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THE EFFECTS OF CS AND CYCLE DURATIONS
ON STIMULUS-ELICITED KEYPECKING
IN THE PIGEON

by

Marilyn Guilkey

A Thesis Submitted to
the Faculty of the Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

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1977

Approved by:

Dr. Richard L. Shull

APPROVAL PAGE

This dissertation has been approved by the following committee of the Faculty of the Graduate School at the University of North Carolina at Greensboro.

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March 24, 1977
Date of Acceptance by Committee

GUILKEY, MARILYN. The Effects of CS and Cycle Durations on Stimulus-Elicited Keypecking in the Pigeon. (1977)
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The relative duration of the CS to the inter-US interval has been found to determine the rate of acquisition and rate of maintained keypecking by pigeons in delay conditioning procedures. Also maintenance of keypecking, but not rate of acquisition, depends upon the absolute CS duration for a given CS/inter-US interval. However, in delay conditioning procedures, delay of US occurrence increases as CS duration increases. In the present study, the effects of CS/cycle ratio and CS duration were examined without the confounding effect of changes in delay of US occurrence by presenting the US at a constant rate during the CS. The CS was superimposed on a VI schedule of reinforcement so that both increases and decreases in the rate of keypecking could be measured.

Response rates during the CS decreased as the CS/cycle ratio increased. Response rates during the not-CS decreased as the CS/cycle ratio increased. Compared to the rate of responding maintained by the VI schedule in isolation, response rates tended to be facilitated during the CS and inhibited during the not-CS. As the cycle duration increased for a given CS/cycle ratio, responding during the CS declined. The effect of cycle duration on response rates during the not-CS was not significant at the CS/cycle ratio studied.

Analysis of responding within successive subintervals of the CS and cycle revealed that response rates tended to increase during the CS when the CS was 30 sec or less in duration and to decrease when the CS was longer than 30 sec. Responding during the not-CS tended to increase during successive subintervals with the rate of increase inversely related to the CS/cycle ratio.

Response rates during both the CS and not-CS were found to be highly correlated with the "contingency ratio," a metric of conditioning which was defined as the ratio of the rate of US occurrence during the CS to the rate of US occurrence during the cycle. However, differences in response rates during the CS as a function of cycle duration could not be accounted for in terms of the contingency ratio or other measures of CS-US contingency.

The changes in temporal patterning of responding as a function CS duration were compared to changes in response rates as a function of component duration that have been reported in the literature on multiple schedules of reinforcement. The suggestion was made that increasing rates of responding during the CS occurred when subjects "anticipated" the offset of the CS.

ACKNOWLEDGEMENTS

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CHAPTER I

INTRODUCTION

In classical conditioning, one stimulus, called the conditioned stimulus (CS), comes to elicit a response that was previously elicited by another stimulus, called the unconditioned stimulus (US). The development of control by the CS is due to its being associated with the US. A problem for theories of conditioning is to specify what is meant by "association" of CS and US. One long-held view is that the critical feature of association is temporal contiguity between the CS and US, so that the amount of conditioning to the CS should depend simply on the number of CS-US pairings or the probability of the US being presented given the CS. Recently, however, Prokasy (1965), Rescorla (1967; 1969) and others (Baum, 1973; Wagner, 1969) have argued that contiguity between stimuli may not be as basic a factor as the degree to which the occurrence of the US is predicted by the occurrence of the CS. According to this view, the amount of conditioning that occurs to the CS should depend not only on the probability of the US given the CS but also on the probability of the US given the absence of the CS (that is, given the not-CS). Rescorla (1969) and others have shown that the conditioning potency of the CS can be reduced by increasing the probability of the US, given the not-CS, even though the probability of the

US, given the CS, remains constant. In the limiting case, presenting the US independently of the CS eliminates the contingency between the CS and US since the occurrence of the CS would predict US occurrence no better than would the absence of the CS.

This conception of conditioning suggests that CS-US association must be defined in terms of the relative probability of US occurrence to the CS and not-CS. In terms of contiguity, "excitatory" conditioning procedures are those in which the US reliably follows the CS and "inhibitory" procedures are those in which the US is not presented following the CS. According to contingency theory, in contrast, these procedures represent the ends of a continuum of excitatory and inhibitory conditioning procedures. The more general description of an excitatory procedure would be one in which the probability of US occurrence is greater given the CS than the not-CS. Analagously, an inhibitory conditioning procedure is one in which the conditional probability of US occurrence is lower given the CS than the not-CS.

Considerable experimental evidence (Rescorla, 1969; Rescorla and Wagner, 1972) supports the idea that the amount of conditioning to a CS is a function of the relative probability that the US will occur during the various stimuli. In addition to the probability manipulations, there is considerable evidence that temporal factors, such as the time between CS onset and the US and the duration of the CS relative to the duration of the not-CS, play an important role. The concern of the present paper is with the question of whether these temporal factors can be understood within the contingency framework or whether they require additional principles.

A number of recent studies have investigated the effects of the CS-US interval and the relative duration of the CS using a sign-tracking preparation. The procedure used in these studies is similar to Pavlovian delay conditioning, in which the CS is presented for a brief period and is followed immediately by the US. Each CS-US presentation is separated by a period of time called the intertrial interval. In the sign-tracking adaptation of this procedure, food-deprived pigeons are subjects, the CS is the illumination of a plastic disk (or "key") and the US is the brief presentation of grain. This procedure has been found to reliably elicit keypecking when the CS is always followed by the US (Brown and Jenkins, 1968), when the probability of US occurrence is less than 1.0 (Perkins, Beavers, Hancock, Hemmendinger, Hemmendinger, and Ricci, 1975) and even when grain presentations occur during both the CS and not-CS (<u>i.e.</u>, during the "intertrial interval"), as long as the probability of US occurrence is greater during the CS than during the not-CS (Gamzu and Williams, 1971).

In a study by Terrace, Gibbon, Farrell, and Baldock (1975), the CS duration remained constant while the not-CS duration (or intertrial interval) was varied for different groups of subjects. The rate of acquisition of keypecking was directly related to the cycle duration of the not-CS. At first glance, this outcome might appear inconsistent with contingency theory, since neither the probability of US occurrence during the CS (1.0) or during the not-CS (0) changed as a function of the not-CS duration. However, it is possible to conceptualize these temporal manipulations in a way that makes these data actually consistent with contingency theory.

First, although the US was always presented following the CS, it occurred following some delay for each particular subinterval within the CS. The average of these delays is equal to half the CS duration. Thus, the CS can be conceptualized as being associated with a certain average delay of US occurrence. Also, each subinterval within the entire inter-US interval (the time between US presentations)--not only the CS--can be regarded as being followed by the US with a given delay, the average of which is half the inter-US interval. Increasing the inter-US duration increases this average delay, which can be thought of as analagous to a measure of the probability of US occurrence irrespective of which stimulus (CS or not-CS) is in effect. Taking the ratio of the average delay of US occurrence given the CS to the overall average delay of US occurrence provides a measure of the _relative_ average delay of US occurrence given the CS. This measure of CS-US contingency, which reduces to the ratio of the CS to inter-US durations, is analagous to the relative probability of US occurrence in that it is an index of the "information" about US proximity provided by the CS. As the CS/inter-US ratio decreases, the relative proximity of the CS to the US increases.

Hence, the CS is more "informative" concerning US occurrence.

In the Terrace et al (1975) study, this ratio decreased as the not-CS increased and therefore the amount of conditioning should have increased. This was reflected in the faster acquisition of keypecking with longer not-CS durations, an outcome that is consistent with this conceptualization of the CS-US contingency.

A similar analysis can be applied to the results of two studies in which both the CS and inter-US interval were varied. In the first study, Groves (1974) varied the ratio of the CS duration to the inter-US or "cycle" duration. For each cycle duration (ranging from 30 to 300 sec) the ratio of the CS to cycle durations was varied. Increasing the CS/cycle ratio for a constant cycle duration resulted in a reduction in the rate of acquisition of keypecking as well as in maintained rates of keypecking. As the CS duration increased, the average delay of US occurrence associated with the CS increased while the overall average delay remained constant for a given cycle duration. Therefore, the relative delay of US occurrence during the CS increased as the CS/cycle ratio increased. In the limiting case, when the CS is equal to the cycle, the relative delay of US occurrence during the CS equals that of the cycle. In this case, no conditioning of keypecking to the CS would be expected, because the CS is not more uniquely associated with, or predictive of, US occurrence than any other stimulus present during the cycle.

Gibbon, Baldock, Locurto, Gold, and Terrace (1977) also found that the relative duration of the CS had a profound effect on both the rate of acquisition of keypecking and maintained rates of keypecking. They varied both absolute inter-US intervals and the CS/not-CS ratio over a wider range of CS and inter-US intervals than did Groves (1974). Figure 1 shows mean number of CS-US presentations (trials) for different groups of subjects to begin keypecking. (The acquisition criterion was the occurrence of a keypeck during three of four consecutive CS presentations.) Gibbon et al (1977) described the function relating number of trials to acquisition of keypecking to the CS/not-CS ratio as a power function with a negative exponent. A power function also appears to describe reasonably well the relationship between the acquisition of pecking and the CS/inter-US interval shown in Figure 1.

The CS/inter-US ratio was clearly an important parameter in conditioning keypecking. In Figure 1, the points corresponding to a particular CS/inter-US ratio were composed of different absolute CS and inter-US intervals. There appears to be systematic effect of CS duration (indicated by the numbers at each co-ordinate) on the number of trials to acquisition. In contrast, Groves (1974) reported that acquisition of keypecking was slower at longer than at shorter inter-US durations. There are several possible reasons for the discrepancy. For example, Groves used a larger range of CS/cycle ratios which also included higher ratios (0.20 to 0.80) than Gibbon et al (1967)

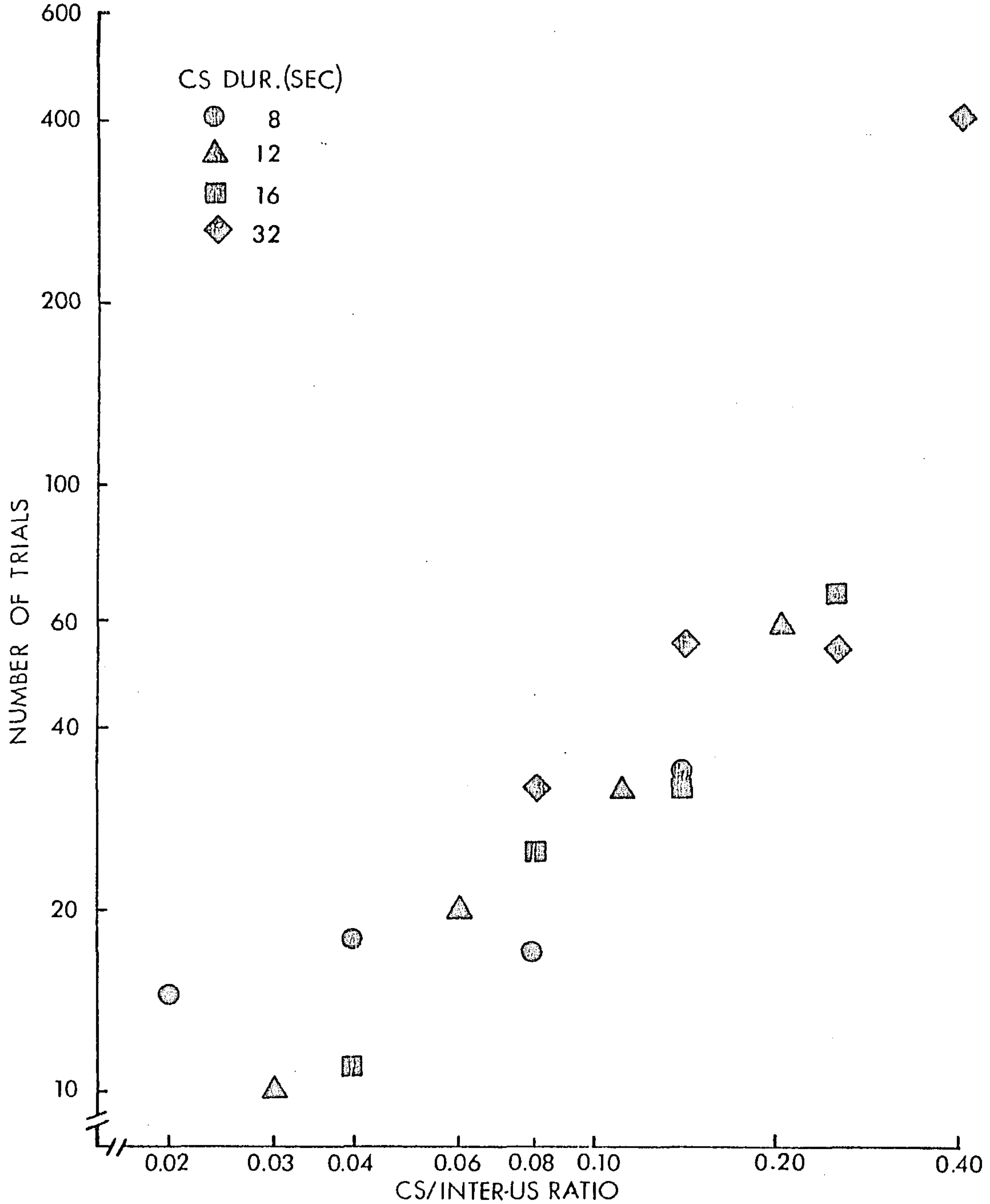

Figure 1. Median number of trials to acquisition of key-pecking as a function of CS/inter-US ratio (From Gibbon <u>et al</u>, 1977).

and so parametric differences might have been responsible for the difference in the results. Also, measures of acquisition differed between the two studies. Groves' conclusions were based on two measures which covaried: the rate of keypecking during the CS on 500 conditioning trials and the number of trials to the first response weighted by CS duration. The rationale for the weighting was that it corrected for the "opportunity" to respond during the CS. Longer CS durations offer the pigeon more time to respond on a given trial. Figure 2 shows the effect of weighting by CS duration on the acquisition data of Gibbon _et al_ (1977) shown in Figure 1. The correction for opportunity to respond clearly reveals an effect of absolute CS duration: for a given CS/cycle ratio, number of trials to acquisition was directly related to CS duration. Clearly, there is no discrepancy in the results of the two studies if comparable measures are used. While it is clear, however, that the opportunity to respond may be an important factor in comparisons between different absolute CS durations, it may also be the case that weighting by CS duration biases the data too heavily against very long CS durations. For example, for a CS duration of 100 sec to be equal to a CS duration of 10 sec on this measure, the _number_ of trials to acquisition for the 100 sec CS would have to be less by a factor of 10!

