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SERIAL CONDITIONING AS A FUNCTION OF STIMULUS, RESPONSE, AND TEMPORAL DEPENDENCIES

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Six experiments were used to examine the effects of explicit response, stimulus, and temporal dependencies on responding in an interfood interval. The first two experiments demonstrated that 10-segment 60-s interfood clocks controlled similar distributions of key pecking in pigeons regardless of whether response–reinforcement contiguity was required, allowed, or precluded. The third and fourth experiments found that in the absence of an explicit response–reinforcement dependency, systematic explicit stimuli in an interfood interval were sufficient to establish and maintain the characteristic distribution of key pecking and that an interval without an explicit clock failed to establish or maintain key pecking. The last two experiments demonstrated that the interfood interval need not be of fixed length, and that a simple correlation of stimuli with increments from either a minimum to a maximum imminency or probability of food presentation controlled behavior in a similar manner. Successively higher rates generally occurred to successively later stimuli in the upper half of the range.

Key words: response dependency, stimulus dependency, temporal dependency, clock stimuli, serial compound, sign tracking, autoshaping, key peck, pigeons

The characteristically increasing average response rate controlled by a typical fixed-interval (FI) schedule is often presumed to be the result of an imperfect discrimination formed on the basis of elapsed time or indirectly based on the number of responses occurring in the interval. Responding is thought to accelerate up to the point of food presentation because the conditions become increasingly like those existing at the moment of previous reinforcement (Skinner, 1938). The lack of sharp stimulus control in an interval schedule is usually taken to indicate that the underlying variables controlling behavior must either be difficult to discriminate accurately or must vary too much for a precise discrimination to emerge.

This theoretical view prompted Ferster and Skinner (1957) to propose that, with an external clock, responding under an FI schedule would become more efficient. In fact, they suggested that an interval with a perfect clock would come to contain only a single response. Their addition of a continuously varying external stimulus to an FI, however, resulted in only a moderate improvement in performance. Responding occurred later in the interval but many responses were still emitted before the moment of reinforcement.

Palya (1985) presented data demonstrating that clock stimuli other than the stimulus directly contiguous with food presentation controlled chronic key pecking by pigeons. The procedure partitioned a fixed 60-s interfood interval into 10 6-s periods, each correlated with a distinctive hue on the response key. It reliably generated and maintained successively higher average rates of key pecking at stimuli successively closer to food. The resulting behavior was attributable neither to hue generalization nor to a simple temporal gradient. A second experiment (Palya & Pevey, 1987) demonstrated that this responding is most appropriately characterized as responding across the last half of an interval rather than responding for some absolute number of seconds or to some absolute number of stimuli preceding food presentation.

In recent years, there has been considerable debate over the factors governing the discriminability of time and the adequacy of various perceptual explanations for the behavior controlled by FI schedules (Church, 1978; Gibbon & Balsam, 1981; Platt, 1979; Zeiler, 1979). Unfortunately there has not been an equally intensive effort to understand why explicit clocks fail to provide the sharp stimulus control that would be required if the early responding

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in an interval were nothing more than a perceptual failure. Clearly a better understanding of the behavior in interfood clocks would therefore contribute to understanding the behavioral equilibrium in temporal intervals in general.

A potentially important, but as yet unknown, aspect of the behavior controlled by interfood clocks is the degree to which it is sensitive to contingencies between occurrences of food presentation and antecedent stimulus (S-S*), response (R-S*), or temporal (T-S*) factors. Therefore, contingencies between reinforcement and the key peck, the availability of a clock, and the time since the previous food presentation were examined in these experiments.

GENERAL METHOD

Subjects

Fifty-five adult White Carneau pigeons obtained from a local supplier were used. Forty-five were experimentally naive. The remainder had had previous experience with an interfood clock. All were housed under a 19:5 hr light/dark cycle in individual cages with free access to water. They were maintained at approximately 80% of their ad-lib weights with pelletized laying mash.

Apparatus

Five experimental chambers were used. The interior of each was a 30-cm cube. An unfinished aluminum panel served as one wall of the chamber and as the stimulus panel; the other sides were painted white. The stimulus panel had a circular feeder aperture through which pelletized food could be obtained when a hopper was elevated. It was 5 cm in diameter and medially located 8 cm above a grid floor. Three response keys, 2 cm in diameter, were located 9 cm apart, 19 cm above the grid floor. Only the center key was used. It required approximately 0.15 N to operate. The translucent Plexiglas key could be transilluminated by a stimulus projector containing 25-lumen bulbs (1815 C2F), each behind a different color filter. The filters were the following Rosco theatrical gels: pink (34), red (26), orange (23), amber (20), yellow (12), green (91), turquoise (73), blue (68), and purple (58). A Lee color correcting filter (218) was used to produce white. Two houselights were adjacent and centrally located on the stimulus panel 8 cm above the keys. They were shielded such that light was directed only toward the ceiling. Ventilation was provided by an exhaust fan mounted on the outside of the chamber. A white noise generator provided ambient masking noise in the room in which the chambers were located. Stimulus events were controlled and key pecks were recorded by a computer system (Doyle & Palya, 1980; Walter & Palya, 1984).

Procedure

Prior to an experimental procedure, naive birds were exposed to a manually operated food magazine until they reliably approached from anywhere in the chamber and ate from the food hopper within 3 s of its elevation.

All procedures were variations of an interfood clock. The underlying procedure common to all experiments was a fixed 60-s interfood interval segmented into 10 6-s periods, each of which could be designated by a different key color. Typically the color sequence was white, pink, red, orange, amber, yellow, green, turquoise, blue, and purple. Human observers reported that the stimuli in this series were easy to differentiate. Previous findings (Kaplan & Hearst, 1982; Palya, 1985) had indicated that stimulus generalization is not a primary determinant of responding to the antecedent stimuli in a serial compound. However, some procedures were implemented with other permutations in order to confirm that hue order was not an important determinant of the behavior. Appendix 1 documents the sequences used in each experiment. In most cases a 3-s food presentation immediately followed the offset of the final stimulus irrespective of behavior, and the stimulus sequence then repeated immediately following food offset with no intertrial interval. The number of food presentations each bird received each session was based on its body weight that day. Typically each bird received between 30 and 50 trials per session. A typical session therefore lasted approximately 40 $\pm$ 10 min.

