedules, pigeons come under the control of both food and non-food stimuli as time-markers. Both types of events are held to serve equally well as time-markers, with differences in the average pause durations following each type of event being due to a local contrast effect.

The duration of the pause period on fixed-interval schedules is highly variable within a session (Catania, 1970; Dews, 1970; Gibbon, 1977; Shull, 1971, 1978). Gibbon (1977) has proposed an account of interval performance in which variability in the pause duration across successive intervals is assumed to result from variation of the subjects' estimate of when reinforcement will become available. First, Gibbon proposes a motivational variable, H, which corresponds to the reinforcer magnitude for a situation. At the start of each interval, H is held to be distributed evenly between the beginning of the interval and the time remaining in the estimated interval. Thus, the "reference level" of reward density may be assessed at the beginning of each interval when elapsed time equals zero. In addition to this overall food density there is a local food density which at any given point is determined by the remaining time in the interval, that is, H divided by the remaining time. Thus, the local density of food increases in a hyperbolic manner, approaching infinity as elapsed time approaches the maximal time to reinforcement as estimated by the subject at the start of a given interval. Responding is held to occur when the ratio of the local food density to the overall food density crosses some threshold value. In Gibbon's terms this sufficient ratio is when responding is worthwhile.

The standard deviation of the latency distribution on interval schedules has been found to be proportional to the interval (Catania, 1970; Gibbon, 1977). Indeed, when the interval duration is increased, a constant proportion of latencies occurs before any given proportion of the interval elapses. This constancy occurs, according to Gibbon, because when the interval is changed, the new distribution of estimates is a simple linear transform of the former distribution of estimates. Both the mean and standard deviation of this distribution are proportional to the interval duration, and so their ratio does not vary as a function of interval size.

According to Gibbon, both food and non-food stimuli exert control equally well as time-markers because both are associated with the same remaining time to food. Gibbon proposes that the shorter pauses observed to follow a brief non-food time-marker presented in lieu of reinforcement may be explained in terms of a local contrast effect. When blackouts are presented instead of some reinforcers, the average food density over the estimated interval is determined by an average of the duration of food access employed, with the blackouts averaged in as zero access time. Thus, the local food density depends on the average access time. The reference level reward density at the beginning of a given interval is more heavily influenced by the most recent initiating event. In intervals initiated by a reinforcer presentation the average reward magnitude represents a relative worsening of conditions. Conversely, in intervals initiated by a blackout the average reward magnitude represents a relative improvement in conditions. Because the ratio of the local to overall food density rather than simply the local density is responsible for the onset of responding, the value of the ratio will not reach threshold until relatively late in the interval when the interval is initiated by a reinforcer presentation; but when the interval is initiated by a blackout, the value of the ratio will reach threshold relatively early in the fixed interval.

To this point in the paper three reasons to expect shortened pauses following non-food time-markers have been discussed. First, subjects may initially be controlled by the most salient time-marker in a given situation. Second, subjects may come under the control of a less salient event if the costs associated with control by the salient event are increased. Both of these possibilities suggest that the events which control performance in a given situation can be altered. Finally, shorter pauses following a given time-marker may sometimes be explained in motivational terms and need not represent selective use of time-markers.

The present experiment investigated whether stimulus events which make equally good predictions of the time to food result in equal average pause durations. For one group of subjects a fixed-duration blackout was interpolated after each food delivery, and the beginning of the fixed interval was marked by the illumination of the response key. All fixed intervals were concluded with reinforcement. The duration of the blackout was varied systematically. At each blackout duration, the distribution of latencies from the beginning of the fixed interval to the first terminal response measured was examined in detail. If the subjects did come under the control of the reinforcer rather than the key-light onset as a time-marker, the latencies to initiate the terminal period might be distributed across the entire interval between reinforcer deliveries and not just over the period occupied by the fixed-interval. Staddon (1972, 1977), for example, has suggested that, as the relative proximity of food delivery increases, the likelihood that subjects will begin to engage in food-directed activities also increases. If the class containing all food-directed activities is not restricted to pecks at the lighted key, then is is conceivable that food-related activities might commence whether or not the key is lighted when the next scheduled reinforcement is sufficiently proximal. When the terminal, or food-related, state is initiated prior to the key-light onset, lighting the response key may serve merely to direct ongoing food-related behavior.

It would then be expected that the probability of terminating the latency to the first response should be higher early in the "trial" period if subjects come under the control of the reinforcer rather than the key-light onset as a time-marker.

Increasing the duration of the blackout, however, has the effect of increasing the cost of control by the reinforcer as a time-marker. When fixed intervals are initiated after a period of blackout, the average amount of work per reinforcer will always be greater if subjects are controlled by the reinforcer rather than the key-light onset as a time-marker. That is, if the average duration of the terminal period is proportional to the interval, then timing the interval between food deliveries would result in a longer average delay than timing the duration of the fixed interval. Thus, if pigeons are sensitive to the delay between the initiation of food-related activity and the occurrence of the reinforcer, then timing the interval between food deliveries will always be associated with a greater cost than timing the fixed-interval period.

In order to determine which interval the pigeons time, it is necessary to compare the probability of latency termination in the fixed-interval period when different blackout durations are used. If temporal control is exercised by the reinforcer alone, then, as the blackout duration is increased, the terminal period will be initiated prior to key-light onset on an increasing proportion of the intervals in a session. In this case, the conditional probability of latency termination should correspond to that observed during the last

2 min of an interval equal to the sum of the blackout and fixed-interval durations. It would, therefore, be important to compare the termination probability functions from the fixed-interval period and the equivalent portion of a food-initiated interval equal to the sum of the blackout and fixed-interval durations. If, however, control is by key-light onset, the latency termination probabilities from blackout conditions should more nearly correspond to those from a food-initiated fixed interval of the same duration.

One other possible outcome is that, when a fixed interval is initiated after a blackout of fixed duration, the termination probability functions will not correspond to those from either of the control conditions just described. That is, the termination probability might be higher without corresponding to the levels which would be expected if only the reinforcer exerted temporal control. Such a finding would be consistent with Gibbon's (1977) proposal that shorter latencies following non-food time-markers result from a local contrast effect. If Gibbon's proposal is correct, then the ratio of the mean and standard deviation of the latency distribution should not change with changes in the duration of the blackout. According to Gibbon, the pause distribution is always a simple linear transform of the distribution of estimates. The distribution of estimates would only change if the interval being timed was either increased or decreased. It would, therefore, be important to compare the ratio of the mean and the standard deviation of the pause distribution from different blackout conditions. If obtained termination probabilities are consistent with Gibbon's proposal, it would also be of interest to equate the rate of food delivery in the trial and blackout periods. If the shortened pauses are due to a local contrast effect, then increasing the rate of food delivery during the blackout should attenuate the effect.

If performance is sensitive to the costs associated with coming under the control of a particular time-marker, one might expect the termination probabilities to reflect an increased, perhaps exclusive, reliance upon the key-light onset as a time-marker when the blackout periods are of variable rather than fixed duration. When variable-duration blackout periods are used, there are costs associated with coming under control of only the reinforcer as a time-marker in addition to those present when fixed-duration blackout periods are used. When variable blackout periods are used, food delivery does not predict the time of key-light onset. If initiation of the terminal period is determined solely by time since the last food delivery, and the pigeons attempt to estimate the time to food by timing the shortest programmed interval, then the average work time in variable-blackout conditions would be much longer than if the blackout duration was fixed. To the extent that performance is sensitive to these contingencies, the use of variable-duration blackouts should encourage control by key-light onset as a time-marker.

Conditions were also studied in which the distribution of inter-food intervals was the same as the distribution of those occurring in black conditions. The only difference was that in control conditions the key-light was on throughout each inter-food interval. If the termination probability functions during the trial period should correspond to those observed during equivalent portions of the variable-interval control procedure it would constitute evidence that temporal control is always by the most salient time-marker. If, however, the termination probability functions from the trial period should correspond with those from a reinforcer-initiated fixed interval equal to the trial duration, the correspondence would provide evidence of control by the key-light onset. Such an outcome would support the notion that the degree of temporal control exerted by a given event depends upon whether such control enhances net reward value.

In summary, the purpose of the present experiment was two-fold. First, it sought to determine whether the different degrees of temporal control exerted by different time-markers result from a local contrast effect or whether such differences reflect the selective use of time-markers. Second, if the selective use of time-markers is indicated, the experiment determines whether such selective control by the different time-markers is simply due to differences in the physical salience of the two events or whether, as reward-versus-cost views of stimulus control would predict, the degree of temporal control exerted by a particular time-marker depends upon the extent to which control by that event enhances net reward value.

# CHAPTER II

# METHOD

## Subjects

The subjects were four White Carneaux and four Silver King pigeons, maintained at approximately 80 percent of their free-feeding weights throughout the experiment. All had prior experimental histories.

## Apparatus

Two experimental chambers were employed in the present experiment. The effects of fixed-duration blackouts were studied in a standard pigeon chamber (manufactured by Lehigh Valley Electronics) measuring 35 by 30 by 35 cm. On the front wall of the chamber two response keys, each 2.5 cm in diameter, were located 10 cm apart and 24 cm above the floor of the chamber. A rectangular opening centered 9 cm beneath the two response keys provided access to mixed grain. The mixed grain was presented by means of a hopper which was mounted behind the front wall and which could be illuminated during reinforcement. Also mounted behind the wall were lights which permitted the right-hand response key to be lighted red. Only that key was used; the left-hand key was covered throughout the experiment. A ventilating fan and white noise helped mask extraneous sounds.