The question of whether or not absolute CS or inter-US duration affects acquisition of keypecking seems to depend upon the measure of acquisition used, and, possibly, on the range of CS/inter-US ratios. On the whole, the weight of evidence suggests

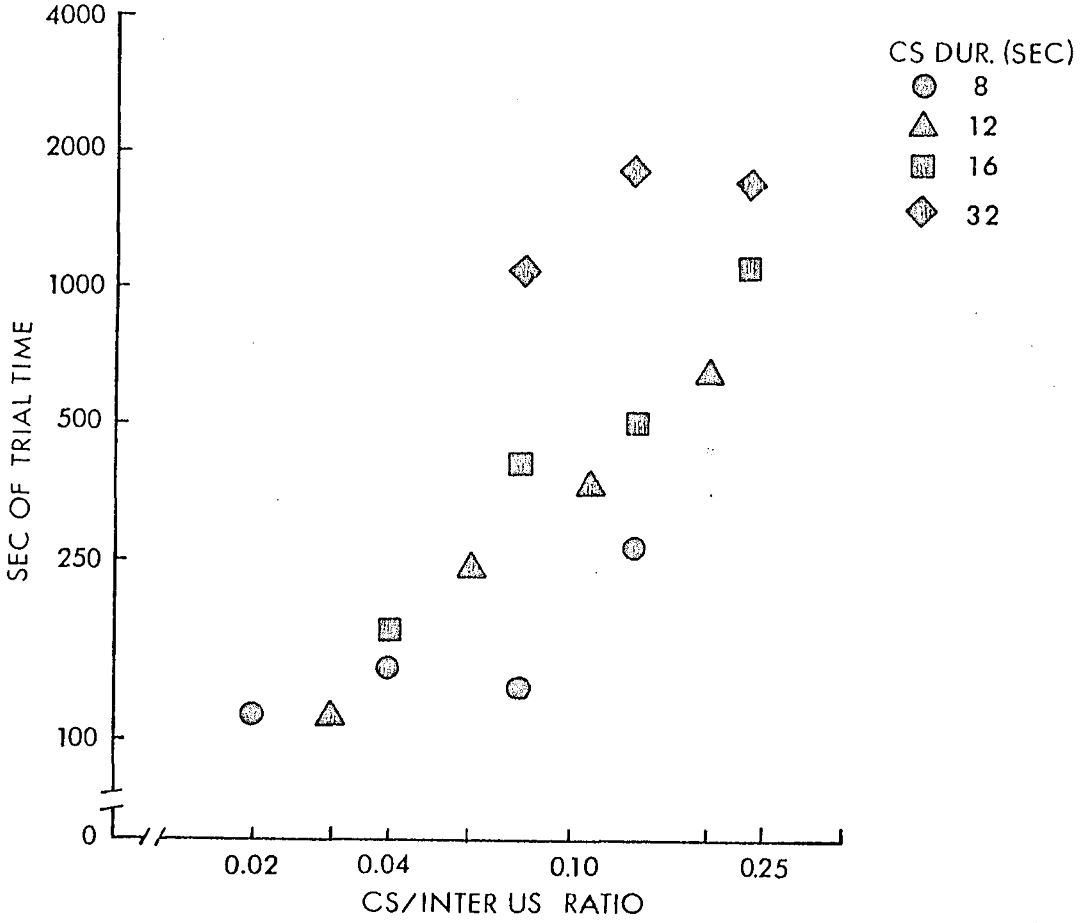

Figure 2. Median accumulated sec of trial time to acquisition of keypecking as a function of CS/inter-US Ratio and inter-US duration. (From Gibbon _et al_, 1977.)

that if there is an effect of absolute inter-US duration, it is not readily evident in the number of trials to acquisition. If the critical temporal variable is the CS/inter-US ratio, as was proposed earlier, such an outcome is quite consistent with the contingency analysis expressed in terms of relative delay. Clearly, an 8 sec CS within a 32 cycle inter-US interval has the same relative proximity to the US as a 16 sec CS within a 64 sec inter-US interval, and so the conditioning effects should be the same, if the relative delay, not the absolute delay, is critical.

Although the results of acquisition of keypecking suggest an invariance with respect to inter-US duration, those on maintained rates of responding do not. Figure 3 shows mean rates of responding as a function of CS/cycle ratio for four different cycle durations (from Groves, 1974). Little responding was maintained at the highest ratio for any inter-US interval. The important point, however, is that at more favorable ratios, increasing the inter-US interval resulted in a reduction in the rate of responding.

A similar trend appears in the data reported by Gibbon et al (1977). Although there was considerable variability, response rates during the CS decreased as the inter-US interval (and absolute CS duration) increased. Increasing the inter-US interval for a given CS duration results in a reduction in the CS/inter-US ratio. If maintained response rates were independent of absolute CS duration, they should have increased as the CS/cycle ratio decreased. However, that was not always the case.

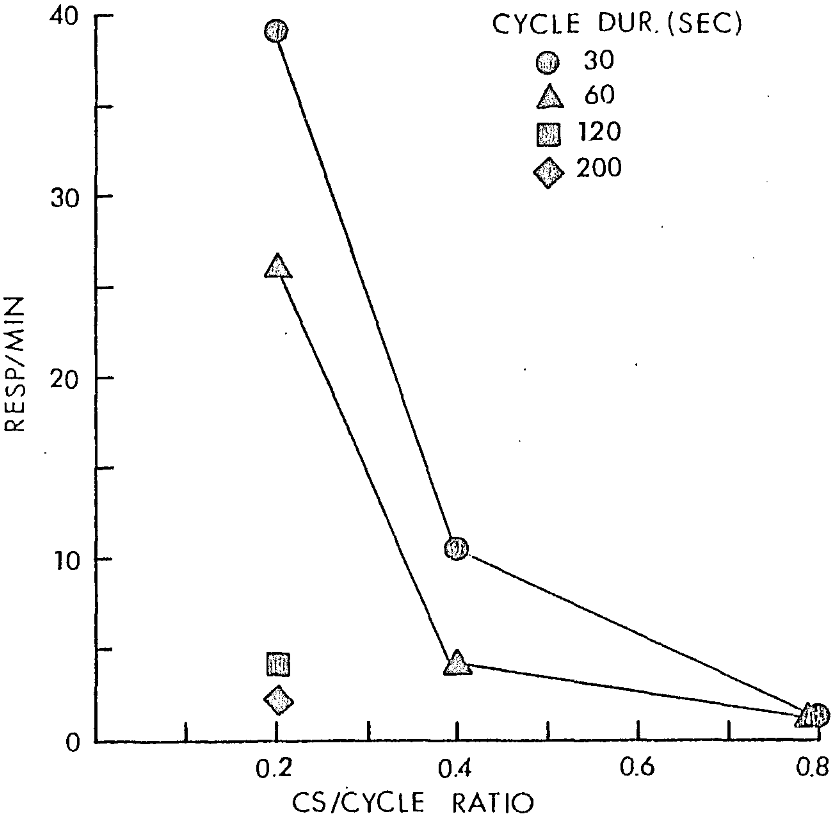

Figure 3. Mean rates of responding during the last three days of each condition as a function of CS/cycle ratio and US/cycle duration. (From Groves, 1974.)

For example, when the CS duration was 16 sec increasing the cycle duration from 112 to 208 sec resulted in higher rates of responding due to the smaller CS/cycle ratio, but increasing the cycle duration to 400 sec resulted in a decrease in the rate of responding during the CS. Obviously, the effect of the CS/cycle ratio on a given CS duration was not independent of the absolute inter-US interval.

With respect to maintained rates of keypecking, relative proximity to reinforcement is not sufficient to account for the differences in maintained rates of responding. Groves (1974) interpreted the decrease in responding as a function of cycle duration as an effect of a decrease in the overall level of US "anticipation" or "expectancy". If the overall expectancy of US occurrence is low, she suggested, the CS will be ineffective in eliciting keypecking even if the ratio of the CS to cycle is otherwise favorable. Infrequent US occurrence may have the effect of simply lowering the "value" of US-related activities, such as pecking in comparison to the other activities available during the experimental session, such as roosting or grooming. Thus, pecking during the CS may decline as a result of competition from other activities. Another explanation for a decrease in responding, suggested by Gibbon _et al_ (1977), is that when the cycle duration is long, the subject may not be attending when the CS is presented. Functionally, this would result in an increasing correlation of the not-CS to the US since US occurrence will be associated with the not-CS if the CS is not noticed.

Another factor that may affect responding during the CS as a function of CS duration is that once responding occurs to the CS it may be maintained, in part, by response-US contiguity. That is, responding during the CS will be followed by the US after some average delay. This delay will be, on the average, longer for a longer CS and this factor may tend to reduce response rates at longer CS durations. This possibility was discussed and rejected by Groves (1974) as an important factor in determining the rate of responding to the CS. She pointed out that a CS of a given duration maintained different rates of keypecking depending upon the CS/cycle ratio, an outcome inconsistent with a differential response-US contiguity account. However, one could argue that delay of reinforcement interacts with the CS/cycle ratio to modulate the rate of responding during the CS.

It seems clear from this review that, while rate of acquisition of keypecking is primarily a function of the relative duration of the CS, relative and absolute values of the CS duration interact to determine the maintained rate of keypecking during the CS. Since in a delay conditioning procedure absolute CS duration cannot be varied without also varying either the CS/inter-US ratio (while keeping the inter-US interval constant) or the inter-US interval (while keeping the CS/inter-US ratio constant), the relative contribution of these two factors cannot be assessed using the delay conditioning procedure. In addition, it is possible that there is some effect of absolute CS duration that is not due to the delay of US occurrence during the CS or the degree of CS-US contingency.

In the present study, a different sign-tracking paradigm was employed to separate the effects of relative and absolute CS duration on maintenance of stimulus-elicited keypecking. To eliminate the confounding between CS duration and delay of US occurrence, a constant probability variable time (VT) schedule (Catania and Reynolds, 1968) was used to schedule grain presentations <u>during</u> the CS. The VT schedule provided a constant rate (or average delay) of US occurrence during the CS and, in addition, insured that the occurrence of the US was random with respect to the time since the previous US occurrence.

The effects of both the CS/cycle ratio and absolute CS duration were studied. (Note that in this context "cycle" duration refers to the sum of the CS and not-CS durations and not to the inter-US interval.) During the CS/cycle ratio manipulations, the average delay of US occurrence remained constant as a function of CS duration. However, in contrast to delay conditioning procedures, the overall rate of US occurrence during the cycle increased as a function of increasing CS/cycle ratio, because increasing CS duration within a fixed cycle resulted in an increase in the <u>number</u> of US presentations during the cycle. The significance of this confounding will be discussed later. Absolute cycle duration was studied by increasing CS and cycle durations proportionately, thus maintaining a constant CS/cycle ratio. The advantage of this procedure compared to the delay conditioning procedure is that the overall rate of US occurrence during both the CS and cycle remained constant for a given CS/cycle ratio. That is, this procedure allowed CS duration to be manipulated while both CS-US contingency and overall rate of US occurrence during the cycle remained constant.

The design of the experiment also reflected a desire to take two other factors into account. First, in previous work on stimulus-elicited keypecking this author noted a tendency towards a great deal of variability in the topography of the elicited response. Although pecking was the most frequent response elicited by the CS, pecking was not necessarily directed at the key during CS presentations and was not, consequently, recorded as "keypecking". Sometimes pecks were directed at some other feature on the chamber wall containing the key or near the feeder aperture and (very frequently) pecks were directed <u>at</u> the key but stopped short of actual <u>contact</u> with the key or were made with insufficient force to operate the microswitch. Even when a high rate of recorded keypecks occurred early in training, by the end of the condition response rates were low due to these changes in the topography of the keypeck or the intrusion of other "food anticipatory" behaviors.

To encourage the maintenance of keypecking as the dominant response, subjects were first trained on an operant (response-contingent) baseline schedule. This was a VI schedule which provided grain presentation for a keypeck at varying intervals. The CS with its associated, but not response-contingent schedule, was then superimposed upon the baseline schedule. The VI schedule remained in effect during both the CS and not-CS so that during the CS both response-contingent and non-response contingent grain presentations occurred. The hope was that the response contingent schedule in effect throughout the cycle would serve to direct stimulus-elicited pecking toward the key. It was not entirely successful. Note that this procedure-superimposing a stimulus paired with "free reinforcement" upon an operant baseline-is similar to procedures used to study "positive conditioned suppression (see Mackintosh, 1974, pp 225-227; Trapold and Overmier, 1972 for a review).

The addition of the baseline schedule permitted a study of the inhibitory effects upon responding during the not-CS. Responding during the not-CS which was maintained by the baseline schedule was expected to be inhibited because the not-CS was associated with a lower probability of US-occurrence than its absence, that is, the CS. The question was how would the CS/cycle ratio affect the degree of response inhibition during the not-CS and would this be independent of the absolute cycle duration?

During the CS some grain presentations were contingent upon the occurrence of a response while others were not. The overall rate of keypecking during the CS was expected to reflect the operation of both CS-US and response-reinforcer contingencies. The former were expected to be excitatory, the latter, inhibitory. That is, while the CS was expected to elicit keypecking due to its relationship with the US, the absence of a response-reinforcer dependency for these grain presentations might be expected to weaken the control of responding by the VI reinforcers. While the CS-US contingency varied as a function of CS/cycle ratio, in all cases the ratio of CS-contingent and response-contingent grain presentations remained the same during the CS. Thus, the interaction between them was expected to be independent of the experimental manipulations.

A further consideration of the present study was to determine whether or not there were systematic changes in the rate of keypecking at different times during the CS, and, if there were, whether or not these changes were related to either absolute or relative CS duration. Ricci (1973) reported that rates of responding tended to increase in successive subintervals of the CS when these intervals were differentially cued by changing the illumination of the key. Gibbon *et al* (1977) recorded responses in successive fifths of the CS and found that, in many cases, response rates tended to increase as a function of time since CS onset at short CS durations and to decrease at long CS durations. Since long CS durations were usually associated with larger CS/cycle ratios, it was not clear whether or not this patterning was due to absolute CS duration *per se* or to some interaction between CS/cycle ratio and CS duration.

Of course, analysis of temporal patterns of keypecking during the CS in delay conditioning is complicated by the fact that time since CS onset is confounded with an increasing proximity to the US occurrence. If the subjects were timing the duration of the CS, responding might be expected to increase as a function of increasing proximity to the US. On the other hand, a decrease in keypecking as the proximity increases might be the result of the occurrence of behaviors such as "hopper tending" competing with keypecking. In the present experiment, this confounding was avoided since the probability of US occurrence did not vary as a function of time since CS onset. Response rates during the not-CS were also examined as a function of time since CS offset.

More detailed information of how responses are distributed within the CS and not-CS may be important for understanding the relationship between CS-US contingencies and responding, especially in situations in which there are both CS-US contingencies for the same response, such as keypecking. Rachlin (1973) has suggested that CS-US contingencies elicit pecking in pigeons primarily at the onset of an excitatory CS, or, in other words, at the transition from a lower to a higher rate of US occurrence. Similarly, pecks are assumed to be inhibited at the transition from a stimulus correlated with a higher rate of US occurrence to a stimulus correlated with a lower rate of US occurrence.

Green and Rachlin (1975) have presented some data to support Rachlin's argument. A multiple schedule in which two schedules of reinforcement were alternated, each schedule correlated with a different extereoceptive stimulus, was the basic schedule used. One component of the multiple consisted of a VI schedule alone; the schedule in the other component consisted of the same VI schedule with a non-response contingent VT schedule also in effect. The absolute duration of each component was varied among conditions with the provision that each component was in effect for half the time. As the component durations increased, the rate of responding in the component with the superimposed VT schedule decreased. This result would be expected if response rates were highest at the beginning of the component and decreased later in the interval. A short duration component would, therefore, consist mostly of high rate "transition" responding, while in a longer component, this high rate of responding would be averaged in with the lower "post-transition" rate of responding. Thus, the average rate of responding would be higher in the short component. An analysis of rates of responding as a function of time since CS onset revealed that, in fact, keypecking decreased as a function of time since the beginning of the component.