EXPERIMENT 1A

One aspect of the description of the behavior controlled by an interfood clock is the degree to which response–reinforcer contingencies determine the distribution of behavior in the interfood interval (Ferster & Skinner, 1957).

Therefore, this and the following experiment examined the effect of the contingency between the dependent variable (key pecking) and the reinforcer on the distribution of that responding in the interfood interval.

METHOD

Subjects and Apparatus

Three naive pigeons and 3 with previous exposure to an interfood clock were used. All procedures were implemented in the same chamber.

Procedure

The procedures were first implemented with the 3 nonnaive birds and then were replicated with the 3 naive birds. All 6 pigeons were exposed initially to a fixed 60-s interfood interval divided into 10 6-s time periods, each correlated with a different key color. All nonnaive birds and 1 naive bird received the standard sequence of colors. The sequence for the remaining 2 birds is given in Appendix 1. Food was presented after the offset of the 10th stimulus irrespective of behavior. This schedule was in effect for 30 sessions for both sets of birds. In the second phase a response dependency was added at the end of the interfood clock. The final stimulus remained in effect until reinforcement. This changed the procedure from a clocked fixed-time (CFT) schedule to a clocked fixed-interval (CFI) schedule. This phase was continued for 42 sessions for the nonnaive birds and 25 sessions for the naive birds. In Phase 3 the baseline procedure was reinstituted by removing the response requirement. Phase 3 was therefore identical to Phase 1 and was in effect for 20 sessions for the nonnaive birds and 25 sessions for the naive birds.

RESULTS AND DISCUSSION

Figure 1 presents the response distributions obtained from Experiment 1A. The mean response rate in each third of each stimulus across the last five sessions of each phase for each bird is presented. The rates to each third of each stimulus are shown in order to depict the within-stimulus distribution of responding. Appendix 2 presents the index of curvature (Fry, Kelleher, & Cook, 1960) for the data provided in each frame of Figure 1 (and all subsequent figures). Index of curvature is a single value that designates the degree to which responding is evenly distributed throughout the interval (.000) or is concentrated only in the final bin (.967). The values presented in Appendix 2 are based on 30 bins per interval. The mean number of responses in the 30 bins included in each frame is provided in parentheses. Unfortunately, index of curvature and other single-value indices are sensitive to factors such as the response rate in the final bins of the interval, in addition to the position of the bulk of responding in the interval. However, because the index of curvature is a traditional measure for the distribution of behavior in an interval, it is available as an appendix. In the present research, instances of low terminal rates, differences in the direction of rate changes across the interval, and instances of trials with only a few responses make the interpretation of the index of curvature problematical. This is especially the case when an effect indicated by the index of curvature is apparent only because of changes in rate in the final portion of the interval.

In Phase 1 (CFT; left column) the schedule controlled successively increasing rates to the successively later stimuli in the early portion of the second half of the interfood interval, followed in most cases by a subsequent decline late in the interval. The increasing rate across the early portion of the second half of the interfood interval is typical of that obtained with CFT schedules (e.g., Palya, 1985). In the present case the rate declined across the final portion of the interval and within the final stimulus in 5 of the 6 birds. This is a frequent finding with these schedules but, as can be seen, not an inevitable one (Gibbon, Farrell, Locurto, Duncan, & Terrace, 1980; Palya, 1985; Palya & Pevey, 1987).

In the second phase a response dependency was added to the interfood clock. The overall pattern of responding across the interfood interval did not exhibit a change substantial and consistent enough to be apparent by simple inspection in the response distributions of most birds, in spite of the fact that the mean rate to the final stimulus increased in 5 of 6 birds. The index of curvature increased in the same 5 birds.

The pattern of responding within the final stimulus was affected inconsistently. Even though the absolute rate to the final third of the final stimulus increased in 5 of 6 birds, 3 birds continued to show a decreasing rate across the final stimulus. Therefore the pattern of