The effects of variable-duration blackouts were investigated in a similar experimental chamber which was also manufactured by Lehigh Valley Electronics and which measured 34 by 30 by 30 cm. The response keys were located 14 cm apart and 14 cm above the floor of the chamber; they were lighted as were those in the first chamber. The two chambers were identical in all other respects.

Standard electromechanical equipment programmed and recorded events. A digital printing counter recorded each response latency separately.

### Procedure

The pigeons were randomly assigned to one of two groups with the restriction that each group contain two birds of each strain. Birds F-1, F-2, F-3, and F-4 were used to investigate the effect of fixed-duration blackouts. The effect of variable-duration blackouts was examined using pigeons V-1, V-2, V-3, and V-4. All birds were given preliminary training on a fixed-interval 2-min schedule of reinforcement. The reinforcer was 4-sec access to mixed grain. Each fixed interval was initiated with the termination of the previous reinforcer delivery, and the first response to occur after 2 min had elapsed was reinforced. Each response during the fixed interval produced a feedback click from a relay mounted behind the front wall. Sessions were terminated after the 31st reinforcer presentation.

Following this initial training a period of blackout separated successive fixed intervals. During a period of blackout all lights in the experimental chamber were extinguished. Pecks to the darkened key were recorded but had no programmed consequences. The next fixed interval was initiated with key-light onset. The duration of the fixed interval was 2 min throughout the experiment. Following training on the blackout conditions, the reinforcer-initiated fixed-interval 2-min condition was redetermined for all subjects.

Fixed-duration blackouts. Fixed-duration blackouts were studied in the following order: 30, 60, 120, 240, and 480 sec. A given blackout remained in effect for at least 25 consecutive sessions and until there was little day-to-day change in the average response latency. The latency to the first response was recorded separately for each fixed interval.

If salience alone determines which events exert temporal control, then the pigeons would always time the interval between food deliveries. To assess this possibility, interreinforcement interval control conditions were conducted. A fixed-interval 3-min schedule served as the control procedure for those conditions in which the fixed-duration blackout was 60 sec. The control procedure for those conditions in which the fixed-duration blackout was 240 sec was a fixed-interval 6-min schedule. The first interval in each session was 2 min for all conditions. Response latencies were not recorded during the first interval. For all control conditions response latencies were recorded exactly as if a fixed-interval trial period had been initiated 2 min prior to reinforcement availability. There was, however, no exteroceptive stimulus change during the interreinforcement interval on control conditions. If the latency distributions from control and blackout conditions should correspond, then the argument that salience alone determines which events exert temporal control would be strengthened.

In order to assess the possibility that shortened pauses following non-food time-markers result from a contrast effect, the rate of food delivery was equated in the blackout and fixed-interval periods. This was accomplished in one condition by presenting reinforcers independently of the birds' behavior during a 60-sec blackout period. The fixed-interval remained constant at 2 min. On half the intervals no grain presentations occurred during the blackout period. For the remaining intervals grain was presented during the blackout either 15 sec or 45 sec following the previous reinforcer. These three types of interval were programmed in an unsystematic order. The number of fixed-interval periods was reduced to 21 during this condition and the total number of reinforcers obtained in a session remained constant at 31. If the contrast mechanism described above is responsible for decreased average pause durations, then this manipulation should attenuate the effect.

Variable-duration blackouts. It may be that a substantial contingency is required to offset any initial bias in favor of being controlled by only the food time-marker. To further increase the cost associated with control by the reinforcer as a time-marker, variable-duration blackouts were also studied. The effects of distributions of blackout durations with means of 30, 60, 120, and 240 sec were studied in the order given for birds V-1, V-2, V-3, and V-4. A given distribution of blackouts remained in effect for at least 25 consecutive sessions and until there was little day-to day change in the average response latency. For each of the variable blackout conditions the blackout durations were distributed geometrically according to a formula proposed by Catania and Reynolds (1968). Each distribution was composed of 15 separate blackout durations which were programmed in an unsystematic order by a film tape reader. Interreinforcement-interval control procedures were also conducted for the variable-duration blackout conditions.

The same distribution of intervals used to program the variable-duration blackouts was used in the control condition. Each interval was followed by an additional 2-min period before reinforcement was due. The only difference between this condition and the variable-duration blackout conditions was that in control conditions the key light was on throughout the inter-food interval. The duration of the first interval in each session was again 2 min for all conditions.

Variable-duration blackout conditions were also conducted in which only two blackout durations were presented within a session. An equal number of long and short blackouts occurred in an unsystematic order within each esssion. Individual response latencies were recorded separately following the long and short blackout durations. First, the birds were studied when either a 10 or a 50 sec blackout preceded the fixed-interval period. Next, the birds were studied when the two blackout durations were 20 and 100 sec. Subjects F-1, F-2, F-3, and F-4 were also studied under this last set of conditions.

# CHAPTER III

# RESULTS

## Fixed-duration Blackouts

Figure 1 presents the mean latency to the first response for each bird as a function of the fixed-duration blackout which preceded each fixed interval. The points labeled 0-sec were obtained from sessions in which the termination of a reinforcer delivery initiated each 2-min fixed interval. All points are means of the last five sessions of each condition. The unconnected open symbols represent redeterminations. When fixed intervals were initiated following a blackout, the mean pause was shorter than when fixed intervals were initiated with food delivery for birds F-1, F-3, and F-4. Such decreased pause duration was less evident for bird F-2. These findings clearly indicate that the blackouts separating successive fixed intervals were not merely periods of "time-out" from the reinforcement schedule. Increasing the blackout duration, however, had no clearly systematic effects on the latency of the first response in the fixed interval.

The average latency of the first response as a proportion of the fixed interval is shown in Figure 2 for each bird for both control and blackout conditions. The points labeled 0-sec are from sessions in which a food delivery initiated the fixed interval. The circles, triangles, and squares represent performance under the 2-min, 3-min, and 6-min fixed intervals, respectively. The open symbols represent redeterminations. As can be seen in Figure 2, when a fixed interval was initiated with food delivery, the relative pause duration was about the same regardless of the schedule value,

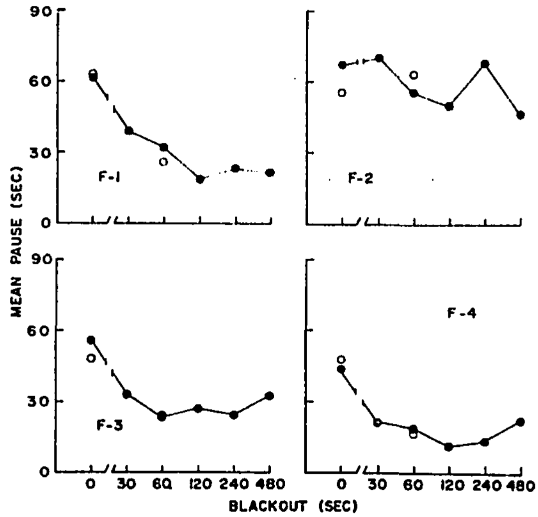

Figure 1

The mean pause for each bird averaged over the last five sessions of each fixed-duration blackout condition. The points labeled 0-sec are from sessions in which food initiated each fixed interval. The unconnected symbols are replications.

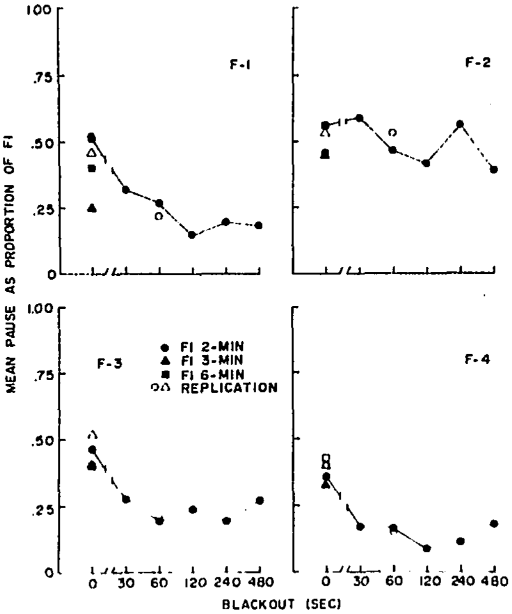

Figure 2

The mean pause as a proportion of the fixed interval for each bird averaged over the last five sessions of each condition. The points labeled 0-sec are from sessions in which food initiated each fixed interval. The open symbols are redeterminations.

excepting the initial determination of the 3-min control condition for bird F-1. When fixed intervals were initiated by the key-light onset, however, the mean latency occupied a much smaller portion of the 2-min interval. These data show that even when they are equally valid predictors of the time to reinforcement, non-food events produce shorter pauses than food. As mentioned earlier, however, there are several reasons to expect that increasing blackout durations should have had a systematic effect on performance. The fact that the mean pause did not clearly decrease with increasing blackout values, therefore, might seem inconsistent with this expectation. There are, however, reasons to expect that the mean pause might not decrease continuously with the increasing blackouts in the present experiment. While increasing the blackout duration resulted in the key-light onset occurring at progressively later relative times in the interfood interval, it also had the effect of increasing the absolute duration of that interval. Hence, increasing the blackout duration may have increased the likelihood of initiating terminal behavior early in the interval while decreasing that likelihood late in the interval. Thus, it would be necessary to examine the distribution of latencies in order to determine if blackout duration had a systematic effect on performance.