These results seem to be inconsistent with an analysis of stimulus-elicited keypecking in terms of CS-US contingencies since relative rates of reinforcement did not vary as a function of component duration. These data suggest that some additional factor such as "rate of transition" or rate of stimulus changes must be considered in addition to CS-US and response-reinforcer contingencies in order to relate behavior to regularities in the animal's environment.

To summarize, the effect of the relative and absolute duration of a stimulus associated with non-response contingent grain presentation was studied. The primary concern was how these manipulations would affect the rate of keypecking maintained by a baseline response-contingent schedule of grain presentation and with relating changes in response rate to differences in the CS-US contingency. Particular attention was given to the effect of these contingencies upon the distribution or temporal patterning of responding during the CS and not-CS.

CHAPTER II

METHOD

Subjects

Twelve adult White Carneaux pigeons with brief experimental histories on trace autoshaping procedures served as subjects. During the experiment, they were maintained at 80 ± 6% of their free-feeding body weights.

Apparatus

A standard pigeon chamber with a front wall measuring 36 x 36 cm and containing three 1.8 cm (diameter) translucent Gerbrands response keys and an opening for a mixed grain feeder (Lehigh Valley Electronics) was used. Only the center key was used in the present experiment. This key was mounted 25.5 cm from the floor of the chamber and was centered above the feeder opening. The key was set to operate with a minimum force of 0.10 N; a relay mounted behind the panel provided a feedback click for each effective keypeck. A houselight, located in the ceiling of the chamber and centered above the center key, provided general illumination during the experimental session. Both the keylight and houselight were turned off and a lamp within the feeder opening was illuminated during the operation of the feeder which was always 3 sec in duration. A speaker in the ceiling of the chamber provided white noise; a fan provided ventilation.

Procedure

General. The CS was associated with a constant probability (Catania & Reynolds, 1968) VT 0.5-min schedule of grain presentations, and was superimposed on the baseline constant probability VI 6-min schedule of (response-contingent) grain presentations. The CS and not-CS were cued by different key colors. A cycle consisted of one presentation of the CS and not-CS. CS and not-CS presentations were strictly alternated; each session began with the not-CS and ended with the CS. Sessions were 40 min in duration, except where noted otherwise, and were conducted daily with few exceptions, and unless days off were needed to control birds' body weights.

Initial training. It was necessary to re-hopper train and re-shape subjects to keypeck. A combination of hand-shaping and autoshaping was used. Then, over a period of about two weeks, each bird was trained on a series of increasingly "leaner" VI schedules of reinforcement (VI 30-sec, VI 1-min, VI 2-min), terminating with the baseline VI 6-min schedule. This schedule consisted of 15 intervals from 24 sec to 1195 sec arranged in random order and punched on a continuous loop of 16 mm film tape. Each reinforcer scheduled by the tape remained available until a response occurred. All subjects were studied on the VI 6-min schedule until response rates appeared to reach asymptote, which took from 25 to 30 sessions. The key was illuminated amber during this period.

CS/cycle manipulations. Two groups of four subjects were studied on the CS/cycle ratio manipulations. Four ratios were selected: 0.125, 0.25, 0.50 and 0.75. One group was studied with a cycle duration of 60 sec and other with 480 sec. Trial durations for the 60 sec cycle were 7.5 sec, 15 sec, 30 sec, and 45 sec. Trial durations for the 480 sec cycle were 60 sec, 120 sec, 240 sec and 360 sec. Two subjects in each group were studied in an ascending sequence of CS/cycle ratios and two in a descending sequence.

Cycle manipulations. The cycle duration rather than the CS/cycle ratio was varied for the remaining four subjects. The CS/cycle ratio remained constant at 0.125 while four cycle durations were studied: 60 sec (7.5 sec CS), 120 sec (15 sec CS), 240 sec (30 sec CS), 480 sec (60 sec CS). Two subjects were studied on an increasing sequence of cycle durations and two on a decreasing sequence.

Sequence of conditions. The sequence of conditions and the number of sessions each condition was conducted for each subject are shown in Table 1. Two complete sequences of CS/cycle ratios or cycle durations were studied for each bird. During the first replication, the CS was green illumination of the key and the not-CS was amber illumination. For the second replication these colors were reversed: the CS became amber and the not-CS, green. The VT schedule that was in effect during the CS consisted of 15 intervals from 2 sec to 100 sec, arranged in random order and punched on a continuous loop of film tape. The grain presentations scheduled by the

TABLE 1

Order of Conditions and Number of Sessions for Each Subject

GROUP 1: 60 SEC CYCLE

Schedule	CS-cycle durations	CS-cycle ratio	Order	Sessions		Order	Sessions	
				Subj. P-133	Subj. P-31		Subj. P-22	Subj. P-144
VI 6-min (bas.)[a]		---------	1	20	25	1	25	25
+VT 0.5-min	7.5-60	0.125	2	15	15	5	15	15
	15-60	0.25	3	18	18	4	15	15
	30-60	0.50	4	15	15	3	18	18
	45-60	0.75	5	15	15	2	15	15
VI 6-min (bas.)[b]		---------	10	20	20	10	15	21
+VT 0.5-min	7.5-60	0.125	6	20	20	9	10	10
	15-60	0.25	7	10	10	8	10	10
	30-60	0.50	8	10	10	7	10	10
	45-60	0.75	9	10	10	6	20	20
	60-60[c]	1.00	11	20	20	11	20	20
+VI 0.5-min	7.5-60	0.125	13	16	15	--	--	--
	45-60	0.75	--	--	--	13	15	15
+VT 0.5-min	60-480	0.125	12	22	20	12	23	21

TABLE 1 (Continued)

GROUP 2: 480 SEC CYCLE								
Schedule	CS-cycle durations	CS-cycle ratio	Order	Sessions		Order	Sessions	
				Subj. P-143	Subj. P-32		Subj. P-51	Subj. P-52
VI 6-min (bas.)[a]		---------	1	25	29	1	29	25
+VT 0.5-min	60-480	0.125	2	15	15	5	29	25
+VT 0.5-min	120-480	0.25	3	18	18	4	15	13
	240-480	0.50	4	15	15	3	18	18
	360-480	0.75	5	15	15	2	15	15
VI 6-min (bas.)[b]		---------	10	20	20	10	20	21
+VT 0.5-min	60-480	0.125	6	20	20	9	10	10
	120-480	0.25	7	10	12	8	10	10
	240-480	0.50	8	10	10	7	10	10
	360-480	0.75	9	10	10	6	20	20
	480-480[c]	1.00	11	21	20	11	20	21
+VI 0.5-min	60-480	0.125	13	17	17	--	--	--
	360-480	0.75	--	--	--	13	15	22
+VT 0.5-min	7.5-60	0.125	12	20	20	12	24	20

TABLE 1 (Continued)

GROUP 3: CONSTANT RATIO

Schedule	CS-cycle durations	CS-cycle ratio	Order	Sessions Subj. P-114	Sessions Subj. P-83	Order	Sessions Subj. P-73	Sessions Subj. P-74
VI 6-min (bas.)[a]		---------	1	25	25	1	27	26
+VT 0.5-min	7.5-60	0.125	2	15	15	5	15	15
	15-120	0.125	3	15	15	4	15	15
	30-240	0.125	4	16	15	3	15	15
	60-480	0.125	5	15	15	2	15	15
VI 6-min (bas.)[b]		---------	10	20	20	10	21	22
+VT 0.5-min	7.5-60	0.125	6	20	20	9	10	10
+VT 0.5-min	15-120	0.125	7	10	10	8	10	10
	30-240	0.125	8	10	10	7	10	10
	60-480	0.125	9	10	10	6	20	20
	60-60[c]	1.00	11	20	20	--	--	--
	480-480[c]	1.00	--	--	--	11	20	21
Random control[d]	7.5-60	0.125	12	21	22	--	--	--
	60-480	0.125	--	--	--	12	20	21

Note: Stimulus-change-only conditions are not included. See text for details

[a] Key colors: CS--green; not-CS--amber

[b] Key colors: CS--amber; not-CS--green

[c] On this condition, sessions were 20 min in duration

[d] See text for details of this procedure

tape during the CS were delivered independently of the bird's behavior.

During the first sequence of CS/cycle ratio or cycle duration conditions, each condition in which the CS and its correlated VT schedule were in effect was preceded by five and followed by ten or fifteen sessions in which the sequence of key color changes was the same as that CS/cycle ratio, but in which the VT schedule was not in effect. The purpose of this procedure was to determine the effect of alternating the key colors on responding maintained by the baseline schedule. That is, this procedure was a control for the "non-associative" effect of stimulus change.

The initial effect of the introduction of the green CS-to-be was considerable disruption of responding during its presentation. However, in later conditions when the green key was presented at the appropriate CS/cycle ratio or cycle duration, response rates tended to be elevated with respect to the baseline. This effect seemed to be an after-effect of the CS-US presentations, because it became more pronounced later in the sequence of conditions. Due to this difficulty, the stimulus-change-only conditions were not included in the second sequence of CS/cycle ratios of cycle durations.

Additional conditions. All subjects were studied on two conditions. The first was a recovery of the VI 6-min baseline in which the key was illuminated green throughout the session. In the second condition, the VT schedule was in effect throughout the session superimposed on the VI 6-min session. This condition was equivalent to a CS/cycle ratio of 1.00, *i.e.* where the CS is in effect throughout the cycle.

The two groups of subjects in which the CS/cycle ratio was manipulated were also studied at the 0.125 CS/cycle ratio on the alternative cycle duration. That is, the subjects originally studied on the 60 sec cycle were switched to the 480 cycle and *vice versa*. This condition simply provided additional within-subjects comparisons of the effect of cycle duration. In a final condition for these two groups of subjects their original cycle duration was employed but all grain presentations during the CS were response-contingent. That is, the VT schedule during the CS was changed to a VI schedule. Two birds on each cycle duration were studied with the 0.125 CS/cycle ratio and two with the 0.75 CS/cycle ratio.

The final condition for the four birds studied on the cycle duration manipulations was an adaptation of the "truly random control" suggested by Rescorla (1967) as the proper control procedure for evaluating the effects of the CS-US contingency. In this condition, the sequence of CS and not-CS key color changes was appropriate for the 60 sec cycle for two birds and for the 480 sec cycle for the other two. However, the VT schedule of grain presentations, usually in effect only during the CS, was in effect throughout the cycle. Since the rate of grain presentation was the same during the CS and not-CS, no conditioning should occur to the CS. This condition can be considered a control for the effects of stimulus change and non-response contingent grain presentation on responding maintained by the VI 6 min schedule.

Data collection. Responses during the CS and cycle, total elapsed CS and cycle time, accumulated latency to the first response on each CS presentation, and the number of CS presentations with a response were recorded during each session.

Both the cycle and CS durations were programmed by timers which divided the interval into eight equal subintervals or "bins." Responses were accumulated in each bin so that response rates as a function time since CS onset and offset could be calculated.

CHAPTER III

RESULTS

The response rates discussed in this section were means of the last five days of each experimental condition. These rates were calculated for each bird by summing responses during the CS or not-CS for those sessions and dividing by the total accumulated time the CS or not-CS was in effect.

Effects of Varying the CS/Cycle Ratio

Figure 4 shows response rates for individual subjects during the CS and not-CS as a function of the CS/cycle ratio. The four subjects in the upper panel were studied with a cycle duration of 60 sec; those in the lower panel with a cycle duration of 480 sec. Although there was considerable inter-subject variability in response rates, both CS and not-CS response rates tended to decrease as the CS/cycle ratio increased. It is also evident that, for the most part, differences between the CS and not-CS response rates were larger when the cycle duration was 60 sec than when it was 480 sec. With respect to the VI 60min baseline schedule, indicated by the horizontal lines, responding during the CS was facilitated except at the 0.75 and 1.00 ratios. Responding during the not-CS was facilitated except at the 0.75 and 1.00 ratios. Responding during the not-CS tended to be inhibited compared to the baseline at all ratio values when the cycle duration was 60 sec, but only at larger CS/cycle ratios when the cycle duration was 480 sec.

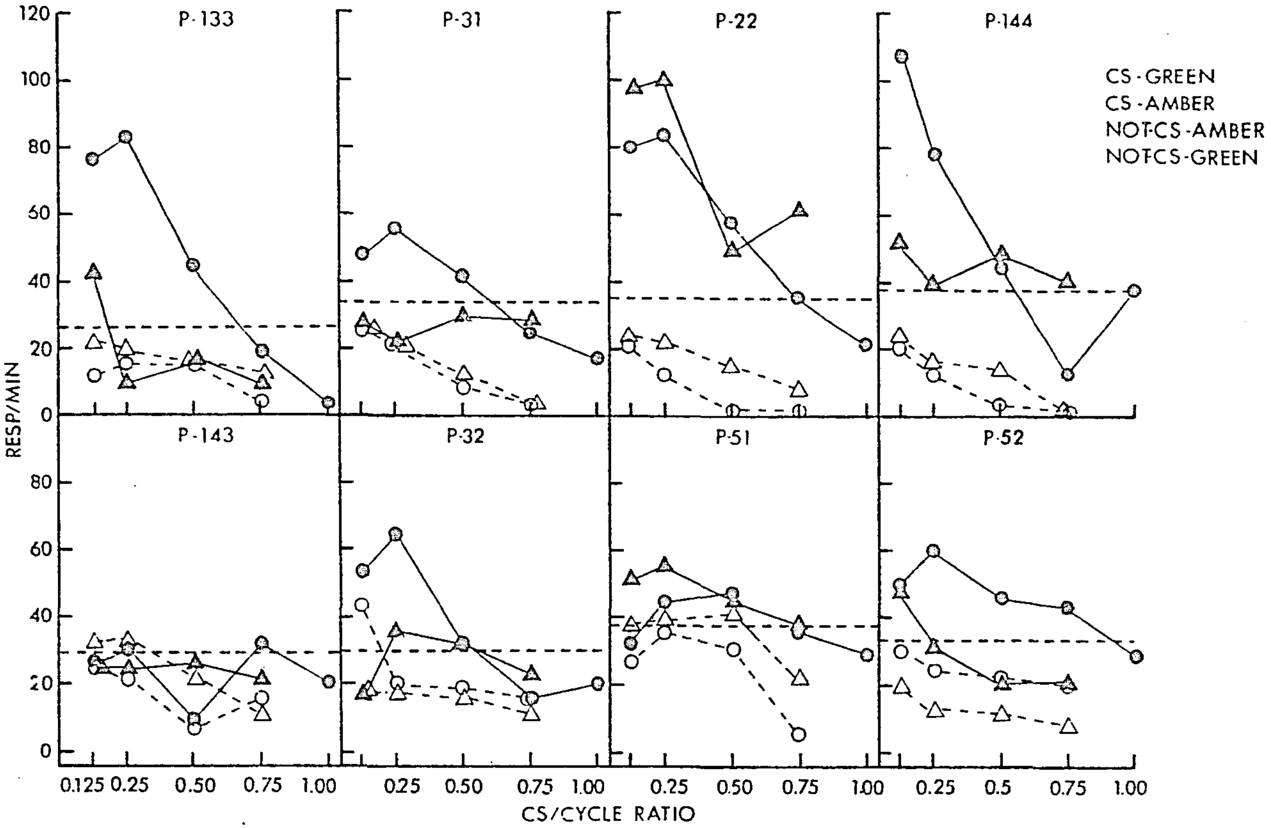

Figure 4. Responses per minute for each subject during the CS and not-CS as a function of CS/cycle ratio. Upper panel: subjects studied with 60-sec cycle. Lower panel: subjects studied with 480-sec cycle. (Horizontal lines indicate mean baseline rates of responding.)