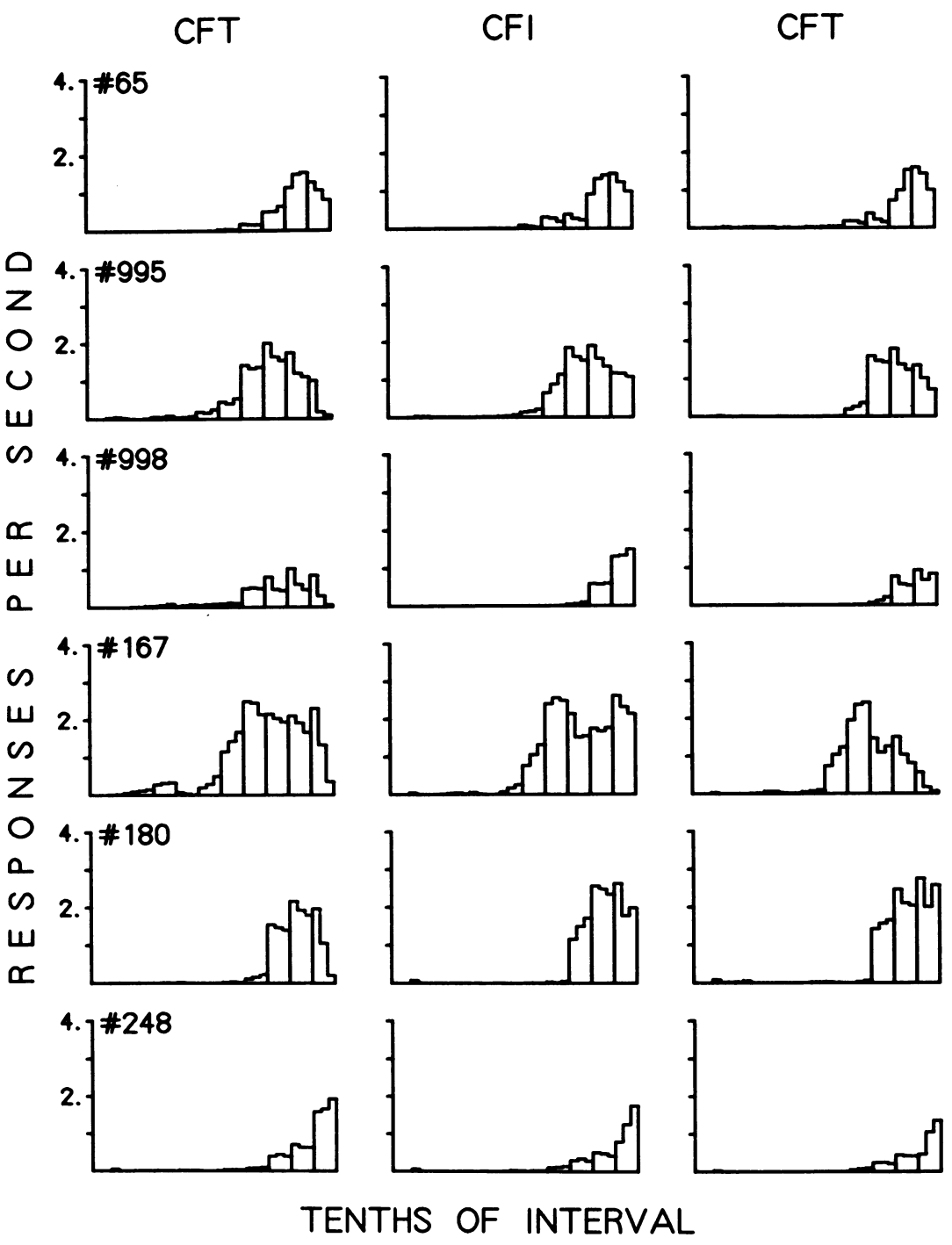

Fig. 1. Asymptotic distribution of responding for each bird to the interfood clock stimuli in each of the three phases of Experiment 1A. The data are the mean response rates in each third of each of the 10 stimuli averaged over the last five sessions. Data for the clocked fixed-time schedules (CFT) implemented in Phase 1 and its reinstitution in Phase 3 are presented in the leftmost and rightmost columns, respectively. Data for the clocked fixed-interval schedule (CFI) implemented in Phase 2 are presented in the center column.

responding within the final stimulus also failed to differentiate clearly behavior maintained by an operant procedure from that maintained by a Pavlovian procedure.

Baseline conditions were reestablished in Phase 3. This return to baseline substantiated the failure to demonstrate any sizable or widespread effects on the overall pattern of responding attributable to the explicit response dependency. The mean rate to the final stimulus declined in all but 1 bird with a return to a CFT schedule. This confirmed the finding that CFI schedules generally maintain higher mean rates to the final stimulus than do CFT schedules. However, the decline did not occur in 1 bird (180) and was very small for 2 others. Response rate decreased for Bird 65 by only 0.02 responses per second and for Bird 995 by only 0.03 responses per second.

Even though the higher response rate to the final stimulus when a response was required was not necessarily substantial or clearly reversible, it was typical. A plausible, albeit post hoc, explanation for this difference could be that the response dependency required a key peck 6 s after the onset of the final stimulus, whereas the CFT schedule allowed competing anticipatory food magazine approach to become prepotent. This view is supported by the fact that 3 of the 6 birds had near-zero rates in the final third of the last stimulus in Phase 1. The failure to recover baseline completely may then have been the perseveration of a response pattern, in the absence of strong factors controlling the reestablishment of the original distribution. The obvious remaining question is why key pecking was maintained at all when other behavior was more closely followed by the reinforcer (Hearst & Jenkins, 1974).

The distribution of responding obtained with a CFI was similar to that controlled by a CFT. This could be seen as the result of different processes (Rescorla & Solomon, 1967) similarly affecting the distribution of responding or as the result of there being only a single effective process responsible for the behavior maintained by the two procedures. A stimulus dependency may actually have been responsible for the distribution controlled by the procedure with an added response dependency, or an adventitious response contingency may have been responsible for the distribution controlled by the stimulus-dependent procedures. Alternatively, the general absence of an effect on patterning when the response dependency was added may be used as evidence that some other factor that was unchanged by adding the response dependency was the primary determinant of the distribution. The controlling variable may have been the interreinforcer interval itself rather than the dependency of food presentation on a specific stimulus or response. The alternative views are impossible to resolve with the present procedure in that any data can be made consistent with either view by appealing to various theoretical stimulus or response elements.

EXPERIMENT 1B

Experiment 1A demonstrated that the addition of an explicit response dependency to an interfood clock made little difference in the obtained distribution of key pecking. Additional information relevant to understanding the importance of the response–reinforcer relationship on behavior in the interfood interval may be obtained by assessing the effects of precluding response–reinforcer contiguity. A procedure that omitted the reinforcer whenever a key peck occurred in the final stimulus (Sheffield, 1965; Williams & Williams, 1969) was therefore implemented to determine the degree to which interfood clock stimuli can establish and maintain key pecking when food presentation never closely followed a key peck.

METHOD

Subjects and Apparatus

Eighteen naive pigeons and three chambers were used.

Procedure

This experiment implemented an interfood-clock procedure with the addition of an omission dependency in the final stimulus. The 18 birds were exposed to a fixed 60-s interfood interval segmented into 10 6-s time periods, each correlated with a different key color. Two variants of the omission dependency were used (Locurto, 1981). For one group a response in the final clock stimulus immediately terminated the trial and resulted in a 3-s timeout, after which the next interval began. For the other group, a response in the final stimulus period also converted the subsequently scheduled food presentation to a 3-s timeout. How-

ever, in this case the response had no effect on the programmed duration of the final stimulus.

This experiment was conducted originally with two groups of 6 birds each and was subsequently replicated with two more groups of 3 birds each. All birds were exposed directly to the omission procedure immediately after magazine training with no pretraining. In the original study all birds in a group had the same stimulus sequence. The birds in the immediate-trial-termination group received a turquoise-orange-white-green-yellow-blue-amber-red-pink-purple stimulus order, and the birds in the food-loss-only group received a pink - red - white - amber - green - orange - turquoise-blue-purple-yellow stimulus order. In the replication three other sequences were used. As noted in Appendix 1, each of the three stimulus sequences was assigned to 1 bird from each group. The first study was in effect for 75 sessions, each of which contained approximately 72 trials. The replication was in effect for 50 sessions, each of which contained approximately 74 trials. Therefore sessions lasted approximately 75 min.