Figure 3 estimates the probability of terminating the latency of the first response at any time since the start of the fixed interval, given an opportunity to terminate a latency of that duration. The terminations per opportunity measure is calculated by dividing the frequency of latency terminations occurring in a given time bin by the number of latencies occurring in that and all longer time bins. These probability estimates were derived from frequency distributions of latencies which were grouped in 12-sec

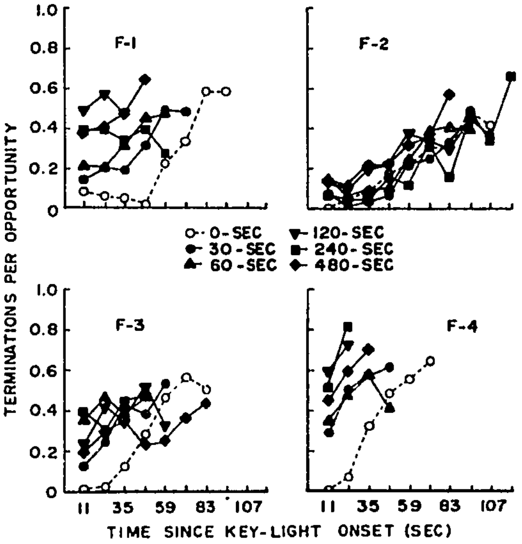

Figure 3

Terminations per opportunity as a function of time since key light onset for each bird with blackout condition as a parameter. The distribution of latencies was collected over the last five sessions of each condition.

interval classes. Distribution data were collected over the last five days of each condition. Because presenting data from recovery conditions would not alter any conclusions reached, only first determinations are represented in the figure.

When the 2-min fixed interval was initiated with the termination of the previous food delivery (open circles) the probability of latency termination was low at times early in the interval and increased monotonically, usually to a maximum near the end of the interval. The conditional probability of terminating the latency increased at times early in the interval when blackout duration was increased. The termination probabilities later in the interval remained constant or decreased slightly. For birds F-1 and F-3 the increases in the termination probabilities early in the interval continued until the functions were approximately flat, indicating a lack of temporal control by the key-light onset. Although this flattening of the functions can not be seen for bird F-4, there was no evidence of further increases late in the interval. For bird F-2, however, the probability of latency termination increased throughout the interval under all conditions studied.

In summary, increasing the duration of the blackout period resulted in increasing probabilities of latency termination early in the fixed interval until the functions were flat. Further increases in the blackout duration resulted in a decrease in the probability of terminating the latency. With the possible exception of bird F-4, the termination per opportunity functions remained fairly flat even though the overall termination probability was reduced. This finding indicates a continued lack of temporal control by the key-light onset when longer blackouts were employed.

The effect of separating successive fixed intervals with blackouts of increasing duration was generally restricted to the first third of the interval, with the effect being most evident in the first time bin. Figure 4 presents the probability of terminating the latency to the first response during the first tenth of the interval for the first determination of each blackout condition. For birds F-1, F-3, and F-4 the termination probability seems strongly related to the duration of the blackout. The size of the effect, however, was much smaller for bird F-2. In general the data of Figures 3 and 4 confirm the impression given by the average latency data. Both indicate that there was an increased tendency to terminate the latency early in the interval.

The increased tendency to terminate the latency early in the interval is consistent with the possibility that the birds were under the control of only the food time-marker. If food-related behavior is initiated on the basis of elapsed time since food alone, terminations per opportunity would be expected to increase at times early in the interval with increases in the blackout duration because, with increasing blackout durations, key-light onset would occur at progressively later times in the inter-food interval. To further assess the possibility that control was simply by time since the last food delivery, termination probabilities from blackout conditions were compared to those taken from the last 2 min (control period) af a food-initiated fixed interval equal to the sum of the blackout and fixed interval periods. In all cases the control period was the 2-min period immediately prior to reinforcement. Latencies were timed from the beginning of the control period whether or not the bird had previously initiated responding in that interval. If temporal control

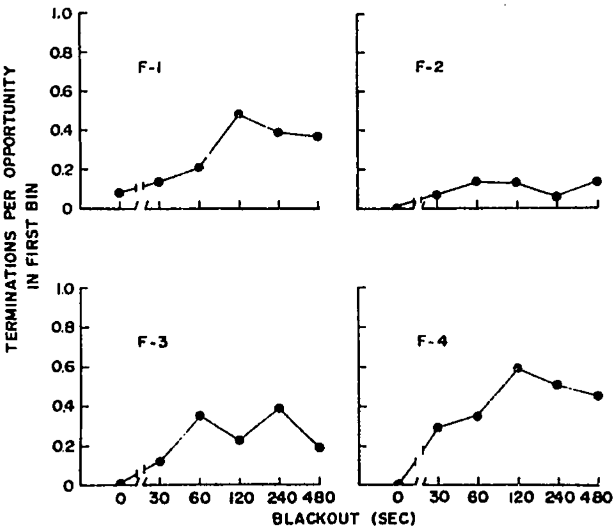

Figure 4

Terminations per opportunity in the first tenth of the fixed interval for each bird averaged over the last five sessions of each condition. The points labeled 0-sec are from sessions in which food initiated each 2-min fixed interval.

is by the food time-marker alone, then the termination per opportunity functions from control and blackout conditions should correspond.

Figure 5 compares termination probabilities observed under the 60-sec (filled triangles) and 240-sec (filled squares) blackout conditions with, respectively, those observed in the control period of the fixed-interval 3-min (open triangles) and fixed-interval 6-min (open squares) conditions for each bird. The open triangles connected with a solid line represent the first determination of the fixed-interval 3-min control condition, while the open triangles connected with a dashed line represent a second determination. The open circles depict the probability of latency terminations when the schedule was a reinforcer-initiated 2-min fixed interval. Distribution data were collected over the last 5 days of each condition. Consistent with the idea that control was by the interval between food deliveries, the blackout and control functions corresponded closely over much of the 2-min fixed interval for birds F-1, F-3, and F-4. Bird F-2 showed good control by the key-light onset in both blackout conditions.

The termination probabilities during the first tenth of the interval for the 240-sec blackout conditions, however, clearly do not correspond with those obtained from the fixed-interval 6-min control conditions. The probability of terminating the latency during the first tenth of the interval was much greater in the fixed-interval 6-min control condition than it was in the 240-sec blackout condition for all birds. The termination probability decreased for all birds in later portions of the

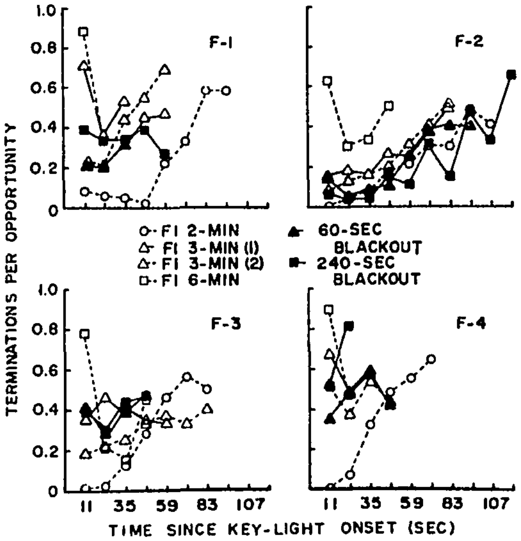

Figure 5

Terminations per opportunity as a function of time since key light onset for each bird. The open symbols depict performance during control periods, while the filled symbols represent performance in intervals initiated after a blackout. The latency distributions were collected over the last five days of each condition.

control period and, except for bird F-2, showed good correspondence with the 240-sec blackout functions. The probability of terminating the latency after more than a tenth of the control period had elapsed in the fixed-interval 6-min conditions also decreased for bird F-4. For this bird, although the termination probability obtained from the 240-sec blackout condition in the second tenth of the interval was higher than that observed during the control condition for bird F-4, this most likely reflects a sampling error. For all birds, however, there was a substantial difference in termination probabilities between the 240-sec blackout and fixed-interval 6-min control conditions in the first tenth of the 2-min period.

When a 60-sec fixed-duration blackout was in effect, the discrepancy between control and blackout termination probabilities during the first tenth of the period was considerably less, excepting the initial determination of this condition for bird F-1.

In summary, the data of Figure 5 suggest that the pigeons may have been under the control of the food-to-food interval but that key-light onset also had some effect. One mechanism which might be responsible for the observed effect of key-light onset might be that a minimum average time is required for the birds to shift from other food-related topographies to the measured key-pecking response. According to this view, even though key pecks can not occur early, initiation of the terminal period would be determined solely by the time since the last food delivery. Alternatively, it may be that, as Gibbon (1977) has suggested, shorter pauses following non-food time-markers result from a local contrast effect. Overall food density is viewed as being enhanced relative to the initiating event when that event is something other than food.