Response rates from Figure 4, averaged across subjects and replications were plotted as a function of CS/cycle ratio and cycle duration in Figure 5. Relationships between CS/cycle ratio are more obvious in this figure: for both cycle durations, CS and not-CS response rates decreased as a function of CS/cycle ratio. However, overall, CS response rates were higher and not-CS response rates were lower when the cycle duration was 60 sec. Figure 5 also shows that there is an interaction between stimulus conditions (CS *vs.* not-CS), CS/cycle ratio, and cycle duration. Differences between CS response rates as a function of cycle duration decreased as the CS/cycle ratio increased. As the proportion of the cycle occupied by the CS approached 1.00, response rates for different cycle durations might be expected to converge since these response rates should be equal when the CS is in effect throughout the session. Actual differences in responding as a function of cycle duration during the CS/cycle ratio of 1.00 were negligible. Similarly, differences between not-CS response rates as a function of cycle duration might have decreased as the CS/cycle ratio approached zero, the condition in which there is no CS. However, in Figure 5, not-CS response rate functions are fairly parallel, suggesting that there was no interaction between cycle durations for the CS/cycle ratios used.

Because of the large inter-subject variability in response rates, there was some question as to whether the mean response rates shown in Figure 5 were representative. Accordingly, a four-way analysis of variance (stimulus x cycle x ratio x

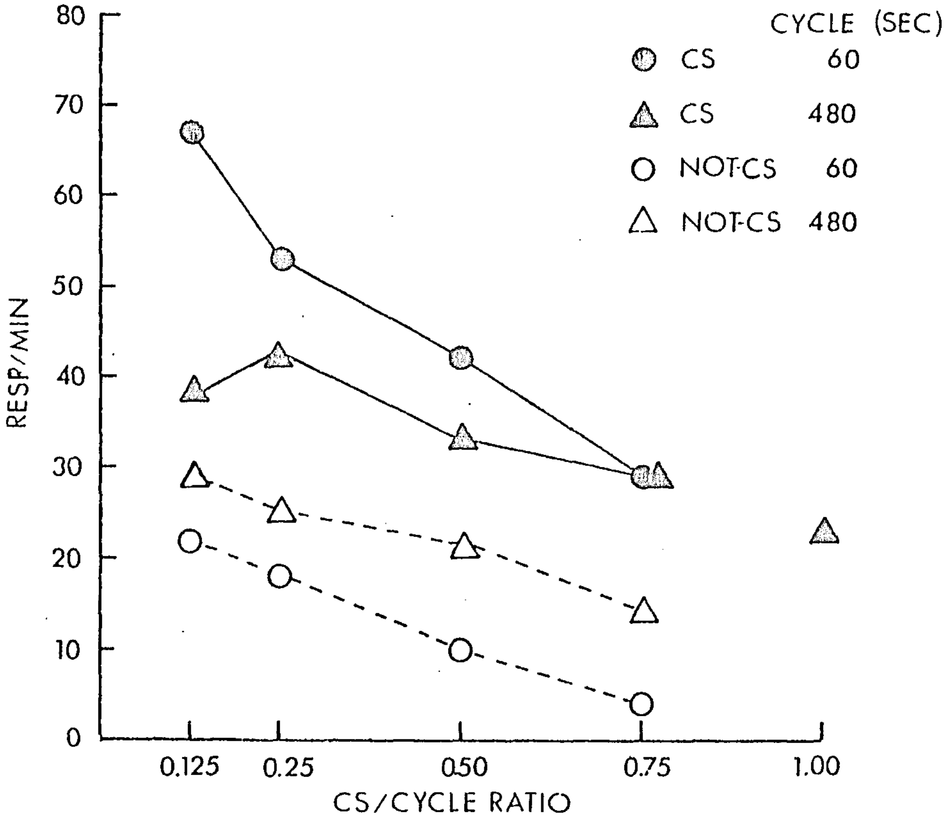

Figure 5. Mean responses per minute as a function of CS/cycle ratio and cycle duration. (Horizontal line indicates mean baseline responses per minute.)

replication) was performed. Baseline rates of the CS/cycle responding were included in this analysis but ratio of 1.00 was excluded from the analysis since there was only one determination. The main effect of CS/cycle ratio was significant ($p \leq 0.001$). Mean response rates in order of increasing ratio were: 38.84; 35.68; 26.54; 18.84; and, for the baseline, 32.94 responses per minute. The main effects of stimulus were also significant ($p \leq 0.01$). Mean response rates were: 40.25 (CS) and 20.90 (not-CS). (See Appendix, Table A.) The stimulus x cycle x ratio interaction was ($p \leq 0.05$), confirming the effect previously discussed. Specifically, CS response rates differed as a function of cycle duration at the 0.125 condition ($p \leq 0.001$), but not at any other ratio. Differences between not-CS response rates as a function of cycle duration were not significant at any ratio. However, as this may have been due to the lack of power of the test and as differences in CS response rates appeared to contribute a disproportionate share of the inter-subject variability, not-CS response rates during the four CS/cycle ratios and the baseline were analyzed separately. The effect of cycle duration on not-CS response rates was found to be significant ($p \leq 0.05$; see Appendix, Table B). The cycle x ratio interaction was not significant.

Additional analyses focused on the differences between CS and not-CS response rates within each cycle and on differences in responding as a function of CS/cycle ratio. CS response rates were significantly different from not-CS response rates only when the cycle duration was 60 sec ($p \leq 0.01$). This outcome may have been due to large inter-subject variability in response rates; with few exceptions not-CS response rates were lower than CS response rates for individual subjects.

In general, the effects of CS/cycle ratios on responding during either the CS or not-CS were greater during the 60-sec than the 480-sec cycle. During the 60 sec cycle, response rates at ratios of 0.125 and 0.25 were significantly higher than the baseline rate of responding and these ratios resulted in significantly higher rates of responding than ratios of 0.50 and 0.75. However, no significant difference was found between CS response rates between the 0.125 and 0.25 ratios. During the not-CS response rates were significantly lower than the baseline levels at all but the 0.125 ratio when the cycle was 60 sec.

When the cycle duration was 480 sec, CS response rates did not differ significantly from the baseline at any CS/cycle ratio. However, CS response rates at the 0.125 ratio were significantly higher than response rates at the 0.75 ratio. During the not-CS response rates were not significantly lower than the baseline levels at any ratio, but the difference between responding at the 0.125 and 0.75 ratios was significantly different. (These comparisons were made with respect to the 0.05 level of significance.)

The results of the analysis of variance are undoubtedly conservative, due to the relatively small number of subjects and the large inter-subject variability. Even though all of the differences between ratios were not statistically significant, it is clear the amount of facilitation of responding produced by the CS was a function of the CS/cycle ratio. Inhibition of responding during the not-CS was also a function of the CS/cycle ratio. Increasing the cycle duration tended to attenuate both the excitatory effect of the CS and the inhibitory effect of the not-CS on responding maintained by a baseline schedule of reinforcement.

Effect of Cycle Duration Manipulations

Variations in the CS/cycle with two different cycle durations resulted in large differences in response rates as a function of CS/cycle ratio and less reliable differences as a function of cycle duration. It was apparent, however, that the difference between cycles in the rate of responding during the CS was greatest when the ratio was 0.125. Additional manipulations of cycle duration were, therefore, made with a fixed CS/cycle ratio of 0.125. The first manipulation used the eight subjects who had been studied on a single cycle duration with different CS/cycle ratios. These birds were switched to the alternate cycle duration, either 60 or 480 sec, and studied at the 0.125 ratio. The resulting response rates were compared with the response rates during the original cycle duration at that ratio. Both CS and not-CS response rates are presented in Table 2.

Table 2

Response Rates as a Function of Cycle Duration

Subject	CS 60 sec	 480 sec	Not-CS 60 sec	 480 sec
P-133	41.80	14.73	21.21	21.89
P-31	28.99	33.38	25.25	23.98
P-22	98.44	77.05	22.82	39.87
P-144	50.65	52.93	23.80	37.76
P-143	42.45	24.39	28.18	31.72
P-32	67.15	18.27	29.41	18.37
P-51	111.96	50.68	39.08	38.35
P-52	81.52	47.99	24.24	19.65
$\bar{x}$	65.37	39.93	26.75	28.95

For six of eight subjects, response rates during the CS were higher when the cycle was 60 sec. For four subjects, response rates during the not-CS were lower during the 60-sec cycle. A two-factor (stimulus x cycle) analysis of variance performed on these data indicated that CS response rates were significantly higher during the 60-sec cycle ($p < 0.001$) but that not-CS response rates did not vary significantly as a function of cycle duration. (See Appendix, Table C.) In addition, CS and not-CS response rates were significantly different from each other only within the 60-sec cycle. That is, responding appeared to be facilitated during the CS only during the 60-sec cycle. These results are consistent with the results of the overall analysis of variance which indicated that there was an interaction between cycle duration and stimulus.

Cycle duration was manipulated more extensively for a second group of four subjects with a constant CS/cycle ratio of 0.125. Data from individual subjects are shown in Figure 6. Response rates during the CS tended to vary inversely as a function of cycle duration, with the exception of subjects, P-114 and P-83, on the initial replication (filled circles). Not-CS response rates appeared to be relatively insensitive to the effects of changes in cycle duration. Response rates during CS and not-CS averaged across subjects are shown in Figure 7 as a function of cycle durations. Mean data reflect the same general effects of cycle duration as the individual subject's data.

These impressions were confirmed by a three-factor (stimulus x cycle x replication) analysis of variance. The main effects of stimulus (CS vs.not-CS) were significant ($p \leqslant 0.05$) as was the stimulus x cycle interaction ($p \leqslant 0.01$) but the effect of cycle duration failed to reach significance. This was due to the inclusion of the baseline rates of responding in the analysis. Strictly speaking, the baseline did not constitute a "cycle" duration since there was not CS present, but these response rates were included so the degree of facilitation during the CS could be evaluated. When baseline measures were omitted, the effect of cycle duration was statistically significant ($p \leqslant 0.05$).

Further analysis revealed that response rates during the CS differed significantly as a function of cycle duration ($p \leqslant 0.001$), but response rates during the not-CS did not. (See Appendix Table D.)

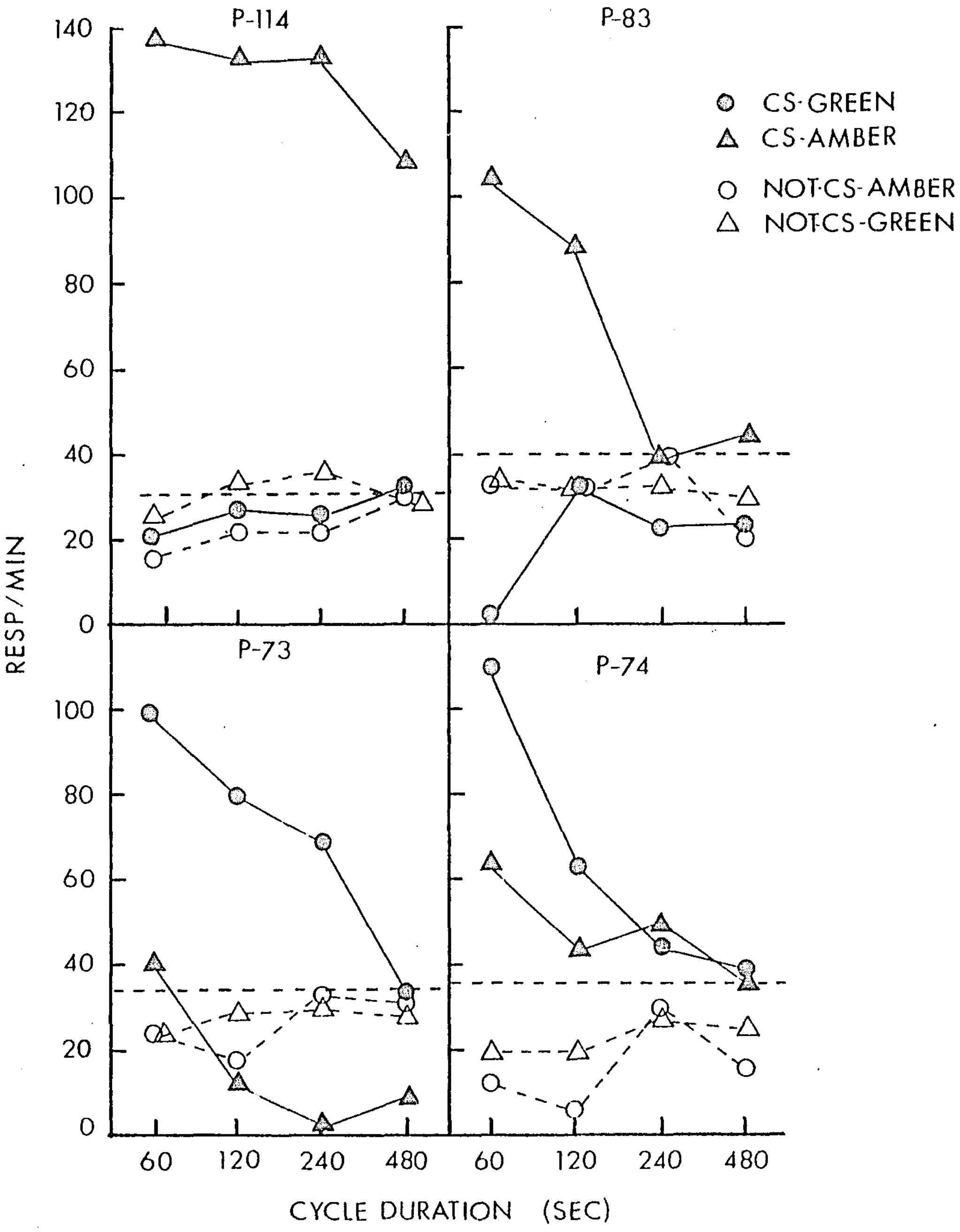

Figure 6. Responses per minute during the CS and not-CS as a function of cycle duration. (Horizontal lines indicate mean baseline responses per minute.)

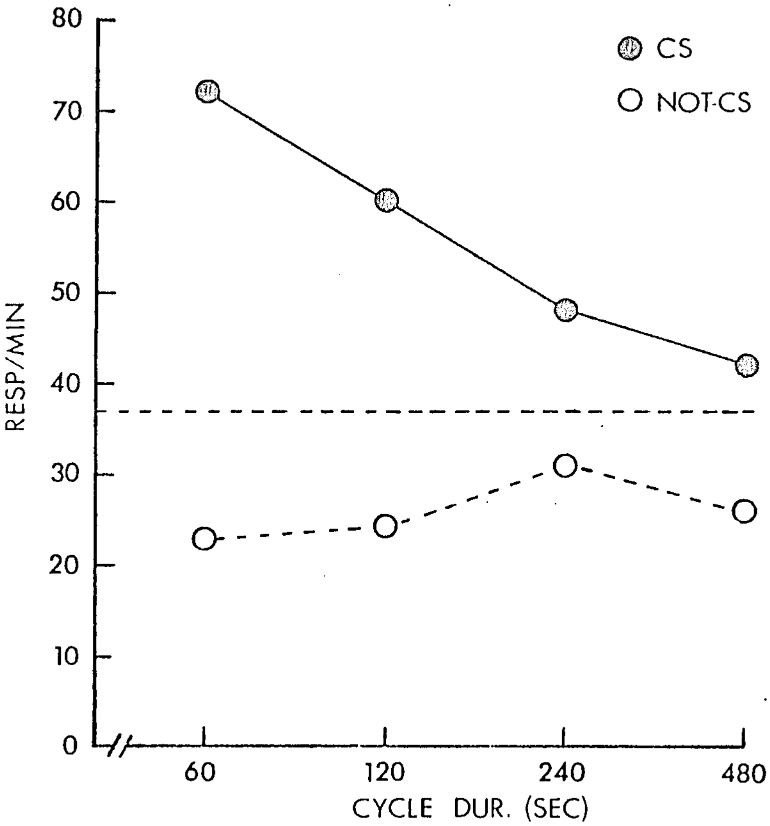

Figure 7. Mean responses per minute as a function of cycle duration. (Horizontal lines indicate baseline responses per minute.)