Results and Discussion

Figure 2 presents the mean response rate to each third of each stimulus across the last five sessions of each condition as a continuous function for each bird. Data from all birds exposed to a condition are presented in a single frame because no within-bird comparisons across phases were possible. The data for the procedure in which a peck terminated the trial as well as canceled food delivery are given in the left frame, and the right frame provides data for the procedure in which a response simply canceled the subsequent food presentation.

Even when no key peck had ever occurred within 6 s of food presentation and no pecks in the presence of the contiguous stimulus were ever reinforced, all but 1 bird pecked at least once during the interfood interval on more than 75% of the trials, and half of the birds pecked at the final stimulus on more than 25% of the trials.

It could be argued that the obtained distribution was a heterogeneous chain of behavior with adventitiously reinforced key pecks in the early links and some other adventitiously reinforced behavior in the final link. However, it would be necessary to postulate some R-S* process that reinforced one topography (anything other than key pecking, e.g., Reynolds, 1961) in the final stimulus and that was capable of adventitiously maintaining a different topography (i.e., key pecking) at the earlier stimuli for 75 sessions (Boren, 1969; Herrnstein, 1966). The simplest explanation appears to be that a response contingency is not a necessary prerequisite for responding to be acquired and maintained to the clock stimuli in the second half of an interfood interval (Hearst & Jenkins, 1974; Schwartz & Gamzu, 1977).

The second notable finding of this experiment was that in some respects the pattern of responding in the interfood interval was comparable to that obtained with a CFT or CFI schedule. Responding started at the midpoint or somewhat later and successively increased across the successive stimuli in the early portion of the second half of the interfood interval.

The omission dependency did have an effect, however. Response rates to an interfood clock with an omission dependency were lower than the rates obtained with naive birds exposed to a clock without an omission dependency. Using Experiment 1A as a reference, the group-mean rates were 0.19, 0.10, and 0.59 responses per second for omission with trial termination, with food loss only, and for a CFT schedule, respectively. Rates to the final stimulus with the omission dependency were very much lower than the rates to the final stimulus in a simple CFT schedule. The group-mean rates were 0.17, 0.05, and 1.38 responses per second for omission with trial termination, with food loss only, and in a CFT schedule, respectively. Considering the procedure, however, this is not surprising. The procedure decreased the probability of food following a trial, established a positive reinforcement contingency between behavior other than key pecking and food presentation, and may be seen as either differentially extinguishing key pecking in the final stimulus or explicitly following key pecking in the final stimulus with a putatively aversive event. It would be expected that a timeout and a return to the beginning of the interfood interval would suppress the behavior that immediately preceded that consequence (Ferster, 1958; Todorov, 1971).

A tangential but interesting finding was that the food-loss-plus-immediate-trial-termination procedure resulted in more instances of at least one key peck to the final stimulus than did the food-loss-only procedure (Locurto,

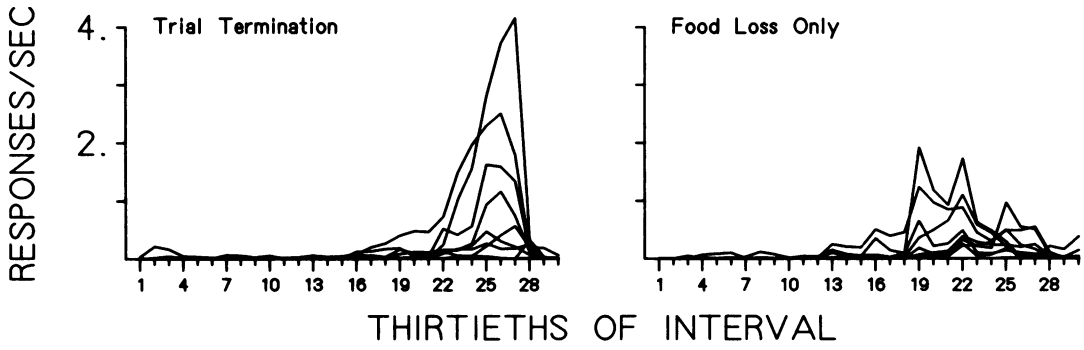

Fig. 2. Asymptotic distribution of responding for each bird to the interfood clock stimuli in the two procedures of Experiment 1B. The data, depicted as continuous functions, are the mean response rates in each third of each of the 10 stimuli averaged over the last five sessions. The data for each of the 9 birds on the omission dependency with an immediate-trial-termination procedure (Trial Termination) are presented in the left frame. The data for the 9 birds under the omission dependency with food-loss-only procedure (Food Loss Only) are presented in the right frame.

Terrace, & Gibbon, 1978). Fifty-one percent (48% if the highest and lowest rate birds were removed) of the occurrences of the final stimulus in the immediate-trial-termination procedure controlled at least one peck, whereas only 24% (14%) of the final stimuli of the food-loss-only procedure contained a peck. In addition, the general form of the distribution differed. The immediate-trial-termination procedure resulted in a higher frequency of increasing rates in the later portions of the second half of the interval as well as a generally higher index of curvature. A potential explanation for this difference is that the immediate response-dependent termination of the final stimulus provided a shorter mean terminal stimulus duration per food presentation (3.86 s rather than 6.00 s) (Gibbon & Balsam, 1981; Jenkins, Barnes, & Barrera, 1981). It seems that an operant interpretation for the increasing rates in the group with an immediate timeout following a key peck would be especially strained. Although the effect could be described as conditioned reinforcement as the result of pairing light offset with food onset, it would have been difficult to predict the direction of the rate change. It would be necessary to postulate a plausible explanation for the chronic reinforcing effect of a timeout designating the absence of food and the reinstitution of a 60-s delay to food presentation.

EXPERIMENT 2A

Experiments 1A and 1B demonstrated that food presentation immediately following a key peck was not central to the explanation of the increasing rate across the early portion of the second half of an interfood clock. Experiments 2A and 2B assessed the effect of explicit stimuli correlated with the passage of time on the distribution of responding in the interfood interval. Experiment 2A examined the distribution of an operantly reinforced response in interfood intervals with and without an explicit clock.

METHOD

Subjects and Apparatus

Three pigeons with previous exposure to interfood-clock schedules and one chamber were used.

Procedure

The 3 pigeons were exposed first to 30 sessions of a 10-segment 60-s CFT schedule. Phase 2 implemented a single-stimulus FI schedule for comparison with the CFT schedule of Phase 1. The 60-s interval was not segmented into 10 separate stimuli; instead, the key was transilluminated with the final hue of the previous phase throughout the entire interfood interval. Food presentation followed the first response after the lapse of 60 s. This single-stimulus FI procedure was continued for 50 sessions.