In order to evaluate the role of motivational factors, the rate of food delivery during the blackout period was equated to that occurring during the key-light period. As described earlier, a 60-sec blackout was used, and response-independent grain presentations either did not occur at all during 50 percent of the blackouts, occurred 15 sec after the last fixed-interval reinforcer during 25 percent of the blackout periods, or occurred 45 sec after the last fixed-interval reinforcer during the remaining 25 percent of the blackout periods. If the shorter pauses after non-food events represent a contrast effect, then increasing the rate of food delivery during the 60-sec blackout period would be expected to attenuate the effect of separating successive fixed intervals with a blackout.

The probability of terminating the latency is presented separately in Figure 6 for intervals following blackouts in which no food delivery occurred (filled triangles), and for intervals following blackouts in which the reinforcer was presented 15 sec (filled squares) or 45 sec (filled circles) after the last fixed-interval reinforcer. Termination probabilities observed in the simple 60-sec blackout condition (open triangles) and those observed when a reinforcer-initiated 2-min fixed-interval schedule was in effect (open circles) are replotted for comparison. Increasing the rate of food delivery during the blackout

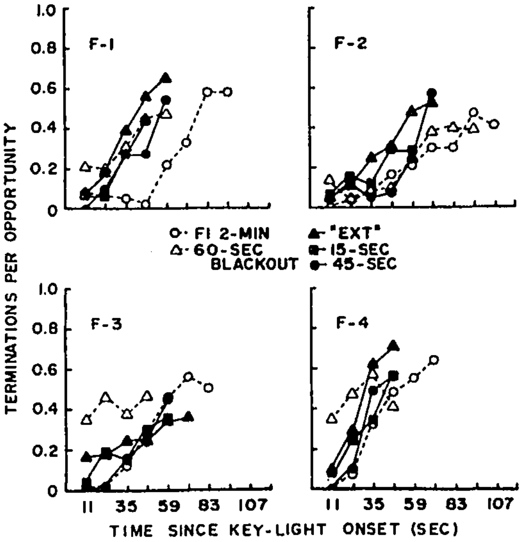

Figure 6

Terminations per opportunity as a function of time since key-light onset for each bird. The filled symbols are from intervals following a 60-sec blackout in which response-independent food was either not delivered (filled triangles), delivered 15-sec after the last food or delivered 45-sec after the last food. The functions from the simple 60-sec blackout and food-initiated fixed-interval conditions are replotted for comparison.

resulted in lower termination probabilities in the first tenth of the interval for all birds as compared to the simple 60-sec condition. For birds F-2, F-3, and F-4 the termination probabilities at later times were most similar to those observed under the reinforcer-initiated fixed-interval 2-min schedule. For bird F-1 the termination probabilities following all three types of blackout period were closest to those observed during the simple 60-sec blackout condition. For all birds there was some tendency for the termination probabilities to be highest following blackouts in which no reinforcer was delivered and lowest in intervals following blackouts in which the response-independent reinforcer was presented 45 sec after the last fixed-interval reinforcer. This could mean that the terminal reward value was influenced most by the most recently occurring blackout. The discrepancy between "extinction" intervals and intervals from the simple 60-sec condition, however, means that more than the most recent event must be assumed to have contributed to the magnitude of the local contrast effect. The data presented in Figure 6, therefore, suggest that a contrast effect may have been responsible for the shortened pauses observed under blackout conditions. These data are also consistent with the possibility that temporal control was not by food under these conditions.

In order to further assess the possibility that the shorter latencies observed during blackout conditions resulted from the contrast mechanism proposed by Gibbon, the ratio of the mean and standard deviation is shown in Figure 7 for each of the fixed-duration blackout

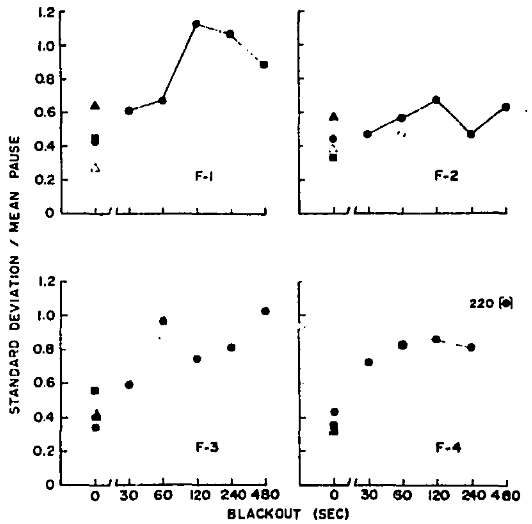

Figure 7

The ratio of the standard deviation of the latency distribution to the mean pause for each bird as a function of blackout duration. The points labeled 0-sec are from food initiated fixed intervals. The circles represent the 2-min interval, the triangles the 3-min interval, and the squares the 6-min interval. The open symbols are redeterminations.

conditions (connected points) as well as for each of the reinforcer-initiated fixed-interval control conditions (points labeled 0-sec). Because the motivational variable in Gibbon's model is multiplicatively related to the local food density, the mean and standard deviation should change proportionally. Hence, the ratio of the mean and standard deviation should not have varied with changes in the duration of the blackout which preceded each fixed interval. As can be seen in Figure 7, however, for birds F-1, F-3, and F-4 the ratio of the mean and standard deviation was an increasing function of blackout duration. The ratio was lowest when each fixed interval was initiated with food delivery, approximating a value of 0.40 regardless of the interval duration. For bird F-2 the value of the ratio for blackout conditions was, in four of six cases, within the range of variability observed from the conditions in which food delivery initiated each fixed interval. This finding further strengthens the interpretation of the data in Figure 5 as indicating that for bird F-2 the key-light onset exercised good temporal control. The systematic variation in the ratio of the mean and standard deviation with increasing blackout durations for birds F-1, F-3, and F-4 means that the specific mechanism of contrast proposed by Gibbon (1977) was not responsible for the shortened pauses observed in the present experiment.

### Variable-duration Blackouts

Figure 8 presents the mean latency of the first response for each bird as a function of the average blackout duration which preceded each

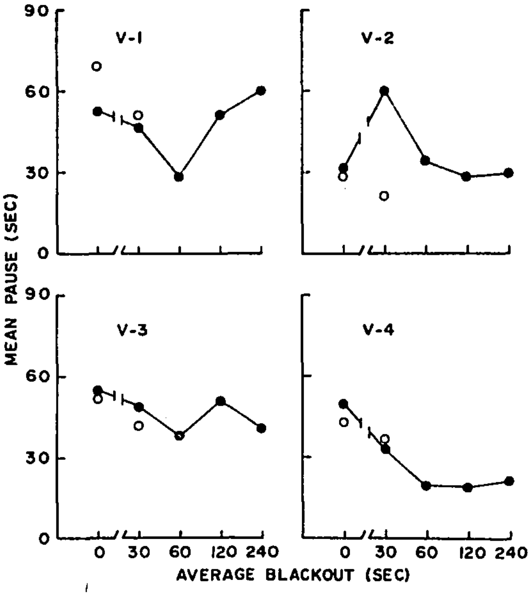

Figure 8

The mean pause for each bird averaged over the last five sessions of each variable-duration blackout condition. The points labeled 0-sec are from sessions in which food initiated each fixed interval. The open symbols are replications.

fixed interval. The points labeled 0-sec were obtained from sessions in which the termination of a reinforcer delivery initiated each fixed interval. All points are averages over the last five sessions of each condition. The unconnected open symbols represent redeterminations. Increasing the average blackout duration resulted in only small decreases in the mean latency, except for bird V-4, whose performance resembled that of the birds studied under fixed-duration blackout conditions. Overall, there was much less effect on the response latency when the blackout period was variable rather than fixed in duration. This finding is consistent with the idea that the pigeons came under the control of the key-light onset as a time-marker for all variable-duration blackout conditions shown.

Figure 9 presents the terminations per opportunity functions for the variable-duration blackout conditions for each subject. The open circles represent the distribution of latencies obtained when each 2-min fixed interval was initiated with the termination of the previous reinforcer. The filled symbols represent latency distributions from sessions in which a variable-duration blackout separated successive fixed intervals. Distribution data were collected over the last five days of each condition. When variable duration blackouts separated successive fixed intervals, the probability of latency termination resembled that obtained when each 2-min fixed interval was initiated with a food delivery, excepting bird V-4. To the extent that the functions from the food-initiated 2-min fixed interval correspond to those from blackout conditions, they are evidence for exclusive control by key-light onset as a time-marker. Only bird V-4

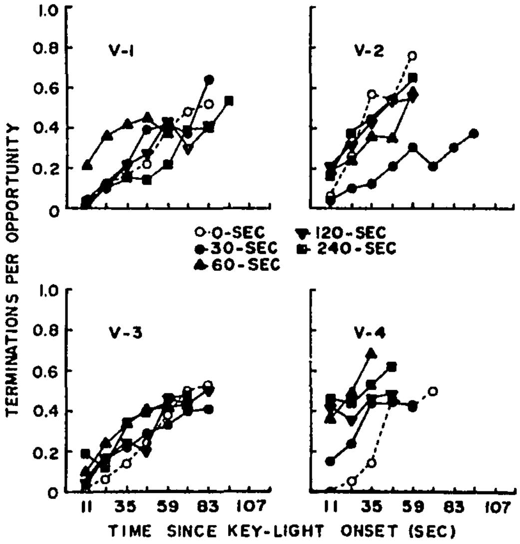

Figure 9

Terminations per opportunity as a function of time since key-light onset for each bird with blackout condition as a parameter. The distribution of latencies was collected over the last five sessions of each condition.

failed to show clear evidence of exclusive control by key-light onset as a time-marker. For this bird the probability of latency termination increased at times early in the interval when the average blackout duration was increased.