CS responding during the 60 and 120-sec cycles was significantly higher than responding during the baseline, indicating a facilitory effect of the CS on responding. However, CS response rates on the remaining two cycle durations did not differ significantly from the baseline level, although they did differ from the response rates during the 60 sec cycle. Not-CS response rates did not differ from the baseline rate at any cycle duration, nor did they differ from each other. (Between cycle comparisons were made at the 0.05 level of significance.)

To summarize, increases in the cycle duration with a constant CS/cycle ratio resulted in a reduction in the rates of responding during the CS, but little, if any, change in the rate of responding during the not-CS at this CS/cycle ratio. Compared to the baseline levels, CS response rates were facilitated only at the two shortest cycle durations, while not-CS response rates showed little inhibitory effect at any cycle duration.

Temporal Effects of CS/Cycle Ratio and Cycle Duration

Responding was examined within subintervals of the CS and cycle to see if differences in response rates as a function of CS/cycle ratio and cycle duration could be due to systematic changes in the rate of responding as a function of time since CS onset and offset.

Response rates during the CS of individual subjects are plotted for each eighth of the CS in Figure 8. In the upper panel of the figure are shown, for each subject, response rates during the four CS durations studied with a cycle of 60 sec and during the 60-sec CS studied with a cycle of 480 sec. Response rates tended to increase during successive subintervals of the CS for all four subjects when the CS was 7.5 sec and 15 sec, and when it was 30 sec for subjects P-133 and P-31. When the CS duration increased to 45 sec, response rates either remained constant or decreased as a function of time since CS onset. When the CS and cycle durations were both increased for these subjects, response rates for three of four subjects during successive subintervals of the 60-sec CS increased.

Response rates as a function of successive eighths of the CS for the subjects originally studied with a 480 sec cycle are plotted in the lower panel of Figure 8. CS durations for these subjects ranged from 60 to 360 sec when the cycle duration was 480 sec. These longer CS durations clearly produced a different pattern of responding than that which predominated during the shorter CS durations shown in the upper panel of this figure. Response rates either remained constant or tended to decrease as a function of successive subintervals of the CS. On the other hand, when these birds were studied with a considerably shorter CS duration (7.5 sec with a 60-sec cycle), response rates during the successive subintervals of the CS increased for two subjects.

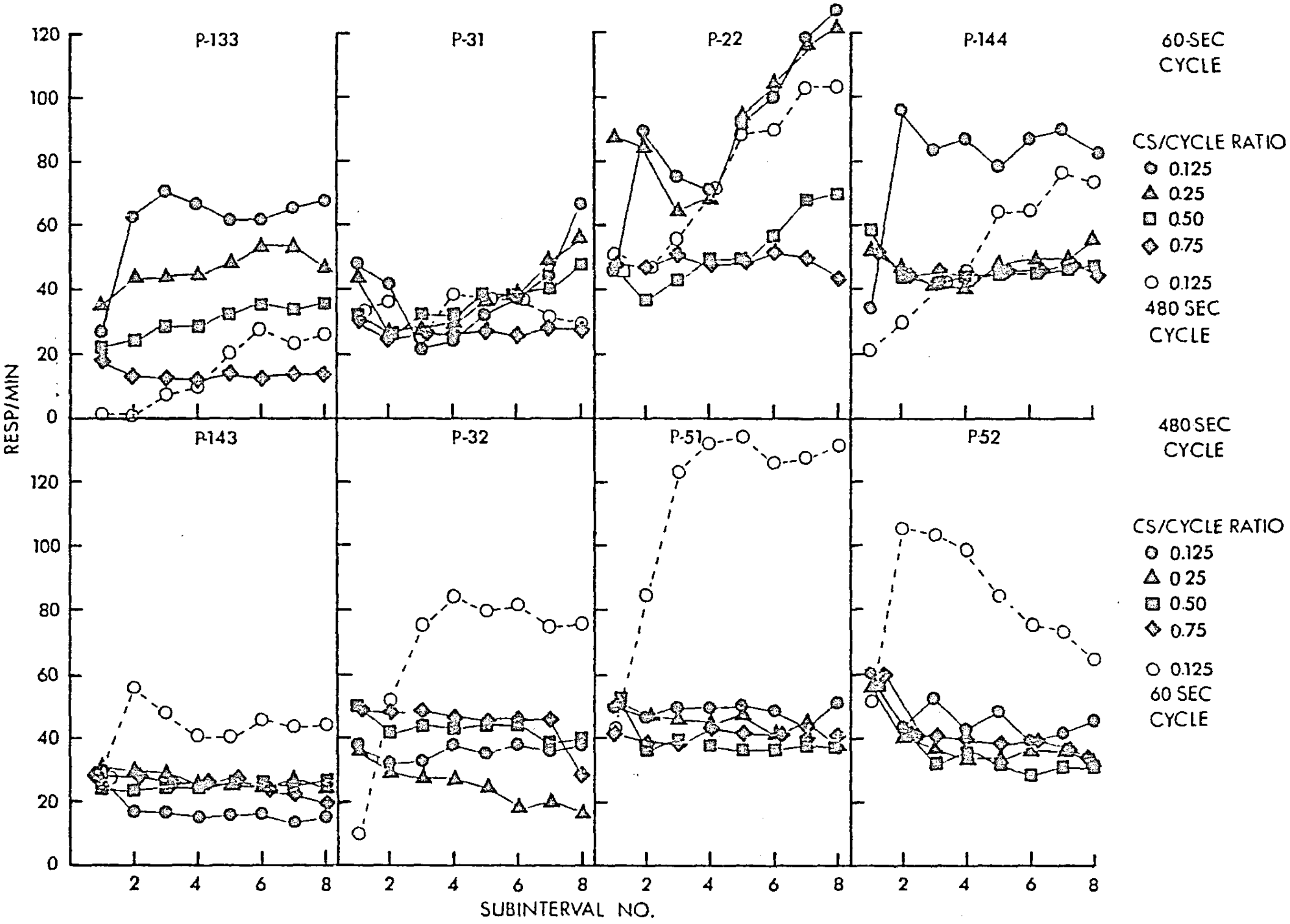

Figure 8. Responses per minute for each subject as a function of successive subintervals within the CS for each CS duration. (Upper panel: 60-sec cycle; Lower panel: 480-sec cycle.)

In most cases, it appeared that the differences in the temporal patterning of responding during the CS were due to absolute CS duration rather than the CS/cycle ratio. The longer CS durations of the 480 sec cycle resulted in very similar patterns of responding during the CS although there were large differences in the CS/cycle ratio. The increasing pattern of response rates during the 60 sec CS of the three subjects in the upper panel of Figure 8 were an exception. It is not clear why these response rates increased as a function of time since CS onset whereas those of the other subjects studied on this CS duration decreased. These data are evidently anomolous; why, is not clear.

The influence of CS duration on the temporal patterning of responding is clearer when response rates during the CS for the subjects studied with varying CS and cycle durations with a constant CS/cycle ratio are examined (Figure 9). Response rates during successive subintervals of the CS tended to increase when the CS was less than 30 sec, although this effect did not occur during all conditions or for all subjects. In some cases, notably for subjects P-114 and P-83, response rates increased only between the first and second subintervals and remained relatively constant thereafter. Response rates clearly decreased during successive subintervals when the CS was 60 sec for only two subjects (P-83 and P-74). On the other hand, response rates for the other two did not tend to increase. These data tend to confirm the conclusion that short CS durations result in an increasing rate of responding during the CS while longer CS

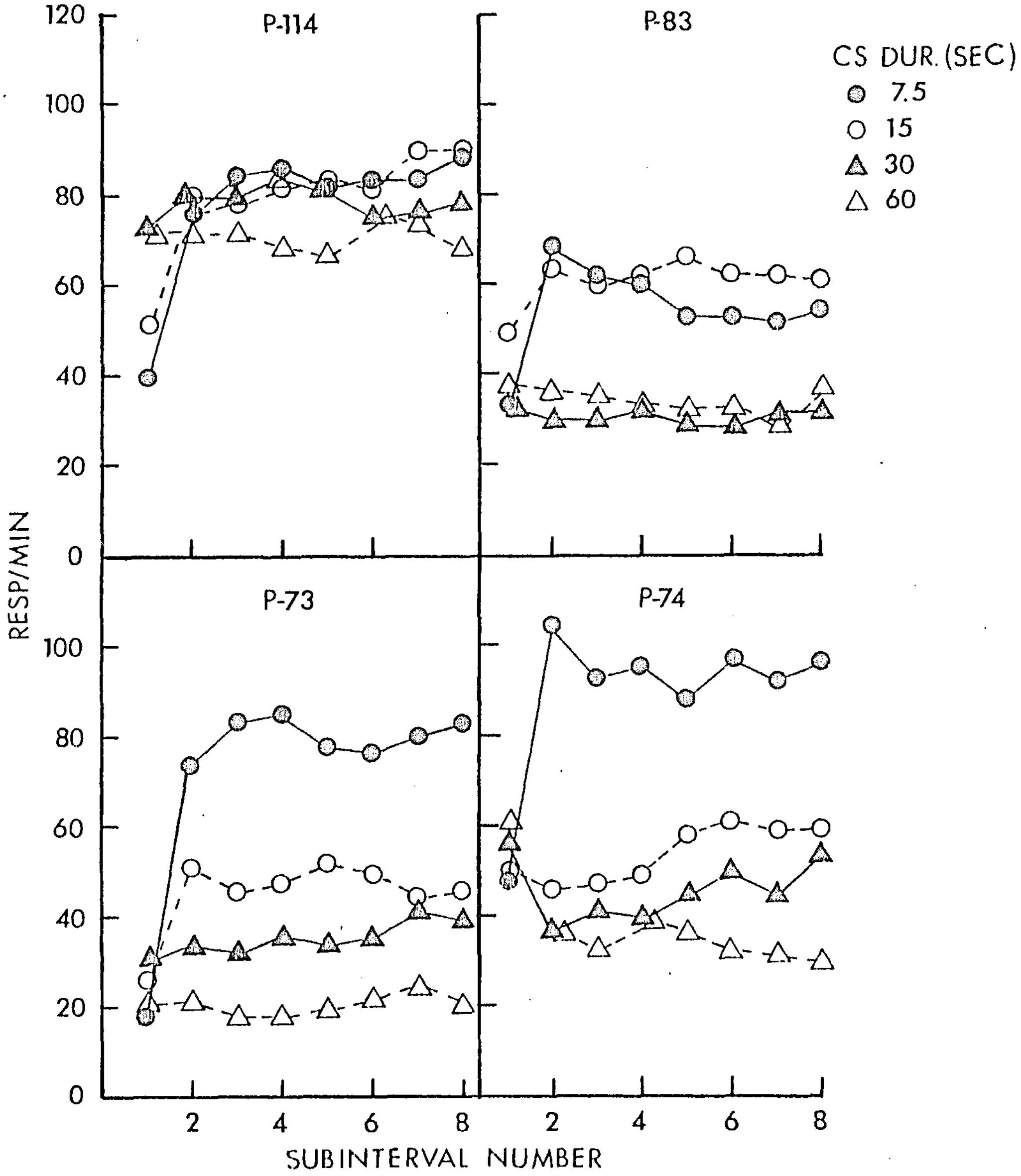

Figure 9. Responses per minute for each subject as a function of successive subintervals within the CS for each CS duration. (Subjects studied with a constant CS/cycle ratio.)

durations result in either no change or a decrease in the rate of responding during successive subintervals of the CS.

The data in Figures 8 and 9 show differences in the distribution of responses during the CS as a function of relative time since CS onset. Thus, it is not possible to see how response rates differed at the same absolute time within the CS. To make these comparisons for the two groups of subjects studied with a single cycle duration, response rates in the subintervals of the cycle during which the CS was in effect were plotted as a function of successive equal-time subintervals for each CS duration. Mean response rates for 60-sec and 480-sec cycle subjects are shown in the upper panel of Figure 10. Note that the duration of the subintervals differs between cycles: 7.5 sec for the 60-sec cycle, 60-sec for the 480-sec cycle.

Response rates during the first 7.5 sec of the 60-sec cycle clearly differed as a function of CS/cycle ratio while response rates during the first 60 sec of the 480-sec cycle did not differ as a function of cycle duration. This conclusion was supported by the results of a three-way analysis of variance (cycle x ratio x replication; see Appendix, Table E): there were significant differences between CS/cycle ratios in the first 7.5 sec when cycle duration was 60 sec ($p \leqslant 0.01$), but differences in the first 60 sec of the 480-sec cycle were not significant. However, it is possible that differences between ratios earlier in the CS may have been larger. Response rates during the 7.5 sec CS are clearly greater than response rates in the first

7.5 sec of the other CS durations, but response rates in the first 7.5 sec of these durations did not differ much among each other.

The lower panel shows response rates as a function of 7.5 sec subintervals for the subjects studied on different CS durations with a constant CS/cycle ratio. These points were obtained by averaging across subintervals of the CS at different CS durations to obtain response rates for absolute times since CS onset.

Note that the same differences in the distributions of responses during the CS as a function of CS duration that were seen with respect to relative time since CS onset can also be seen in Figure 10 as a function of absolute time since CS onset. Response rates increased during successive subintervals of the CS when CS durations were short but decreased during successive subintervals of the CS when CS durations were long.

Temporal Patterns of Responding During the Not-CS

Response rates during the not-CS were compared within successive subintervals of the cycle as a function of absolute time since CS offset for each CS/cycle ratio within a given cycle. Response rates for individual subjects studied on either the 60 or 480 sec cycle are shown in Figure 11; mean response rates for each cycle duration as a function of CS/cycle ratio are shown in Figure 12. Note that subinterval duration was 7.5 sec when the cycle was 60 sec and 60 sec when the cycle was 480 sec. Thus, comparisons between cycles are with respect to relative time since CS offset.