Phase 3 added clock stimuli to the FI schedule. The clock advanced each 6 s through the same sequence used in the initial CFT schedule of Phase 1. The last stimulus remained in effect until the response-dependent food pre-

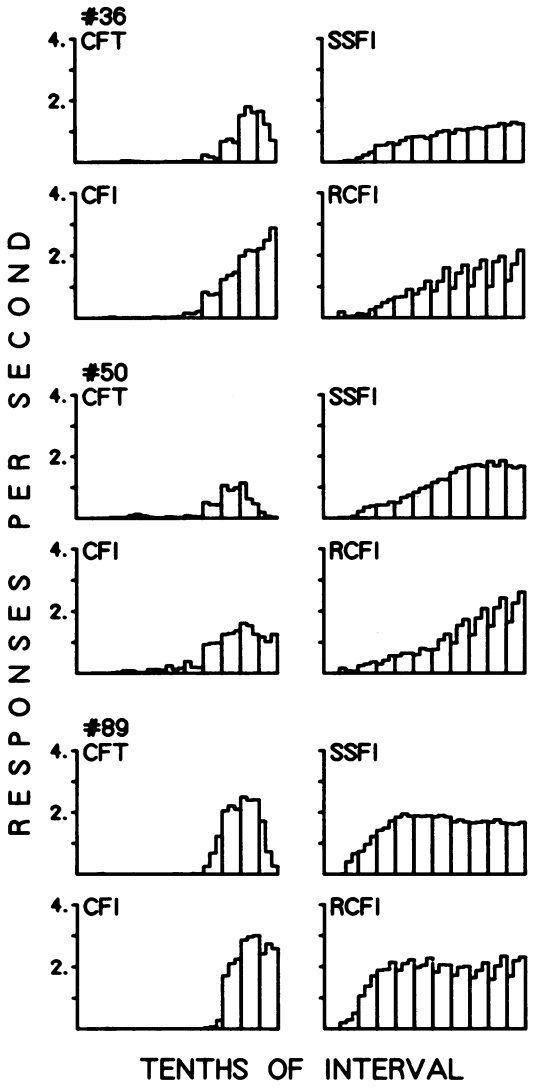

Fig. 3. Asymptotic distribution of responding for each bird across the interfood intervals in each of the four phases of Experiment 2A. The data are the mean response rates in each third of each of the 10 stimuli (or consecutive 30ths of the interval) averaged over the last five sessions. The upper left frame in each set presents the data obtained with a clocked fixed-time schedule (CFT) (Phase 1). The upper right frame in each set presents the data obtained under a single-stimulus fixed-interval schedule (SSFI) (Phase 2). The lower left frame in each set depicts the data obtained with a clocked fixed-interval schedule (CFI) (Phase 3), and the lower right frame depicts the data obtained with a randomly clocked fixed-interval procedure (RCFI) (Phase 4).

sentation occurred. This CFI schedule was identical to the Phase 1 procedure with the exception of the added response dependency. This phase lasted 30 sessions.

In the fourth phase both the stimulus change every 6 s and the response dependency were retained, but the order of the clock stimuli was randomized. For each 60-s interfood interval, the 10 clock stimuli were each presented once in a random order. This randomly clocked FI procedure was in effect for 20 sessions.

Results and Discussion

Figure 3 presents the data obtained in this experiment. The mean response rate to each third of each stimulus across the last five sessions of each phase for each bird is depicted. The upper left frame in each set presents the data obtained with a CFT schedule. This schedule controlled successively increasing rates to the successively later stimuli in the second half of the interfood interval as was expected. All 3 birds exhibited the terminal rate decline seen in most of the birds of Experiment 1A.

The upper right frame in each set presents the data obtained under a single-stimulus FI schedule. The distribution of behavior obtained with this procedure was typical of an FI schedule but differed substantially from that maintained by a CFT schedule. Even though both schedules generated successively higher rates in successively later portions of the interval, responding in the single-stimulus FI schedule began, on average, much earlier. In addition, rate changes within each 10th of the interval were much less pronounced. This was expected because there were no correlated explicit stimulus changes. As the result of extending the interval until the response requirement was met, the mean interval duration over the last five sessions of this phase was 60.59 s.

Phase 3 added clock stimuli to the simple FI schedule of Phase 2. As a result, less responding occurred in the early portions of the interval. The resulting distribution of responding can be seen in the lower left frame of each set. In general, the pattern of responding across the interfood interval appeared to be the same as the behavior maintained by a CFT schedule. This comparison of CFT and CFI schedules replicated the finding obtained in Experiment 1A. The only notable difference between CFT and CFI is, again, the higher mean response rate at the last portion of the interval when a response is required. The mean interval length over the last five sessions of this phase was 60.40 s.

The final phase maintained the response dependency but randomized the clock stimuli.

This manipulation was implemented to provide a comparison between the behavior controlled by a randomly clocked FI and a single-stimulus FI. In general, the overall response distribution obtained with this procedure was the same as that controlled by a single-stimulus FI schedule. The mean rates in each 10th of the interval were very similar to those obtained with the single-stimulus FI schedule. This finding indicated that a fixed number of stimulus changes in an interval was not a sufficient condition to obtain lower mean response rates in the early portions of an interval. The mean interval length over the last five sessions of this phase was 60.39 s.

However, the randomized-clock procedure did produce an interesting effect. A clearly defined drop in response rate in the first third of each of the final stimuli occurred, followed by a rate increase across the remainder of the stimulus duration. This effect occurred for the most part in the second half of the interval and was increasingly pronounced as the interval elapsed. In this respect the individual component stimuli of a randomly clocked FI schedule produced first-half suppression similar to that found in a CFI, a simple FI (Skinner & Morse, 1957), or in chained FI schedules (Byrd, 1971).

Ferster and Skinner (1957) presumed that the laws of contiguity, discrimination, and least effort would result in only a single response in a perfectly clocked FI schedule. Therefore, any additional responding in that interval would necessarily be the result of a failure to discriminate or some other additional process such as conditioned reinforcement. In this regard, Ferster and Skinner followed the theoretical perspective of Spence (1956), from which responding to the antecedent stimuli of the second half of a clock would be seen as higher than expected.