The probability of terminating the latency during the first tenth of the fixed interval is shown for each bird in Figure 10 over each mean blackout duration studied. In contrast to the fixed-duration blackout conditions, for birds V-1, V-2, and V-3 the probability of terminating the latency during the first bin is low and shows no systematic relationship to the mean blackout duration. The performance of bird V-4, however, seems strongly related to mean blackout duration.

In summary, the data of Figures 9 and 10 indicate that separating successive fixed intervals with variable-duration blackouts makes it more likely that temporal control will be by key-light onset.

The open triangles in Figure 11 present for each bird the probability of latency termination observed during the last 2 min of a reinforcer-initiated variable-interval 3-min schedule. The open squares represent the probability of latency termination during the control period of a reinforcer-initiated variable-interval 6-min schedule. The probability of latency termination observed during the corresponding blackout conditions are replotted for comparison. The filled triangles represent performance when the average blackout duration was 60 sec, while the filled squares represent performance when the average blackout duration was 240 sec. The open circles represent the probability of latency

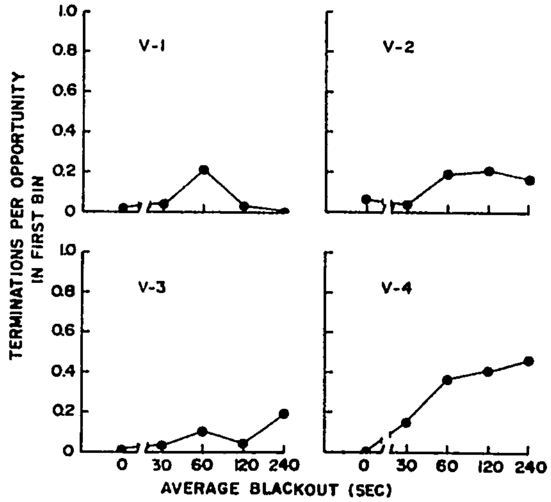

Figure 10

Terminations per opportunity in the first tenth of the fixed interval for each bird averaged over the last five sessions of each condition. The points labeled 0-sec are from sessions in which food initiated each 2-min fixed interval.

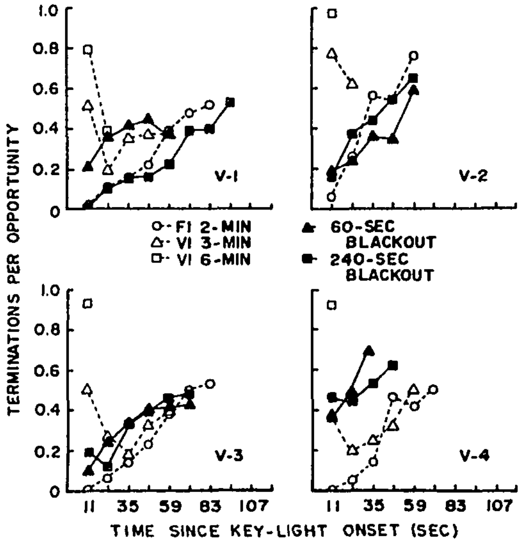

Figure 11

Terminations per opportunity as a function of time since key-light onset for each bird. The open symbols depict performance during control periods while the filled symbols represent performance in intervals initiated after a blackout. The latency distributions were collected over the last five days of each condition.

termination when a reinforcer-initiated fixed-interval 2-min schedule was in effect. Distribution data were collected over the last five days of each condition. As can be seen in Figure 11 there were large differences in the probability of terminating the latency during the first tenth of the period between control and blackout conditions when the mean blackout duration was 60 sec. There was no correspondence at all between control and blackout functions when the average blackout was 240-sec. Thus, the data of Figure 11 argue against the idea that pigeons time the interval between food deliveries when variable-duration blackouts separate successive fixed intervals. Moreover, three of the four birds appear to have come under the control of the key-light onset as a time-marker. This finding supports the idea that performance is sensitive to the different contingencies which follow from control by different time-markers.

If temporal control is by the food time-marker, then a negative correlation between the duration of the pause and the duration of the prior blackout would be expected. If it is assumed that the magnitude of the contrast effect proposed by Gibbon is determined solely by the most recent blackout duration, the motivational account would also predict such a negative correlation. Figure 12 presents for each bird the median pause duration following blackouts of different durations. The distributions of blackouts for each condition was divided into four equal interval classes. Each panel represents a different condition, with the average blackout duration indicated at the top of each panel.

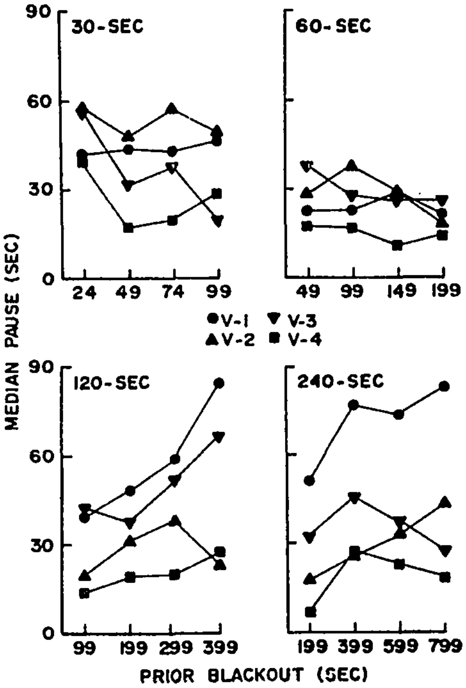

Figure 12

The median pause as a function of the prior blackout duration for each bird over the last five sessions of each condition. Each panel depicts performance under a different variable-duration blackout condition.

The circles represent the performance of bird V-1, the triangles that of bird V-2, the inverted triangles that of bird V-3, and the squares represent the performance of bird V-4. As can be seen in the figure, there was no negative correlation between pause duration and prior blackout duration. Either there was no relationship at all or the relationship was positive with longer pauses following longer blackout durations, although in some instances the lack of a negative correlation may have been due to a floor effect, with the minimum pause occurring after several blackout durations. Thus, these data provide additional evidence that performance was not under the control of time since food alone. The failure to observe a negative correlation between pause duration and prior blackout duration could be accommodated by Gibbon's model, however, if it is assumed that the average blackout duration, rather than only the immediately prior blackout, determines the magnitude of the contrast effect. If the average blackout duration is responsible, then it would not be necessary to predict a negative relationship between pause and blackout duration.

In summary, the data of Figure 12 are inconsistent with the idea that birds always come under the control of the most salient time-marker. The failure to observe a negative correlation between pause duration and prior blackout duration is consistent with the idea that the birds were timing from key light, a possibility that is considered later. These data are also consistent with the contrast effect proposed by Gibbon as well as with the proposal that whether a given event exercises temporal control depends upon how such control affects net reward value.

Variable-duration blackout conditions were also conducted in which only two blackout durations occurred within a session. Whether successive fixed intervals were separated by the shorter or longer blackout period was determined randomly. Using only two blackout durations made it possible to examine the distribution of pauses following the longer and shorter blackout periods separately. Figure 13 depicts the performance of birds V-1, V-2, V-3, and V-4 when the blackout duration was either 10 or 50 sec. The open symbols present terminations per opportunity in intervals following the 10-sec blackout. The filled symbols represent the relative frequency of latency terminations in intervals following the 50-sec blackout. As can be seen in Figure 13, the probability of terminating the latency was higher throughout those intervals which followed a 50-sec blackout. This would be expected if control was by the food time-marker. These data are problematic, however, for the contrast mechanism proposed by Gibbon. In order for Gibbon's model to account for the data presented in Figure 6 and Figure 12, it proved necessary to assume that the magnitude of the contrast effect was determined by the average blackout value and not merely by the immediately prior blackout. If the average blackout duration determined the magnitude of the contrast effect, then there should have been no difference in the termination probabilities as a function of prior blackout duration unless, of course, whether or not the birds average depends on the number of different blackouts in a situation.

Birds V-1, V-2, V-3, and V-4 were also studied under conditions in which the blackout duration was either 20 sec or 100 sec. Figure 14

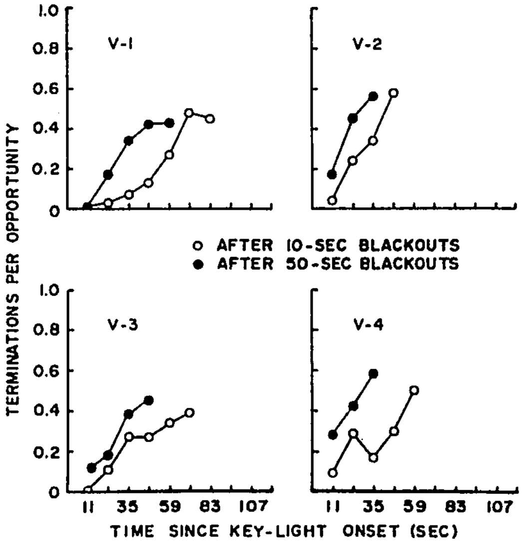

Figure 13

Terminations per opportunity as a function of time since key-light onset for each bird with prior blackout duration as a parameter. The distribution data were collected over the last five sessions of the condition.