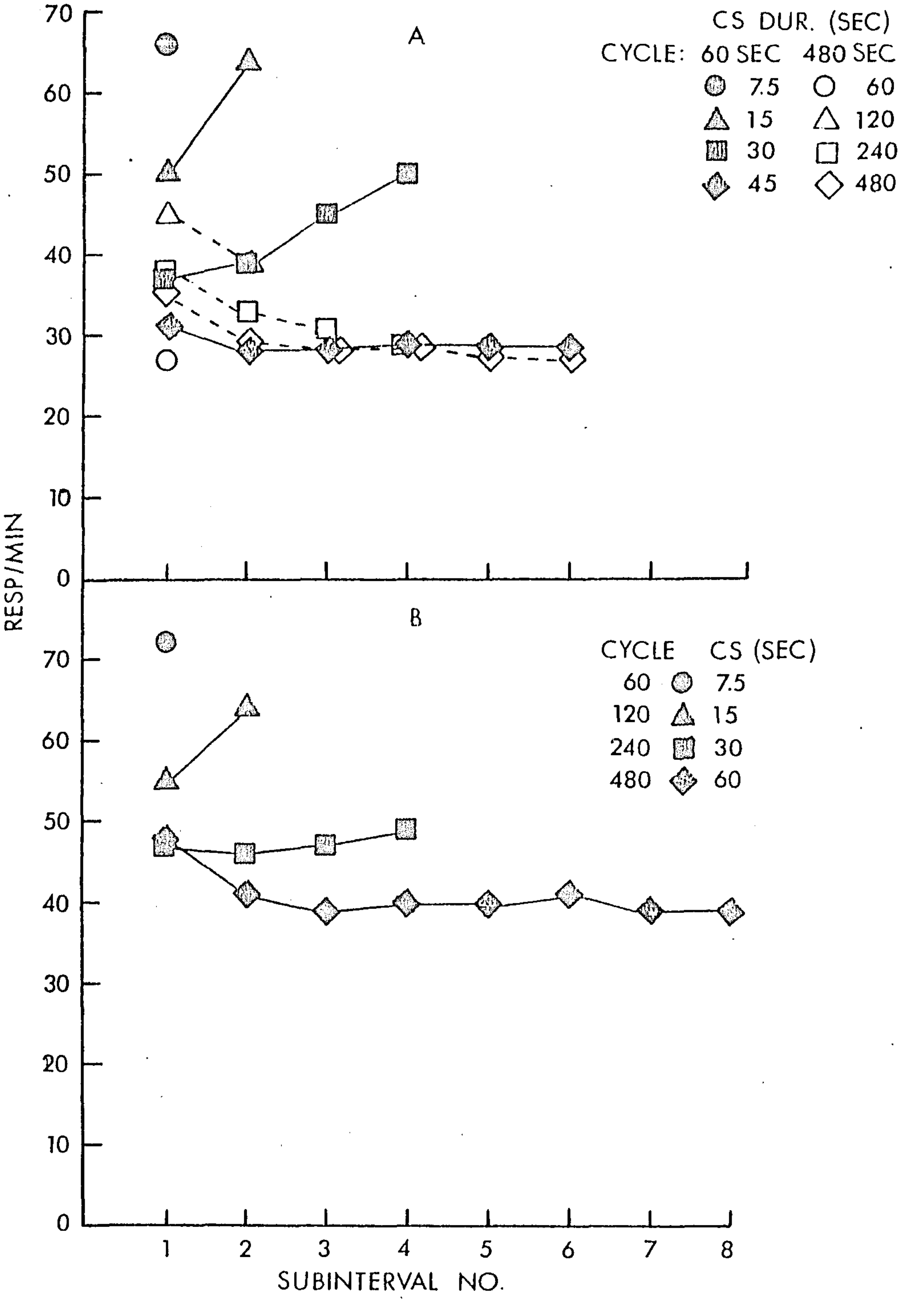

Figure 10. Panel A: Responses per minute during the CS as a function of 7.5 sec (for the 60-sec cycle) or 60 sec (for the 480-sec cycle) subintervals of the CS for each CS/cycle ratio. Panel B: Responses per minute during the CS as a function of 7.5 sec subintervals of the CS for each cycle duration with a constant CS/cycle ratio (0.125).

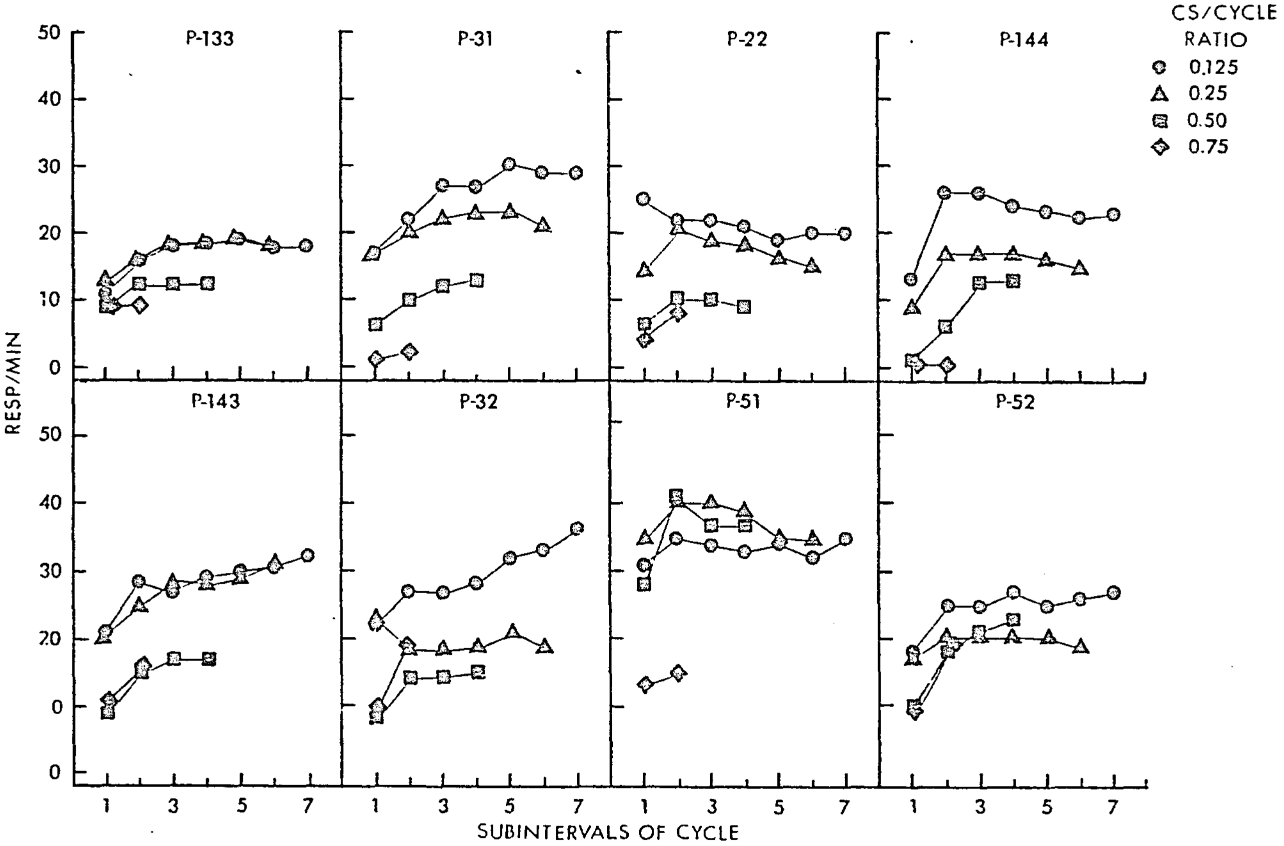

Figure 11. Responses per minute during the not-CS as a function of successive eighths of the cycle for each subject and CS/cycle ratio. (Upper Panel: 60-sec cycle; Lower Panel: 480-sec cycle.)

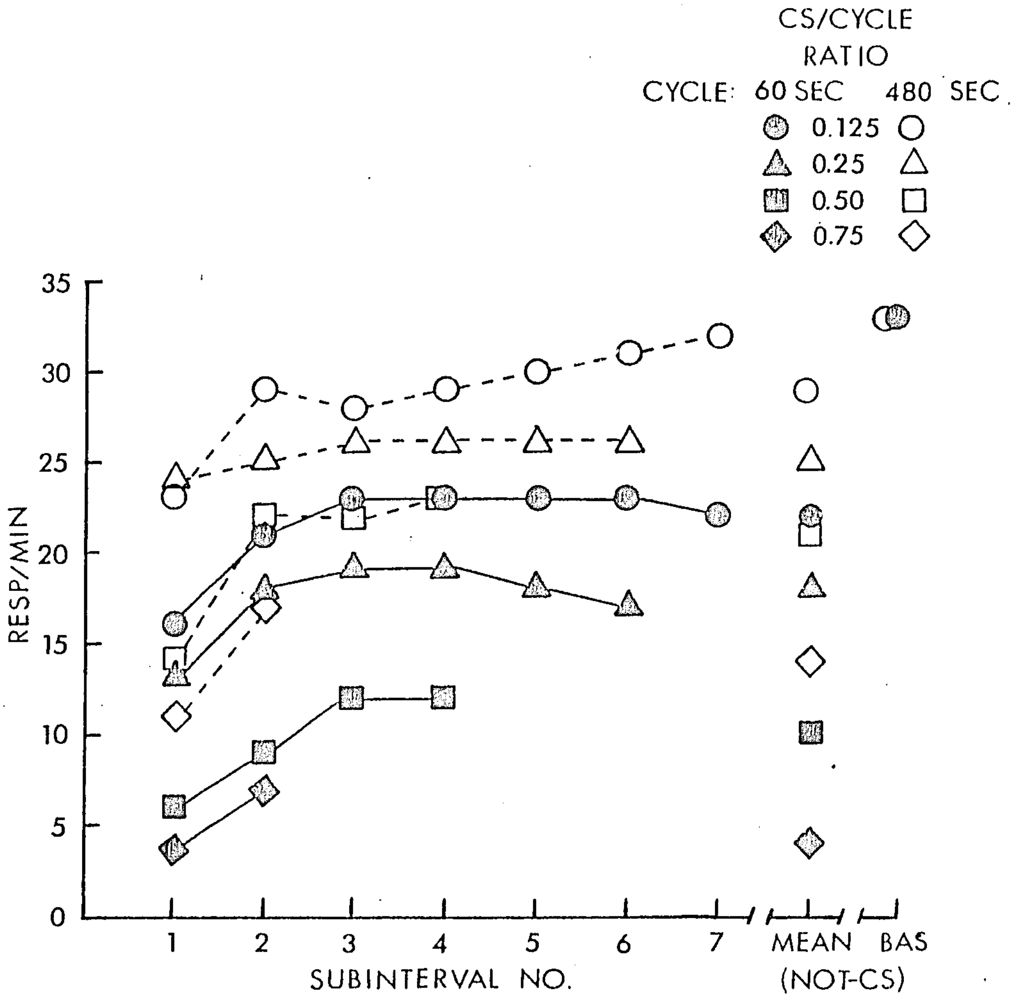

Figure 12. Mean not-CS responses per minute as a function of successive eighths of the cycle for each CS/cycle ratio and cycle duration.

Some subjects tended to increase their rates of responding during successive subintervals of the not-CS (P-133, P-31, P-143, P-32, and P-52). The largest increase in responding occurred during the first one or two subintervals and frequently responding was maintained at a fairly stable rate during the remaining subintervals. Response rates during both cycle durations increased more rapidly during successive subintervals and reached higher asymptotic levels when the CS/cycle ratio was low--that is, when the not-CS was in effect for a larger proportion of the cycle.

Differences between cycle durations were evident in the higher asymptotic rates of responding at a given CS/cycle ratio during the 480-sec cycle.

Response rates during the not-CS on a given cycle appeared to differ as a function of the CS/cycle ratio in the first subinterval of the not-CS as well as later in the not-CS interval. There also appeared to be an effect of cycle duration on response rates in the initial subinterval for a given CS/cycle ratio. However, these differences may have been due to the differences in the durations being compared: 7.5 sec for the 60-sec cycle and 60 sec for the 480-sec cycle. It is possible that these differences in response rates at not-CS onset would be reduced or even reversed if equal absolute times since not-CS onset were compared.

Correlations Between CS and Not-CS Response Rates

CS and not-CS response rates tended to co-vary as a function of the cycle duration. Although this result will be shown to be consistent with an account of conditioning effects in terms of CS-US contingencies, the correlation between response rates also may have been due to continuation of the ongoing rate of responding in the CS to the not-CS. While this seemed unlikely since there were large absolute differences in the response rates during the CS and not-CS at most CS/cycle ratios, nevertheless, the correlation between response rates at the offset of the CS and the onset of the not-CS was examined. For each subject, pairs of CS and not-CS response rates at each CS/cycle ratio (or cycle duration for the third group of subjects) at CS offset and not-CS onset were used to obtain a correlation coefficient for each subject. These are shown in Table 3. As can be seen, these correlations vary from high positive to high negative correlations. (Negative correlations resulted when responding was suppressed during the CS.) The fact that low or negative correlations were obtained strongly suggests that there was no necessary relationship between response rates during the CS and not-CS. That is, these data argue against the idea that response rates during the CS, rather than CS-US contingencies, determined the rate of responding during the not-CS.

Table 3

Correlation Coefficients Between Response Rates at CS-Offset and Not-CS Onset

Cycle Duration (sec)	Subject	Replication 1	Replication 2
60	P-133	0.92	-0.82
	P-31	0.73	0.11
	P-22	0.64	0.67
	P-144	0.95	0.17
480	P-143	0.83	0.61
	P-32	0.90	0.03
	P-51	0.22	0.83
	P-52	0.70	0.95
	P-114	0.93	-0.24
	P-83	-0.57	-0.17
	P-73	-0.86	-0.94
	P-74	-0.58	-0.77

Response Rates During the CS and Not-CS With a VI 0.5-min Schedule In Effect During the CS

The eight subjects studied on the CS/cycle ratio manipulations were also studied on either the 0.125 or 0.75 ratio with a VI 0.5-min schedule during the CS. replacing the VT 0.5-min schedule that was in effect on the other conditions. Mean response rates as a function of cycle duration and CS/cycle ratio are shown in Table 4. It is, first of all, evident that the same effects of cycle duration and CS/cycle ratio that were previously obtained with the VT schedule were also obtained with the VI schedule: response rates were higher during the 0.125 ratio than during the 0.75 ratio, and response rates during the CS were higher at the 0.125 ratio when the CS duration was 60 sec than when it was 480 sec. Response rates were somewhat higher during the not-CS when the cycle duration was 480 sec, but this difference was not a large one.

Table 4

Mean Response Rates With A VI Schedule During the CS

Cycle Duration (sec)	CS/Cycle Ratio	Response/min	
		CS	Not-CS
60	0.125	71.80	21.37
	0.75	39.86	3.97
480	0.125	52.82	25.78
	0.75	48.34	11.14

With respect to the response rates maintained by the VT schedule during the CS, response rates on the VI conditions were generally higher. This was not surprising since all grain presentations during the CS were contingent upon a response. However, response rates during the not-CS on these conditions were comparable to those obtained in conditions in which the VT schedule was in effect during the CS.

The "Random Control" Procedure

The four subjects originally studied on the cycle duration manipulations were studied with this procedure in which the CS and not-CS key colors alternated but the VT schedule ran throughout the cycle. Mean response rates as a function of stimulus (CS or not-CS) are shown for each subject in Table 5 along with response rates on the condition in which the CS and

VT schedule were in effect throughout the cycle (CS/cycle ratio equals 1.00). Response rates during the CS and not-CS were expected to be equal during this condition since the VT schedule was in effect during both stimuli. This was the case for three of four subjects. For the fourth, P-83 the response rate during the CS was almost completely suppressed compared to either the response rate during the not-CS or that maintained by the baseline VI 6-min schedule. It was not clear why this happened on this condition; the CS did occasion suppression of responding for this subject on other conditions (see Figure 6).