Dews (1962), on the other hand, like Hull (1943, 1952), suggested that the behavior controlled by a single-stimulus FI schedule was the result of a relative-delay-of-reinforcement gradient. From Dews' perspective the rate of responding in each portion of an interval was an index of the extent to which that behavior could be supported by reinforcement delayed by that relative amount (e.g., one half the interval), rather than the discriminability of that temporal portion of the interval from the time of reinforcement. Therefore, in the absence of additional processes, interfood intervals of any duration would control essentially identical distributions of behavior. The rate controlled by reinforcement delayed by one half of an interval would be the same regardless of the absolute delay. From this perspective, responding to the middle portions of a single-stimulus interval or to the middle stimuli of an interfood clock would be expected.

The behavior obtained with a clocked interfood interval does not support a simple version of either Ferster and Skinner's (1957) discriminability gradient or Dews' (1962) relative-delay-of-reinforcement gradient. Perceptual explanations of early responding in interval schedules without correlated stimuli, such as those based on discriminability of temporal stimuli, fail to account for chronic responding to the antecedent stimuli in an interfood clock. The present procedure may be seen as nothing more than the formalization of the theoretical temporal stimuli often advanced to explain FI performance (Zeiler, 1977). In the present case, however, it is expected that the stimuli would be easily discriminable. The discriminability view must therefore invoke an additional process, such as conditioned reinforcement or higher order conditioning, and further must suggest that that effect is not necessarily susceptible to the laws of discrimination and least effort.

Although explanations based on relative delay of reinforcement fare better than those based on perceptual factors, they, too, also fail to predict adequately the results of the present experiment. Relative delay from a response in a particular portion of the interval to food presentation remains unchanged regardless of the availability of clock stimuli. A delay-of-reinforcement position would therefore be required to invoke some additional process to account for the difference between the distributions obtained under the single-stimulus and clocked interfood intervals and to explain the lower than expected rates with the clock.

EXPERIMENT 2B

Experiment 2A demonstrated that the presence of clock stimuli modulated the distribution of operantly maintained responding in interfood intervals and was capable of chronically controlling responding to the antecedent stimuli in the second half of the interval. Experi-

ment 2B examined the importance of the clock stimuli for the acquisition and maintenance of key pecking when that behavior was not supported by an explicit response–reinforcer dependency. Two subexperiments were used in order to examine both a single-stimulus maintenance task and a single-stimulus acquisition task.

Method

Subjects and Apparatus

Fifteen naive pigeons and five experimental chambers were used.

Procedure

The first subexperiment examined the ability of a single-stimulus FT schedule to maintain responding that had been acquired with a CFT schedule. Phase 1, therefore, implemented a 10-segment 60-s CFT schedule with 12 birds for 30 sessions. The standard color sequence was used with 4 birds. The color sequence used for the remaining birds is given in Appendix 1. Phase 2 simply removed the clock stimuli, and food presentation continued to occur every 60 s. In the event that initial rates affected the outcome of this procedure, two subgroups were formed. For 7 of the birds, the single stimulus in effect during the interfood interval was the initial stimulus of their sequence in Phase 1. For the other 5 birds, the final stimulus of their Phase 1 sequence was used. This single-stimulus FT schedule was continued for 25 sessions.

The second subexperiment examined the ability of a single-stimulus FT schedule to establish the distribution of key pecking characteristically obtained when naive birds are exposed to a CFT schedule. Subsequently, this group of 3 pigeons was used to replicate the procedures implemented in the preceding subexperiment. In Phase 1 of this subexperiment the birds were exposed to 30 sessions of a 60-s single-stimulus FT schedule. In Phase 2 a 10-segment 60-s CFT schedule was in effect for 25 sessions. Phase 3 reinstituted the single-stimulus baseline procedure for 25 sessions. The stimulus sequences used for each bird during each phase of this subexperiment are given in Appendix 1.

Results and Discussion

Figure 4 depicts the results of Experiment 2B. The mean response rate in each 30th of the interval across the last five sessions of each phase is depicted as a continuous function for each bird and combined in a single frame, because within-bird comparisons across phases were not necessary. The upper left frame depicts the behavior obtained under the initial CFT schedule in Subexperiment 1. Responding was typical of a CFT schedule and showed accelerated responding across the early portion of the last half of the interval. The upper right frame shows that a single-stimulus interval failed to maintain responding in every bird. The mean number of trials to a criterion of 20 trials without a response was 142 for the birds exposed to intervals with only their initial clock stimulus and 377 for the birds exposed to intervals containing only their final clock stimulus.

The lower set of frames depicts the results of the second subexperiment. The leftmost frame shows that key pecking was not acquired under a single-stimulus procedure. The center frame shows that, when these birds were subsequently exposed to an interfood clock, all 3 exhibited the characteristic distribution of key pecking, except for one that apparently pecked only in the last stimulus. The lower rates in these birds as compared to similar procedures in Experiments 1A and 2A may be seen as evidence for blocking by the context (Tomie, 1985). According to this view, the context (e.g., walls, houselights, white noise, etc.) becomes conditioned as the result of being paired with food presentation. This conditioning then serves to block the ability of the clock stimuli to control key pecking as the result of being followed by the food presentation. The rightmost frame demonstrates that when a single-stimulus interfood interval was reinstituted responding virtually ceased, thus confirming the inability of single-stimulus intervals to maintain key-pecking without an explicit response requirement. The mean number of trials before the criterion of 20 trials without a response for these 3 birds was 459 trials.