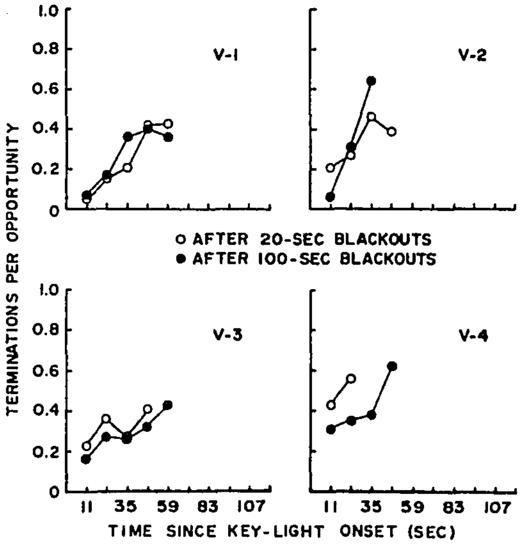

Figure 14

Terminations per opportunity as a function of time since key-light onset for each bird with prior blackout duration as a parameter. The distribution data were collected over the last five sessions of the condition.

presents the termination probabilities for this condition as a function of elapsed latency time for each bird. The open symbols represent the termination probability in intervals following the 20-sec blackout, while the filled symbols represent the probability of latency termination in intervals following the 100-sec blackout period. Although the termination probabilities were elevated relative to those observed in a food-initiated 2-min control period in both types of intervals, there was either no difference in termination probabilities after the two blackout durations for birds V-1, V-2, and V-3 or the termination probabilities were lower following the 100-sec blackout. The lower termination probabilities would be expected after 100-sec blackouts due to the longer absolute inter-food interval necessarily associated with the 100-sec blackout. The data from all four subjects argue against the notion that the pigeons were under the control of the food time-marker. If the reinforcer had exerted effective temporal control, the probability of terminating the latency should have been greater following the 100-sec blackout period than following the 20-sec blackout period.

Birds F-1, F-2, F-3, and F-4 were also studied when, on a random basis, either a 20-sec or a 100-sec blackout period separated successive fixed-intervals. Figure 15 presents the termination probability as a function of elapsed latency time for each bird. The open symbols represent the termination probability in intervals following the 20-sec blackout period. The filled symbols present that probability in intervals following the 100-sec blackout. As can be seen in Figure 15, the termination probability in the first and second interval classes was higher following the 100-sec

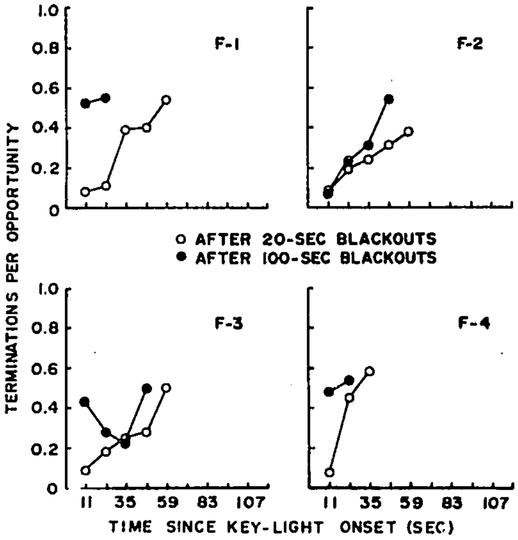

Figure 15

Terminations per opportunity as a function of time since key-light onset for each bird with prior blackout duration as a parameter. The distribution data were collected over the last five sessions of the condition.

blackout than following the 20-sec blackout for birds F-1, F-3, and F-4. The termination probability was also higher over parts of the interval for bird F-2. Unlike birds V-1, V-2, V-3, and V-4, these subjects showed evidence of control by the food time-marker when the mean blackout duration was 60 sec. The difference between the two groups of birds is most likely due to the fact that birds F-1, F-2, F-3, and F-4 had not been exposed to the longer and more variable blackouts that birds V-1, V-2, V-3, and V-4 had experienced. In summary, when only two blackout durations were presented within a session, the data of Figures 13, 14, and 15 argue against the notion that control was by the most salient time-marker. In addition, the data pose difficulties for the contrast mechanism proposed by Gibbon. The best interpretation seems to be that performance was under the temporal control of the key-light onset.

Figure 16 presents the rate of response for each tenth of the fixed interval or control period. The total number of responses which occurred in each time bin was divided by the total amount of time spent in each tenth of the 2-min period. Points represent the mean response rate averaged over the last five sessions of each condition averaged across birds F-1, F-2, F-3, and F-4. All points have been plotted as a function of elapsed time in the fixed interval. The filled triangles represent performance under the 60-sec blackout conditions, while the filled squares represent performance under the 240-sec blackout condition. The open circles, open triangles, and open squares depict the average rate of response during the control period when the schedule was, respectively, a 2-min, 3-min, or 6-min reinforcer-initiated fixed interval. As can be

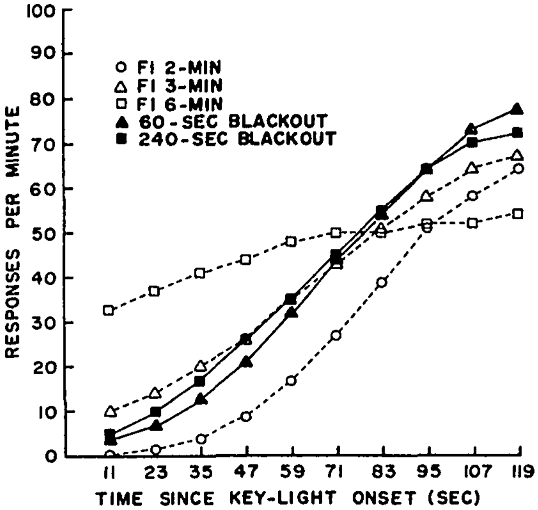

Figure 16

Responses per minute as a function of time since key-light onset averaged across birds F-1, F-2, F-3, and F-4 over the last five days of each condition. The open symbols are from control periods, while the filled symbols represent performance in intervals initiated after a blackout.

seen in Figure 16, when the reinforcer-initiated schedule was changed from 3 min to 6 min in duration, the asymptotic rate of response decreased, as would be expected if performance is sensitive to the rate of reinforcement. If in the blackout conditions response rate had been determined by the interval between food deliveries alone, then the rates from the 60- and 240-sec blackout conditions should have corresponded to those observed during the last 2 min of the fixed-interval 3-min and fixed-interval 6-min conditions, respectively. Consistent with the latency data, however, the response rate measure reveals some control by key-light onset. In addition, the asymptotic rates during blackout conditions were higher than those observed during the reinforcer-initiated fixed-interval 2-min condition.

Figure 17 presents the response rates observed when variable-duration blackouts separated successive fixed intervals. The filled triangles represent the 60-sec average blackout condition while the filled squares represent performance when the mean blackout duration was 240 sec. The open circles represent performance under a reinforcer-initiated fixed-interval 2-min schedule. The open triangles and squares represent, respectively, performance under a variable-interval 3-min and variable-interval 6-min schedule. Figure 17 shows that the maximum rate of key pecking decreased when the schedule was changed from fixed-interval 2-min to variable-interval 3-min. A further decrease was observed in the maximum rate when the variable-interval schedule was increased to 6-min. As in the fixed case, the rates from blackout conditions were lower than control rates early in the interval.

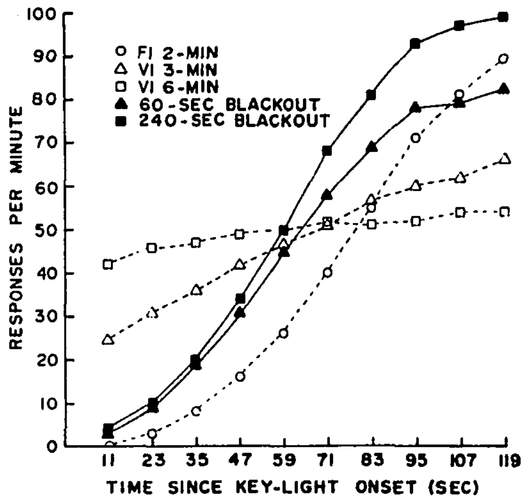

Figure 17

Responses per minute as a function of time since key-light onset averaged across birds V-1, V-2, V-3 and V-4 over the last five days of each condition. The open symbols are from control periods, while the filled symbols represent performance in intervals initiated after a blackout the mean value of which was either 60 or 240 sec.