Table 5

Response Rates On the Random Control
and 1.00 CS/cycle Ratio

Subject	Cycle (sec)	Random Control CS	not-CS	1.00 CS/cycle ratio
P-114	60	16.34	16.40	15.03
P-83		1.76	13.59	24.17
P-73	480	12.20	12.73	11.58
P-74		21.47	24.91	15.78

In the random control procedure, the VT schedule was in effect throughout the cycle so that the stimuli associated with the CS and not-CS were functionally irrelevant. Thus, the CS-US contingency on this condition and the condition in which the CS and VT schedule were in effect throughout the cycle was the same. For two subjects, P-83 and P-74, however, there were differences in response rates between these conditions. The fact that response rates were higher on the random control for one subject and lower for the other suggests that differences were not a systematic effect of the stimulus changes in the random control procedure.

CHAPTER IV

DISCUSSION

The results of the present experiment confirm and extend the results of previous studies (Gibbon et al, 1977; Groves, 1974) on the importance of the relative duration of the CS in eliciting keypecking in pigeons. In the present study, grain presentations scheduled during the CS resulted in facilitation of responding maintained by a concurrently programmed baseline VI schedule of grain presentation. The amount of facilitation of responding was inversely related to the CS/cycle ratio.

A novel finding of the present study was that responding during the not-CS was suppressed or inhibited compared to the baseline rate of responding. The degree of inhibition was directed related to the CS/cycle ratio.

A significant effect of absolute cycle duration was also obtained: for a given CS/cycle ratio, response rates during the CS varied inversely with cycle duration. This effect could not be attributed to differences in the average delay or density of US occurrence during the CS nor to the overall rate of US occurrence during the cycle, since these remained constant. At the particular value of the CS/cycle ratio that was used when cycle duration was systematically manipulated, there was little effect of cycle duration on response rate during the not-CS.

The Question of the Baseline

The excitatory effect of the CS was measured in terms of increased responding compared to the VI 60min baseline schedule. However, there is another candidate for the baseline, the condition in which the CS and VT schedule were in effect throughout the cycle (1.00 CS/cycle ratio). This condition was studied to evaluate the effect of the grain presentations on responding in the absence of a differential CS-US contingency. Since there was no differential CS-US contingency, keypecking should not have been elicited. That is, facilitation of responding was not expected to occur. In fact, during this condition, response rates were lower than during the VI 6-min schedule for most subjects (see Figure 4). This outcome is consistent with other studies (Rachlin and Baum, 1972) which have found inhibitory effects of "free reinforcers" on responding maintained by response-contingent schedules of reinforcement. Thus, this condition may provide the proper baseline for evaluating the effects of the CS-US contingency because it controls for the effect of the VT schedule of US presentation on the rate of responding maintained by the VI 6-min schedule. It is assumed that these effects of grain presentation were independent of the CS-US contingency.

If this condition were used as the baseline, estimates of the amount of facilitation of responding produced by the CS-US contingency would be larger, since responding on the 1.00 CS/cycle ratio was generally lower than on the VI 6-min baseline.

However, while the question of what constitutes an appropriate baseline for measuring the amount of facilitation is an important one, the concern in the present study was to relate differences in responding to changes in the CS-US contingency.

The Development of a Contingency Ratio

The purpose of a functional analysis is to relate changes in behavior to changes in events in the organism's environment. Talking about CS-US contingencies is a way of describing the relationships between these events. There is some value in developing a quantitative description or "metric" of contingency to which changes in behavior can be related.

The measure of CS-US contingency that seemed to describe changes in rate of acquisition of keypecking by pigeons in delay conditioning procedures was the ratio of the average delay of US occurrence during the CS to the overall average delay of US occurrence, which reduces to the ratio of the CS and cycle (inter-US) durations. The CS/cycle ratio is not an adequate description of the CS-US contingencies in the present study because the overall delay (or rate) of US occurrence was not a function of the cycle duration. However, a contingency ratio which describes these contingencies in the present study can be developed which is analogous to the CS/cycle ratio in delay conditioning procedures. Rates of US occurrence (the reciprocal of delay) during the CS and not-CS remained constant during the experiment and were independent of the CS/cycle ratio.

The rate of US occurrence during the CS is denoted by "P_1", that during the not-CS by "P_o". The overall rate of US occurrence was a function of both P_1 and P_o, weighted by their relative durations of occurrence or by the CS/cycle ratio, "R", and the not-CS/cycle ratio, 1-R, respectively. The equation for the contingency ratio is expressed as follows:

$$C = \frac{P_1}{R(P_1) + (1-R)P_o} \qquad (1)$$

The contingency ratio for the not-CS is expressed by substituting P_o for P_1 in the numerator of Equation 1.

In computing the contingency ratios for the values of P_1, P_o, and R used in the present study, grain presentations programmed by the VT and VI schedules were summed. The logic of this decision was that, although the response-reinforcer contingencies were different, the primary consideration was describing the stimulus contingencies. This treatment seemed justified on the basis of the results of comparisons between the VT 0.5-min and VI 0.5-min schedules. Values of the contingency ratio for the present study are shown in Table 6. Ratios for the CS are greater than 1.0, indicating that the CS should be excitatory for all CS/cycle ratios. Values for the not-CS were less than 1.0, indicating that the not-CS should be inhibitory. Note also that the ratios for both the CS and not-CS decrease with increasing CS/cycle ratios. For the CS, this indicates that the excitatory effect of the CS-US contingency decreases as the CS/cycle ratio increases. A contingency ratio of 1.0 indicates that no conditioning should occur since the rates of reinforcement during the CS and cycle would be equal. For the not-CS, decreasing contingency ratios mean that the inhibitory effect of the not-CS on responding increases as the CS/cycle ratio increases.

Table 6

Values of the Contingency Ratio as a Function of CS/cycle Ratio

	CS/cycle Ratio			
	0.125	0.25	0.50	0.75
CS	5.20	3.25	1.86	1.30
Not-CS	0.40	0.25	0.14	0.10

To examine the correlation between the contingency ratio values shown in Table 6 and response rates during the CS and not-CS, mean response rates from Figure 5 were plotted against these ratios in Figure 13. It is evident that there is a substantial correlation between the contingency ratio and rates of responding during both the CS and not-CS.

The contingency ratio decreases with increasing CS/cycle ratios when the CS is excitatory ($P_1 > P_o$), attaining a minimum of 1.00 when the CS/cycle ratio is 1.00, and increases with increasing CS/cycle ratios when the CS is inhibitory $P_1 > P_o$), attaining a maximum of 1.00 when the CS/cycle ratio is 1.00. Absolute values of the contingency ratio depend upon the ratio of rates of reinforcement during the CS and not-CS (P_1/P_o).

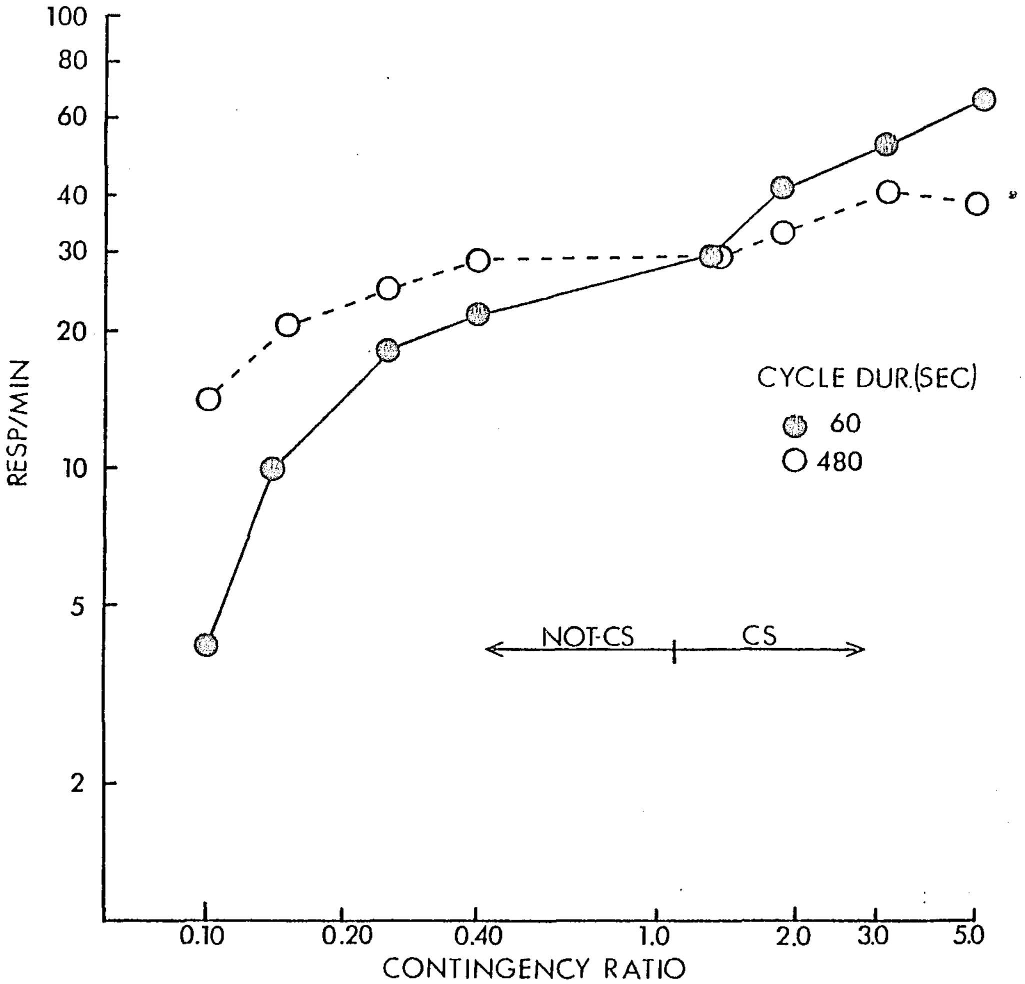

Figure 13. Mean CS and not-CS response rates as a function of the contingency ratio.

For a constant CS/cycle ratio, increasing values of P_1/P_o result in larger values of the contingency ratio. The relationships between CS/cycle ratio and the ratio of reinforcement rates in the CS and not-CS are summarized in Figure 14 which shows values of the contingency ratio as a function of CS/cycle ratio for different ratios of P_1/P_o.

The contingency ratio can also be applied when probability or delay of US occurrence rather than rate is varied. Probability values can be simply substituted for rates in equation 1. Delay of US occurrence is the reciprocal of rate, that is, a given delay can be transformed into a measure of the rate of US occurrence by taking the reciprocal. In the usual delay conditioning paradigm (*i.e.*, that used by Gibbon *et al*, 1977, and Groves, 1974) where P_o, the rate of US occurrence during the not-CS, is zero, the contingency ratio, C, reduces to the ratio of the inter-US (cycle) to CS duration as shown:

$$C = \frac{P_1}{R\ (P_1) + (1-R)\ P_o}$$

$$= \frac{P_1}{R\ (P_1)} = \frac{1}{R}$$

$$= \frac{\text{cycle}}{\text{CS}}$$

where $P_1 = 1/CS$, $P_o = 0$ and R is the CS/inter-US ratio.

The contingency ratio calculated according to equation 1 is conceptually similar to an "expectancy" ratio model recently developed by Gibbon (1977) to account for the occurrence of responding on periodic schedules of reinforcement. A feature

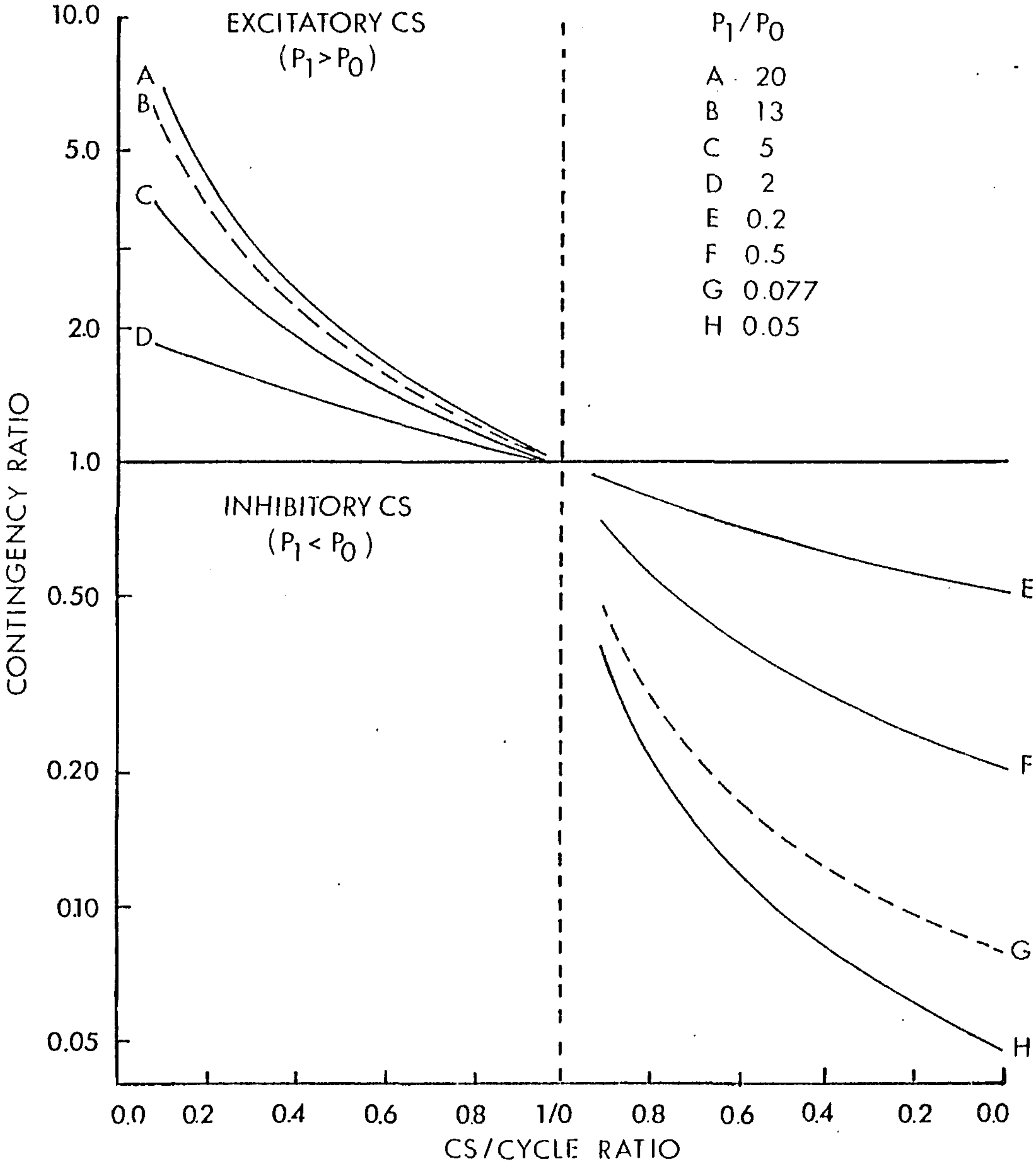

Figure 14. Values of the contingency ratio as a function of CS/cycle ratio and the ratio of the rates of US occurrence given the CS and not-CS. (Functions B and G show the P_1/P_0 ratio values during the CS and not-CS, respectively, in the present experiment.)

common to both ratios is that the values of the ratios are not affected by absolute rate or probability of US occurrence. The results of the present study have no bearing on this issue since rates of US occurrence during the CS and not-CS remained constant. A metric of contingency, the phi coefficient, has been proposed by Gibbon, Berryman and Thompson (1974) which is sensitive to the absolute values of the probability of US occurrence during the CS and not-CS and to the relative durations of CS and not-CS. At the present time there is insufficient data to evaluate the relative merits of the phi coefficient and the contingency ratio.