It is apparent that the clock stimuli have two important effects. An interfood clock modulates the output of an FI schedule. There was a clear reduction in responding in the early portions of the interval when stimuli correlated with the passage of time were present in Experiment 2A. However, this reduction was not complete. A great deal of unnecessary responding remained in the face of periods correlated with the absence of food, and that responding

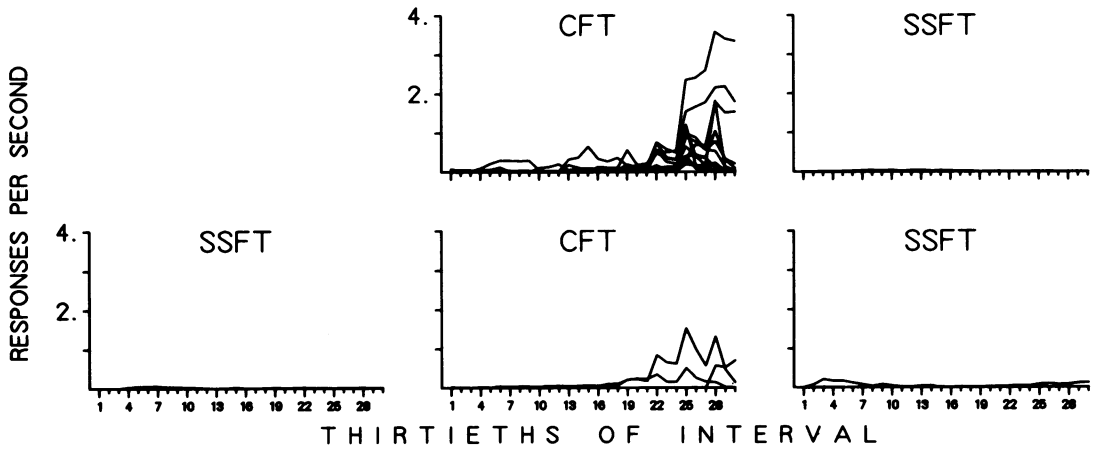

Fig. 4. Asymptotic distribution of responding for each bird across the interfood interval in each phase of the two subexperiments of Experiment 2B. The data, depicted as continuous functions, are the mean response rates in each third of each of the 10 stimuli (or consecutive 30ths of the interval) averaged over the last five sessions. The upper set of frames present the data obtained from each of the 12 birds in the first subexperiment. The upper left frame depicts the data for the clocked fixed-time schedule (CFT) (Phase 1), the upper right frame depicts the data for the single-stimulus fixed-time schedule (SSFT) (Phase 2). The lower set of frames present the data obtained from each of the 3 birds in the second subexperiment. The lower left frame depicts the data for the single-stimulus fixed-time schedule (SSFT) (Phase 1). The lower center frame depicts the data obtained with the clocked fixed-time schedule (CFT) (Phase 2). The lower right frame depicts the data obtained with the return to a single-stimulus fixed-time (SSFT) schedule (Phase 3).

was not predicted adequately by the laws of discrimination and least effort. Second, an interfood clock reliably establishes key pecking as the dominant behavior in the second half of an interfood interval in the absence of reliable contiguity between a key peck and food presentation.

In general, the data obtained in Experiments 1 and 2 indicated that an interfood interval controlled the same distribution of key pecking regardless of whether an operant or respondent process was the most plausible source of that behavior. The most obvious interpretation for responding in a single-stimulus FI schedule is an operant one, whereas the most obvious view for the results of the omission procedure is that the pecking was respondent. Although an exclusively operant or exclusively respondent interpretation for these results could be offered, a clear proof of a single underlying learning process in a particular procedure may be impossible or irrelevant (Hearst, 1975). A simple emphasis on the functional effects of variables such as response–reinforcer and stimulus–reinforcer conjunctions seems most appropriate.

In sum, these findings invite the view that a successively increasing response rate to the second half of an interval represents the normal allocation of increasing amounts of behavior across the second half of a temporal interval, rather than being the result of some additional factor such as temporal confusion. Responding to the early stimuli in the second half of the interfood interval may therefore find its explanation in a perspective based in relative notions of contiguity, higher order conditioning, or conditioned reinforcement. These relative views are consistent with increasing rates of chronically maintained behavior to explicit, discriminably different, stimuli that are correlated with successively later portions of the second half of an interfood interval.

EXPERIMENT 3A

The increasing rate to the final stimuli of an interfood clock may be determined by the constancy of the interfood interval. For example, the fixed interfood interval may generate some fixed gradient to which the successive clock stimuli must be correlated if they are to control pecking. Experiments 3A and 3B examined the effect of the contingency of a constant time since a preceding food presentation and reinforcement on the distribution of responding in an interfood interval. In Ex-