Table 1 presents the Index of Curvature for each subject for all conditions. This measure reflects the relative degree of change in response rate over time. When the index is zero there is no temporal control. As the index approaches 1.0 there is a higher degree of positive acceleration of the response rate over time. For fixed-duration blackouts the index was smallest under the 240-sec control condition and somewhat greater under the 60-sec control condition. The index for the grouped response rate data was largest when food initiated each 2-min fixed interval. The index was intermediate for both the 60-sec and 240-sec blackout conditions, and there was only a small difference in the index between the two blackout conditions. For birds F-1 and F-4 the direction of the difference between the 60-sec and 240-sec blackout conditions is consistent with the idea that the terminal period was initiated on the basis of elapsed time since food. For these two birds the index suggests a greater degree of temporal control under the 60-sec blackout condition than under the 240-sec blackout condition. For bird F-3 there was little difference between the two blackout conditions. For bird F-2 the index was similar for the food-initiated 2-min interval and both blackout conditions, providing additional evidence that for this bird the key light exercised good temporal control throughout the experiment.

For variable-duration blackouts the index was also smallest under the 240-sec control condition and increased slightly under the 60-sec control condition. The index was, however, much smaller for the 60-sec control condition in the variable case than in the fixed case. The index was greatest for these birds when food initiated each 2-min fixed interval as well. The index was intermediate in the two blackout conditions. With the exception of bird V-1, there were only small differences in the index for the two variable-duration blackout conditions.

In summary, these data reveal much less of a difference between the effects of variable and fixed blackout durations than was indicated in the measures of response latency. At the same time, the response rate data are in accord with the latency data in arguing against the idea that control was by the food time-marker alone. Key-light onset also exerted control over key pecking early in the fixed-interval period.

## Table 1

### Index of Curvature for Blackout and Control Conditions

| Pigeons | 240-sec Control | 60-sec Control | 60-sec Blackout | 240-sec Blackout | Food-initiated 2-min FI |
|---|---|---|---|---|---|
| | Conditions | | | | |
| Fixed-duration Conditions | | | | | |
| F-1 | .07 | .27 | .44 | .34 | .54 |
| F-2 | .13 | .39 | .53 | .51 | .52 |
| F-3 | .14 | .33 | .35 | .38 | .53 |
| F-4 | .00 | .22 | .31 | .24 | .40 |
| Group | .08 | .29 | .38 | .34 | .48 |
| Variable-duration Conditions | | | | | |
| V-1 | .06 | .17 | .33 | .54 | .50 |
| V-2 | .04 | .06 | .36 | .38 | .43 |
| V-3 | .03 | .19 | .34 | .33 | .45 |
| V-4 | .04 | .26 | .33 | .28 | .48 |
| Group | .04 | .16 | .34 | .36 | .46 |

# CHAPTER IV

# DISCUSSION

Separating successive fixed intervals with a period of blackout reduced the latency of the first response under all fixed-duration blackouts studied. When fixed intervals were initiated with food delivery, the relative pause duration was about the same regardless of the inter-food interval. When a fixed-duration blackout separated successive fixed intervals, however, the average latency occupied a much smaller portion of the interval. When variable-duration blackouts separated successive fixed-intervals, however, the mean latency showed a much smaller decrease. In general, there was much less effect on the mean latency of separating successive fixed intervals with a period of blackout when the blackouts were variable rather than fixed in duration.

The conditional probability of terminating the latency increased at times early in the interval with increasing blackout duration, while the termination probabilities later in the interval remained constant or decreased slightly. This clockwise rotation of the terminations per opportunity functions with increasing blackout durations continued until the functions were approximately flat, indicating a lack of temporal control by key-light onset. When variable-duration blackout periods separated successive fixed intervals, however, no clockwise rotation of the termination per opportunity functions was observed for three of four birds. Key-light onset exercised good temporal control when variable- rather than fixed-duration blackouts were used.

Three reasons to expect shorter pauses in intervals initiated with non-food time-markers have been mentioned. First, it may be that pigeons always come under the control of the food time-marker, the more salient event. A second possibility is that whether a given event exercises temporal control over performance depends on whether such control enhances the net reward value. Finally, it may be as Gibbon (1977) has proposed, that the shorter pause durations following non-food time-markers result from a local contrast effect.

### Evaluation of the Motivational Account

The changes in the probability of latency termination observed under fixed-duration blackout conditions are consistent with the motivational mechanism proposed by Gibbon (1977). If it is assumed that the negative effect of blackouts increases with longer blackout durations, then the relative value of the anticipated average feeder duration would increase with increases in the blackout duration. Hence, an increasing likelihood of terminating the latency early in the interval as blackout duration is increased would be predicted by the model. The considerably smaller changes in the termination probability observed when variable blackouts of different mean durations separated successive fixed intervals are also consistent with the model. If it is assumed that performance is sensitive to the harmonic rather than the arithmetic mean of the different blackouts in a session, then the magnitude of the contrast effect would be expected to be much smaller when variable rather than fixed-duration blackouts separate successive fixed intervals. Thus, the changes in the average latency as well as the changes in the termination probability observed under fixed- and variable-duration blackout conditions are consistent with Gibbon's proposal.

The effect of separating successive fixed intervals with a period of blackout was attenuated when response-independent reinforcers were presented during a 60-sec blackout period. This finding is consistent with the idea that motivational factors influenced the latency duration. The additional finding that the termination probability depended upon how late in a fixed blackout period response-independent food was delivered also is consistent with the predictions of Gibbon's model. In half of the 60-sec blackout periods in this condition no food deliveries occurred. Hence, the fixed-interval was initiated following identical circumstances in these intervals and the intervals of the simple 60-sec blackout condition. Because the intervals were initiated after equal periods of blackout, if only the most recent blackout determines the magnitude of the contrast effect then the termination per opportunity functions from the two conditions should have corresponded. As was shown in Figure 6, this was not the case. The termination probabilities in intervals following blackouts in which no food was presented were lower in the condition in which reinforcers were delivered during some of the 60-sec blackout periods in a session than in the simple 60-sec blackout condition. This means that more than the most recent blackout duration must be assumed to determine the magnitude of the contrast effect.

Additional evidence on this point comes from the variable-duration blackout conditions. If the immediately prior blackout duration most influences the magnitude of the contrast effect, then Gibbon's proposal would predict a negative correlation between the preceding blackout duration and the following latency duration. Consistent with this possibility, when either a 10-sec or 50-sec blackout was randomly presented in a session, the termination probabilities were higher in intervals initiated following the longer blackout in some conditions. When a more variable distribution of blackouts was employed, however, no negative relationship between prior blackout duration and subsequent pause duration was found. As was shown in Figure 12, either there was no relationship between blackout and subsequent pause duration or the relationship was positive, with longer pauses following longer blackout durations. These data would be consistent with Gibbon's proposal only if the magnitude of the contrast effect was determined by the average blackout duration. If this is the case, however, it is unclear how Gibbon's model would deal with the finding that when only two blackout durations occurred within a session the probability of terminating the latency depended upon the immediately prior blackout duration.

According to Gibbon, in those intervals initiated by a non-food time-marker the average reward magnitude represents a relative improvement in conditions. The mean time at which the ratio of the local to overall food density reaches the threshold value is held to be related multiplicatively to a motivational variable. The value of this motivational variable is determined by the ratio of the value of the average reward magnitude to the average value of the non-food event. Thus, the ratio of local to overall food density reaches threshold relatively early in intervals initiated with the non-food event. The local food density at any time in a particular interval depends on the estimate of the time to food made at the beginning of that interval. Because the mechanism responsible for the variability of these estimates is held to be unaffected by motivational variables, the variability of the latency distributions should change in direct proportion to changes in the mean time at which the ratio of local to overall food density reaches threshold. Hence, if Gibbon's proposal is correct the ratio of the mean and standard deviation of the pause distribution in the present experiment should not have varied with changes in the duration of the blackout. As was shown in Figure 7, however, the ratio of the mean and standard deviation of the latency distributions was constant only for the conditions in which each interval was initiated with food delivery. The ratio increased with increasing blackout durations when the fixed interval was initiated with key-light onset. Thus, the specific motivational mechanism proposed by Gibbon is inconsistent with these data.

In summary, while consistent with the notion that motivational factors served to reduce pausing when blackouts separated successive fixed intervals, the data are problematic for the specific mechanism of contrast proposed by Gibbon.

### Evaluation of Stimulus Control Accounts

Another possible explanation of the observed changes in the termination probability with changes in the blackout duration is that the birds were under the control of the food time-marker, the more salient time-marker. It may be that, as the relative proximity of food delivery is increased, the likelihood that the birds will begin to engage in food-directed activities also increases. If the class containing all food-directed activities is not restricted to pecks at the lighted key, then it is possible that food-related activities might commence whether or not the key is lighted when the next scheduled reinforcement is sufficiently proximal. When the terminal, or food-related, period is initiated prior to key-light onset, lighting the response key may serve merely to direct ongoing food-related behavior. Evidence for this would be a correspondence between the termination per opportunity functions from blackout and control conditions. Consistent with this possibility, the blackout and control functions for the fixed-duration conditions corresponded closely over much of the 2-min fixed-interval period. Evidence of control by key-light onset, also was observed during the first tenth of the fixed interval when a 240-sec fixed-duration blackout separated successive fixed intervals. The termination probabilities in the first tenth of the interval for the blackout condition were substantially lower than the termination probabilities in the first tenth of the corresponding control period. When a 60-sec fixed-duration blackout was in effect, the discrepancy between control and blackout termination probabilities during the first tenth of the period was considerably less. If the initiation of key pecking was determined solely by time since the last food delivery, no discrepancy between blackout and control probabilities would be expected. The observed discrepancies suggest that the pigeons may have been under the joint control of the food-to-food period and time since key-light onset. Perhaps the observed effect of key-light onset represents some minimum average time required for the birds to shift from other food-related topographies to the measured key-pecking response. It may be that the initiation of the terminal period was determined solely by the amount of time elapsed since the preceding reinforcer delivery, while the likelihood that the specific terminal response would be key pecking was determined by the amount of time since key-light onset. If this were the case, it would explain the observed correspondence between the blackout and control functions as well as the increasing discrepancy between the control and blackout termination probabilities in the first tenth of the interval as blackout duration was increased. At longer blackout values the birds would be much more liekly to be in the terminal period at the time of key-light onset, and, hence, a constant effect of key-light onset would result in an increasing discrepancy between control and blackout termination probabilities as blackout duration is increased. Thus, the latency data from fixed-duration blackout conditions are consistent with the idea that pigeons were under the control of the food time-marker.