The Effects of Absolute Cycle Duration

Although the contingency ratio accounts fairly well for differences in rates of responding as a function of CS/cycle ratio, it cannot account for the changes in rates of responding that occurred as a function of cycle duration. The decrease in the amount of facilitation of responding during the CS and, to a lesser extent, in the amount of inhibition of responding during the not-CS as the cycle duration increased cannot be attributed to differences in the CS-US contingency, since rates of US occurrence during the CS and cycle remained constant for a given CS/cycle ratio.

However, these results are not without precedent. Other investigators have found that response rates in the higher-valued component of a multiple schedule tend to increase and response rates in the lower-valued component tend to decrease as the component durations decrease (Green and Rachlin, 1975; Kileen, 1972; Shimp and Wheatley, 1971; Todorov, 1972). Rachlin (1973) has suggested that increased response rates during the component with the higher rate of reinforcement when components are short were the by-product of the way responding was distributed within the component. According to his account, keypecks are maximally excited at the transition to the component with the higher rate of reinforcement and maximally inhibited at the transition to the component with the lower rate of reinforcement. Therefore, when components alternate rapidly, high rates of responding are obtained because a larger proportion of the time is spent during transitions.

Several studies have found that response rates in the higher-valued schedule are highest at the beginning of the component and decrease as a function of time since component onset (Arnett, 1973; Green and Rachlin, 1975; Nevin and Shettleworth, 1966). Similarly, response rates tend to be lowest at the beginning of the lower-valued schedule. Menlove (1975) found similar patterns of responding in the first 5 sec of the component whether the component was 5 sec or 180 sec in duration and concluded that there was no active change in patterns of responding as a function of component duration. These data are in general agreement with Rachlin's account of the effects of CS-US contingencies on the distribution of keypecking during the CS.

However, examination of the distribution of responding during the CS in the present study indicated that response rates did not occur in a fixed pattern since time of CS onset, but that there were active changes in the patterning of responses during the CS as a function of CS duration. Response rates tended to increase during successive subintervals of the CS when CS duration was 30 sec or less, and, with some exceptions, to decrease when CS duration was greater than 30 sec. (In the limited data collected with a VI schedule in effect during the CS, essentially the same patterns of responding as a function of CS duration were obtained. Thus, temporal patterning was not due to the response-independent schedule during the CS.)

An alternative explanation for the effect of CS duration on patterns of responding during the CS was suggested recently by Buck, Rothstein, and Williams (1975). They also found that response rates in the higher-valued component increased during successive subintervals and suggested that this effect might be due to the end of the component being reliably associated with the onset of the lower-value schedule. Other data suggest that subjects may respond at a higher rate during a stimulus which is associated with an upcoming period of lower density reinforcement. In one study, Pliskoff (1963) found that response rates were higher during a "warning" stimulus presented five seconds before the offset of the higher-valued component and the onset of the lower valued component. In addition, response rates were lower during the warning stimulus that preceded the offset of the lower-valued component. Similarly, Wilton and Gay (1969) found that response rates were higher during a component that was always followed by a component with a lower rate of reinforcement than they were during a component that was always followed by a higher density of reinforcement.

It seems clear that stimuli associated with the termination of a particular schedule of reinforcement can have excitatory and inhibitory effects on responding as well as those associated with the onset of a particular schedule of reinforcement. In order for responding to increase or decrease in anticipation of a change in reinforcing conditions or CS-US contingencies, the time of stimulus change must be discriminable. In the present study, the CS and not-CS durations were fixed within a given condition and the CS and not-CS alternated regularly. Subjects could therefore anticipate the occurrence of CS and not-CS onset if these intervals were "timed" so that the passage of time within the stimulus was associated with the upcoming stimulus change. It seems plausible that subjects would be more likely to time the CS duration if the duration were short. This would account for the increase in response rates during successive subintervals of the CS only during relatively short durations. Another possibility is that response rates increased somewhat at the termination of the CS regardless of absolute CS duration, but, if this increase in response rate was restricted to a few seconds before the offset of the CS, the change in rate would have a relatively small effect on the overall rate of responding during the CS when CS durations were long. However, there was no indication of an increase in the last subinterval of the 45 sec CS in which response rates tended to decrease during the interval although the bin width (5.6 sec) was short enough, it would seem, to detect such a tendency. At longer CS durations longer bin durations might have obscured a tendency for response rates to increase during the last few seconds of the CS.

This account of changes in temporal patterning of responding in the CS is admittedly somewhat speculative. More detailed data on changes in response rates as a function of times since CS onset and offset need to be collected in order to fully explore and explain the effect of absolute CS duration on rates of responding. This analysis does suggest, however, that the effect of CS duration would be minimized by varying CS durations within the session or by randomizing the occurrence of CS and not-CS presentations, so that the occurrence of the CS or not-CS could not be predicted by the passage of time since a change in stimuli.

Response rates during the not-CS tended to increase during successive subintervals. This increase might have reflected either the dissipation of the effects of the inhibitory CS-US contingency as a function of the passage of time since not-CS onset, an excitatory effect of the anticipation of the upcoming CS, presentation with the passage or time, or a combination of these effects. Note, however, that the rate of responding within each subinterval of the not-CS seemed to be more a function of the CS/cycle ratio and less a function of the absolute not-CS duration than responding within the CS. Response rates were higher at not-CS onset, increased more rapidly, and were higher at not-CS offset when the CS/cycle ratio was short than when it was long. Nor did temporal patterning appear to change as a function of cycle duration for a constant CS/cycle ratio, although this conclusion is based on comparisons of relative rather absolute times since not-CS onset. A more molecular analysis might reveal greater differences in response rates at not-CS onset and offset as a function of cycle duration than were found in the present study.

Suggestions for Further Work

The present work revealed symmetrical effects of relative CS duration on both excitatory and inhibitory CS's. These effects seemed to be accounted for by differences in the CS-US contingency as measured by the contingency ratio as developed in the preceeding discussion. Further work needs to be done to determine the effect of changes in both relative and absolute probabilities of US occurrence.

The discovery of an effect of absolute cycle duration on responding during the CS (and, possibly during the not-CS) that could not be attributed to differences in CS-US contingencies suggests that models of conditioning must take the effects of the temporal patterning of responding into account. Specifically, subjects seem to be sensitive to the duration of stimuli even when these durations are not related to differences in the rate of US occurrence. Subjects, or pigeons at any rate, seem especially sensitive to stimuli, including the passage of time, which are associated with changes in conditions of US occurrence or reinforcement. Further research needs to concentrate on "microanalysis" of changes in responding that occur immediately prior to or following stimulus change.

The present paradigm was useful in investigating both inhibitory and excitatory effects since both increases and decreases in response rates could be obtained. In general, inhibitory effects on responding during the not-CS were more consistent and exhibited less inter-subject variability than the excitatory effects on responding during the CS. This was evident fairly early in the experiment when it was noticed that subjects tended to engage in a wide variety of behaviors during the CS besides keypecking and that all these behaviors tended to reduce the occurrence of stimulus-directed keypecking. In some cases, these behaviors tended to predominate and keypecking for some subjects during the CS was almost completely suppressed during some conditions.

Subjects could also engage in a wide variety of behaviors during the not-CS. However, in this case, these behaviors all contributed to the inhibition of responding during the not-CS. This is, of course, the reason for the greater regularity of the inhibitory data. It might be more advantageous to examine CS-US contingencies by focusing on the inhibitory conditioning effects.

Although other behaviors that occurred during the CS and not-CS tended to have the same effect on keypecking, it should not be assumed that these behaviors were qualitatively similar. Observation of subjects during the experiment was very limited and unsystematic. However, the general impression obtained was that behavior during the CS tended to be of the nature of approaching the CS, pecking at or around the key, or pacing back and forth along the front panel. These behaviors can be characterized as "food anticipatory" or "terminal" behaviors (cf. Staddon and Simmelhag, 1971) which are associated with the imminent delivery of food. On the other hand, during the not-CS, subjects frequently retreated to the rear of the chamber and stood facing the back wall or interspersed pecking with quarter and half turns away from the front panel and the key. These behaviors can be characterized as "interim" activities which Staddon and Simmelhag (1971) and Rand (1977) have found to occur during periods of low reinforcement probability. Data reported by Wasserman, Franklin and Hearst (1974) indicate that pigeons tend to approach stimuli positively correlated with food presentation. These two tendencies may be the most general way CS-US contingencies exert an effect on the behavior of organisms.

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APPENDIX
ANALYSIS OF VARIANCE TABLES

TABLE A

ANALYSIS OF VARIANCE
CYCLE x RATIO x STIMULUS x REPLICATION

Source of Variation	df	MS	F
Main Effects			
Between Subjects			
1. Cycle Duration	1	87.68	0.11
2. Subjects w gps	6	785.66	
Within Subjects			
3. CS/cycle ratio	4	2,031.55	23.37***
4. Cycle x ratio	4	272.27	3.13*
5. Ratio x Subjects w gps	24	86.93	
6. Stimulus (CS vs not-CS)	1	14,948.46	25.80**
7. Cycle x Stimulus	1	3,025.94	5.22*
8. Stimulus x subjects w gps	6	579.27	
9. Replication	1	274.59	0.59
10. Cycle x replication	1	46.71	0.10
11. Replication x subjects w gps	6	464.93	

TABLE A (Continued)

Source of Variation	df	MS	F
12. Ratio x stimulus	4	1,036.77	9.31***
13. Cycle x ratio x stimulus	4	365.71	3.28*
14. Ratio x stimulus x subjects w gps	24	111.36	
15. Ratio x replication	4	230.80	2.19
16. Cycle x ratio x replication	4	143.95	1.37
17. Ratio x replication x subjects w gps	24	105.40	
18. Stimulus x replication	1	800.03	5.43
19. Cycle x stimulus x replication	1	388.63	2.64
20. Stimulus x replication x subjects w gps	6	147.40	
21. Ratio x stimulus x replication	4	211.48	3.78*
22. Cycle x ratio x stimulus x replication	4	116.67	2.09
23. Ratio x stimulus x replication x subjects w gps	24	55.93	

TABLE A (Continued)

Source of Variation	df	MS	F
Simple Main Effects			
Cycle x Stimulus			
1. Between cycles -CS	1	2,071.94	3.02
2. Between cycles not-CS	1	1,034.91	1.50
3. Within cells (cycle x stimulus)	12	685.56	
4. Between stimulus-60-sec cycle	1	15,712.78	26.83**
5. Between stimulus-480-sec cycle	1	2,261.64	3.86
6. Stimulus x subjects w gps	6	579.27	
Cycle x Stimulus x Ratio			
7. Between cycles at 0.125-CS	1	3,299.07	13.47***
8. Within cells (cycle x stimulus x ratio x subjects w gps)	30	244.99	

*p $\leqslant$ 0.05
**p $\leqslant$ 0.01
***p $\leqslant$ 0.001

TABLE B

ANALYSIS OF VARIANCE
CYCLE x CS/CYCLE RATIO x REPLICATION (NOT-CS ONLY)

Source of Variation	df	MS	F
<u>Between Subjects</u>			
1. Cycle duration	1	1041.71	8.39*
2. Subjects w gps	6	124.13	
<u>Within Subjects</u>			
3. CS/cycle ratio	4	1345.38	34.58**
4. Cycle x ratio	4	80.44	2.07
5. Ratio x subjects	24	38.91	
6. Replication	1	70.85	0.62
7. Cycle x replication	1	24.39	0.21
8. Replication x subjects	6	113.99	
9. Ratio x replication	4	10.54	0.48
10. Cycle x ratio x replication	4	62.73	2.83*
11. Ratio x replication x subjects	24	22.16	

*$p \leq 0.05$
**$p \leq 0.001$

TABLE C

ANALYSIS OF VARIANCE
CYCLE x STIMULUS

Source of Variation	df	MS	F
	Main Effects		
1. Cycle Duration	1	1,080.42	5.24
2. Cycle x Subjects	7	205.95	
3. Stimulus	1	4,920.32	12.28*
4. Stimulus x Subjects	7	400.63	
5. Cycle x Stimulus	1	1,528.22	15.81*
6. Cycle x Stimulus x Subjects	7	96.62	
	Simple Main Effects		
Cycle x Stimulus			
Between cycles -CS	1	2,589.28	17.11**
Between cycles not-CS	1	19.36	0.13
Pooled error	14	151.29	
Between Stimuli-60-sec cycle	1	5,966.40	23.99**
Between Stimlui 480-sec cycle	1	482.13	1.94
Pooled error	14	248.63	

*$p < 0.01$

**$p < 0.001$

TABLE D

ANALYSIS OF VARIANCE
CYCLE x STIMULUS x REPLICATION

Source of Variation	df	MS	F
Main Effects			
1. Cycle Duration	1	533.76	2.92
2. Cycle x Subjects	12	182.68	
3. Stimulus	1	11,012.60	10.90*
4. Stimulus x Subjects	3	1,010.22	
5. Replication	1	1,672.62	0.41
6. Replication x Subjects	3	4,067.11	
7. Cycle x Stimulus	4	1,473.41	8.52**
8. Cycle x Stimulus x Subjects	12	172.74	
9. Cycle x Replication	4	197.57	0.47
10. Cycle x Replication x Subjects	12	414.50	
11. Stimulus x Replication	1	806.70	0.22
12. Stimulus x Replication x Subjects	3	3,591.30	
13. Cycle x Stimulus x Replication	4	77.86	0.19
14. Cycle x Stimulus x Replication x Subjects	12	407.13	

TABLE D (Continued)

Source of Variation	df	MS	F
Simple Main Effects			
Cycle x Stimulus			
1. Stimuli at 60-sec cycle	1	9,642.75	28.39***
2. Stimuli at 120-sec cycle	1	5,167.81	15.19**
3. Stimuli at 240-sec cycle	1	1,199.76	3.53
4. Stimuli at 480-sec cycle	1	895.90	2.63
5. Pooled Error	15	340.24	
6. Cycles - CS	4	1,806.88	10.17***
7. Cycles - not - CS	4	200.30	1.27
8. Pooled Error	24	177.71	

*$p \leq 0.05$
**$p \leq 0.01$
***$p < 0.001$

TABLE E

CYCLE x RATIO x REPLICATION
(FIRST CS SUBINTERVAL COMPARISONS)

Source of Variation	df	MS	F
Main Effects			
Between Subjects			
1. Cycle Duration	1	855.92	0.70
2. Subjects w gps	6	1,212.74	
Within Subjects			
3. CS/Cycle Ratio	3	1,268.45	8.87**
4. Cycle x Ratio	3	861.68	6.02*
5. Ratio x Subjects	18	142.99	
6. Replication	1	1,139.09	2.06
7. Cycle x Replication	1	112.38	0.20
8. Replication x Subjects	6	550.80	
9. Ratio x Replication	3	386.49	2.17
10. Cycle x Ratio x Replication	3	255.87	1.51
11. Ratio x Replication x Subjects	18	178.05	

TABLE E (Continued)

Source of Variation	df	MS	F
Simple Main Effects			
1. Between Cycles at 0.125 Ratio	1	3,304.52	8.05*
2. Between Cycles at 0.25 Ratio	1	71.74	
3. Within Cell (Pooled Error)	24	410.43	
4. Between Ratios at 60-sec Cycle	3	1,961.67	13.72**
5. Between Ratios at 480-sec Cycle	3	168.55	
6. Ratio x Subjects	18	142.99	

*$p < 0.01$
***$p < 0.001$