When variable-duration blackouts separated successive fixed intervals, however, the latency data provided much less support for this hypothesis. When control and blackout termination probabilities were compared for these conditions large differences were found during the first tenth of the period when the average blackout duration was 60-sec. The control and blackout functions did not correspond at all when the mean blackout duration was 240 sec. Thus, these findings provide little support for the notion that the pigeons were under the control of the interval between food deliveries when variable-duration blackouts separated successive fixed intervals. In most cases the termination per opportunity functions for blackout conditions more nearly corresponded to those observed when a food-initiated 2-min fixed-interval schedule was in effect, than they did to those observed under control conditions. The absence of a negative correlation between prior blackout duration and subsequent latency duration also argues against the proposal that pigeons always time the interval between food deliveries. If the probability of initiating the terminal period increases with time since food, then the probability of latency termination should be higher after the longer blackouts. Hence, a longer pause would be expected to follow the shorter blackout duration while shorter pauses would be expected to follow the longer blackout durations.

The idea that performance is always controlled by the most salient time-marker also has difficulty accounting for the effect of presenting response-independent food at different times in a 60-sec blackout. Whether the birds were timing the shortest programmed inter-food interval or some average of the inter-food times, then in this condition the probability of latency termination in intervals following blackouts in which no food was delivered should have been at least as high as those observed in the simple 60-sec blackout conditions. As was shown in Figure 6 this was not the case. Thus, the data pose a number of problems for stimulus control accounts which propose that the degree of temporal control exerted by a given event depends solely on its inherent salience.

A number of investigators have shown that the maximum rate of key-pecking depends on the absolute duration of the inter-food interval (Catania & Reynolds, 1968; Groves, 1973; Killeen, 1975, 1978). Higher maximum response rates are associated with short inter-food intervals and lower maximum response rates are associated with long inter-food intervals. Consistent with these findings, the asymptotic rate of response in the present experiment decreased when the duration of a reinforcer-initiated schedule changed from 3 to 6 min both for the fixed-interval and variable-interval control conditions. If control had been by the interval between food deliveries alone in the blackout conditions, the rates from the blackout conditions should have corresponded to those observed during the last 2 min of the inter-reinforcement-interval control conditions. If response rate had increased monotonically with the time since the last food, then the control and blackout response rates should have corresponded over the 2 min prior to reinforcement. The response rate measure, however, revealed control by key-light onset under both the fixed- and variable-duration blackout conditions. Moreover, when response rates from blackout conditions were compared to rates observed in the food-initiated 2-min fixed interval no reliable differences in temporal control were found between the variable- and fixed-duration conditions. As compared to control in food initiated intervals, temporal control was lessened by about the same degree in both the variable-and fixed blackout conditions. Thus, the differential effects of fixed- and variable-duration blackouts revealed in the latency data are not as evident in the response rate data. Although the index of curvature measure revealed a difference between intervals initiated with food and those initiated with the key-light onset for both groups, there were no reliable differences in the index of curvature measure between fixed- and variable-duration blackout conditions. It might be possible to give an account of the response rate data simply in terms of the differential salience of the food and key-light time-markers. Such an account, however, would not explain the clearly different effects of fixed- and variable-duration blackouts seen in the latency data.

Alternatively, if comparisons are made between blackout conditions and their appropriate inter-food interval control conditions, a differential effect of fixed- and variable-blackout durations can be seen. For this comparison, variable-duration blackouts appear to have resulted in larger deviations from control rates than did fixed-duration blackouts, particularly at the shorter blackout value. It is possible, however, that this merely reflects the considerably higher control rates to be expected on variable schedules.

The difference between the 60-sec fixed-duration blackout and control conditions was considerably smaller than the difference between the 240-sec fixed-duration blackout and control conditions. This relationship also holds for a comparison of the 60- and 240-sec variable-duration blackout conditions. These findings suggest that the greater degree of temporal control exerted by the key-light onset in variable conditions was not simply due to the increased variability but was due to the increased average duration of the work period when variable- rather than fixed-duration blackouts separated successive fixed-intervals.

The finding that the pigeons tended to come under the control of the food time-marker when fixed-duration blackouts separated successive fixed-intervals but were more likely to come under the control of key-light onset when variable-duration blackouts were employed is consistent with the idea that performance is sensitive to the different contingencies which follow from control by different time-markers. It may be that pigeons are sensitive to the amount of work time per reinforcer. Timing the interval between food deliveries would result in a longer average terminal period than timing the duration of the key-light period, whether fixed- or variable-duration blackouts separated fixed intervals. It may be, however, that when fixed-duration blackouts separate successive fixed intervals, control by the food time-marker results in a larger net reward value than does control by the non-food time-marker. This account assumes that there is a substantial cost, at least for pigeons, associated with control by a non-food time-marker. Attending to time since a non-food event may occupy a large portion of a pigeon's repertoire, thereby reducing reinforcement from alternative sources. If the likelihood that an event will exert temporal control over subsequent behavior depends upon whether such control results in an enhanced net reward value, then it would be expected that control by key-light onset would be more likely when the blackout periods were variable than when they were fixed in duration. When variable-duration blackouts were used, average work time associated with control by the food time-marker would be greater for equal mean values than if the blackout duration was fixed. The fact that key-light onset exercised much greater control when the blackouts were of variable duration is consistent with the idea that the pigeons were sensitive to this contingency. This view also accounts for the effect of presenting response-independent food during a fixed-duration blackout. Because such food presentations reduced the validity of food as a predictor of time to food, net reward value may have been greater when control was by the key-light onset, the more valid predictor of food.

Thus, whether a given event exerts temporal control may be determined by a balancing of costs. In the present experiment the pigeons may have balanced the cost of attending to a valid but non-salient stimulus dimension against the cost of attending to a more salient but less valid stimulus dimension. This proposal is consistent with the results obtained when human reaction times are differentially rewarded (Snodgrass et al., 1967). The idea is in contrast to the view that the shorter pauses sometimes observed to follow non-food time-markers result from an energizing effect of non-reward, as has been suggested by a number of investigators (Amsel, 1958; Bloomfield, 1969; Gibbon, 1977; and Terrace, 1972). Rather, the decreased pausing may be explained in discriminative terms. Shorter pauses following non-food time-markers may simply reflect an absence of inhibitory discriminative control (Staddon, 1972, 1977). The absence of such control would be due to the fact that control by the food time-marker enhances net reward value. As has also been suggested (Logan, 1960; Rachlin, 1976), rather than being a direct reflection of response strength, the characteristics of performance in a given situation may serve to maximize net reward value.

In conclusion, the observed changes in the probability of terminating the latency period when a period of blackout separated successive fixed intervals appears not to have been the result of the specific mechanism of contrast proposed by Gibbon. Rather, the latency data argue that temporal control was exerted by the food time-marker when fixed-duration blackouts separated successive fixed intervals and by key-light onset when the blackout duration was variable. The mechanism which determined which of the time-markers exerted temporal control could not, therefore, have been the physical salience of a given time-marker. The data are, however, consistent with the possibility that temporal control by a given event depended upon whether such control enhanced net reward value.

# CHAPTER V

## SUMMARY

The present experiment investigated whether stimulus events which make equally good predictions of the time to food result in equal average pause durations. For one group of pigeons a fixed-duration blackout was interpolated after each fixed-interval food delivery and the blackout was varied systematically. It was found that the probability of terminating the pause increased early in the fixed interval as the duration of the blackout was increased. The probability of terminating the latency at different times in the 2-min fixed interval on fixed-duration blackout conditions corresponded to that observed during an equivalent portion of a food-initiated fixed interval equal to the sum of the fixed interval and blackout durations. This finding is consistent with the proposal that initiation of the terminal period was under the control of time since food. The comparisons also revealed some control over key-pecking by the key-light onset, with the degree of such control increasing with blackout duration. A second group of pigeons was used to investigate the effects of making the blackout periods variable in duration. The mean blackout duration was varied systematically. It was found that the probability of pause termination over the 2-min fixed interval differed only slightly from that observed when food initiated each fixed interval. This finding is consistent

with the proposal that the key-light onset exercises a greater degree of temporal control when fixed intervals are separated by blackouts of variable duration. Several mechanisms are discussed as possible explanations for the different pause-producing effectiveness of the key-light onset when fixed and variable duration blackouts separate successive fixed intervals. It was concluded that the extent to which a given event exercises temporal control depends on whether such control enhances the net reward value.

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