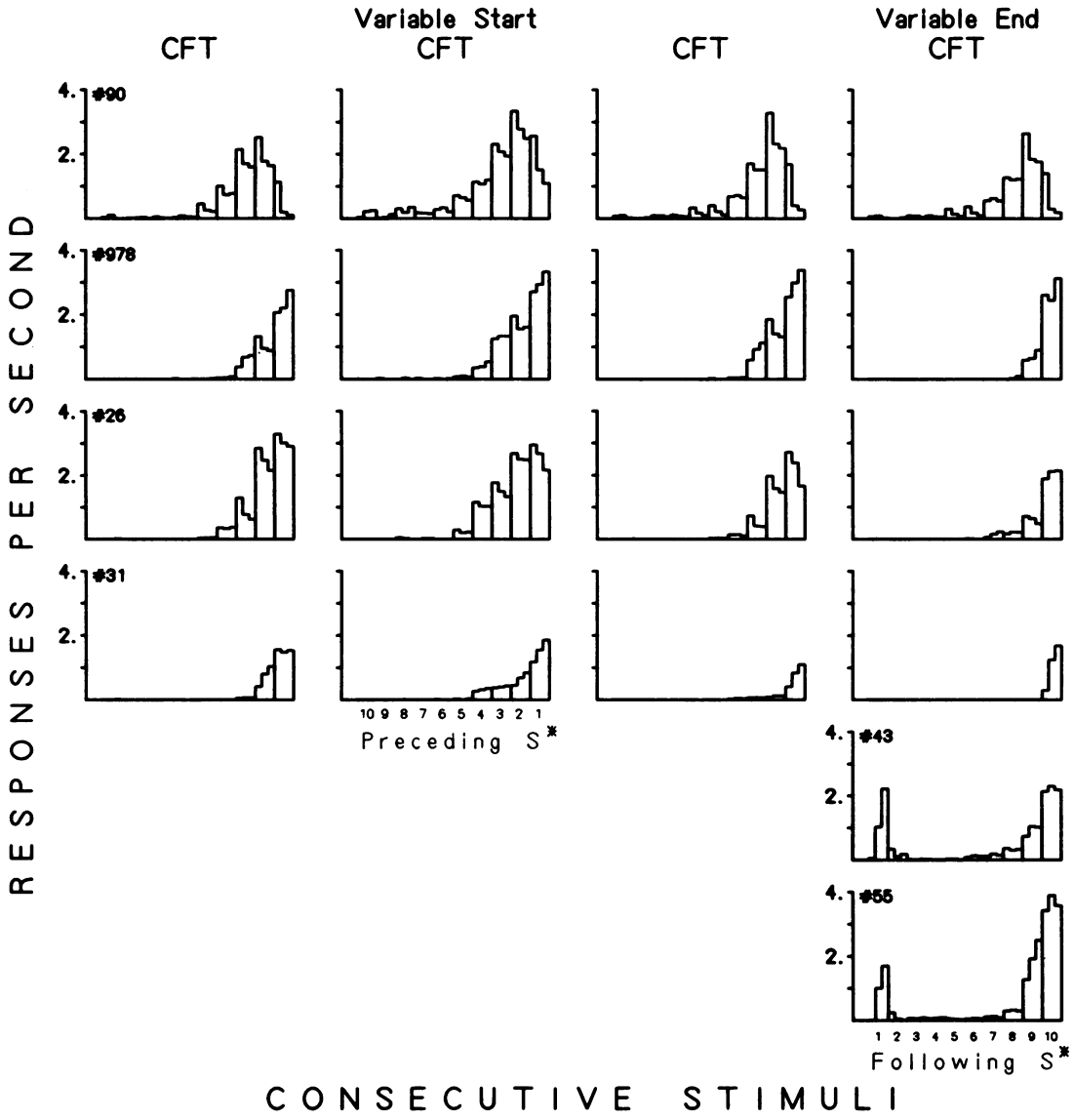

Fig. 5. Asymptotic distribution of responding for each bird to the interfood clock stimuli in each of the four phases of Experiment 3A. The data are the mean response rates in each third of each of the 10 stimuli (or consecutive 30ths of the interval) averaged over the last five sessions. The leftmost column presents the data for the clocked fixed-time schedule (CFT) (Phase 1). The second column depicts the data for the variable-start clocked fixed-time schedule (Variable Start CFT) (Phase 2). The rightmost stimulus in this column of frames (labeled 1) always immediately preceded food presentation. The stimulus labeled 2 was always the penultimate stimulus. The stimulus labeled 3 preceded the penultimate stimulus. This protocol continues to the left. The third column depicts the data obtained under the baseline clocked fixed-time schedule (CFT) (Phase 3). The rightmost column presents the data for the variable-end clocked fixed-time schedule (Variable End CFT) (Phase 4). The leftmost stimulus in these frames (labeled 1) always immediately followed a food presentation. The stimulus labeled 2 followed this stimulus if food did not occur following the first stimulus. The stimulus labeled 3 followed the second stimulus if food did not occur. This protocol continues to the right. The stimulus labeled 10 was the 10th consecutive stimulus since food and was always followed by food.

periment 3A two different types of variable interfood intervals were implemented.

Method

Subjects and Apparatus

Six pigeons were used. Four had had previous experience with various interfood-clock procedures, and 2 were experimentally naive. One experimental chamber was used.

Procedure

Phase 1 exposed 4 birds to a 10-segment 60-s CFT schedule for 12 sessions. Phase 2 randomly varied the duration of the interfood interval by beginning the interval at any of the 10 stimuli with equal likelihood. The procedure therefore resulted in an interval that contained only 6 s of purple followed by food, an interval that contained 6 s of blue followed by 6 s of purple followed by food, or turquoise, blue, purple, food, and so on. Each different stimulus was therefore correlated with a different constant delay to food presentation. This variable-start CFT schedule was in effect for 14 sessions. Phase 3 was a return to the baseline conditions of Phase 1 and was continued for 10 sessions.

Phase 4 randomly varied the duration of the interfood interval by randomly ending the interval after any of the 10 stimuli. The procedure therefore resulted in an interval that contained only 6 s of white followed by food, an interval that contained 6 s of white followed by 6 s of pink, followed by food, or white, pink, orange, followed by food, and so on. Food presentation followed each stimulus equally often. As a result, each different stimulus was correlated with a different constant delay since the most recent food presentation but not with a constant delay to food presentation. Two magazine-trained but otherwise experimentally naive birds were added with this phase. They were exposed to this variable-end CFT schedule for 50 sessions. The remaining 4 birds received 55 sessions.

Results and Discussion

The data obtained in Experiment 3A are provided in Figure 5. The mean response rates in each third of each stimulus across the last five sessions of each phase for each bird are depicted. The left column depicts the data obtained under the baseline CFT schedule.

Successively higher rates occurred to stimuli successively closer to the subsequent food presentation. One bird exhibited a terminal decline in rate, but the remaining 3 did not. In Phase 2 food presentation was preceded by a variable number of stimuli, each of which always occurred a fixed time before food presentation. The data presented in the second column of Figure 5 show the response rate in the presence of each stimulus. The bars are ordered from right to left in terms of stimuli preceding food presentation. All stimuli were not present on all trials. The bars for the initial stimulus are based on approximately 10 exposures, whereas bars for the final stimulus are based on approximately 100 exposures. Response rates were again successively higher to stimuli successively closer to the subsequent food presentation. It can also be seen that, in this variable-interfood-interval procedure, responding occurred to more stimuli and at a somewhat higher rate than in the preceding fixed-interfood-interval procedure. The index of curvature based on the data in the figures decreased in every case. With one exception (Bird 90), responding began to the stimulus that was at the approximate temporal midpoint between the stimulus with the longest delay to food presentation and the one contiguous with food presentation.

The third column depicts the return to the constant interfood interval baseline. Even though the baseline distributions were not totally recovered, the behavior change indicated that the somewhat higher rates obtained with variable interfood intervals were reliable. The fourth column depicts the data obtained with the variable interfood clock that provided food following each position in the sequence equally often. With this procedure the delay to food presentation given a particular stimulus varied, and the clock stimulus in effect at a particular time since food presentation was fixed. The bars are ordered from left to right in terms of stimuli following food presentation. All stimuli were not present on all trials. The bars for the initial stimulus are based on approximately 130 exposures, whereas bars for the final stimulus are based on approximately 20 exposures. The data for the 2 naive birds started with this procedure are presented at the bottom of this column. Surprisingly, this variable-end procedure maintained a successively increasing rate to stimuli that followed food with suc-

cessively greater delays. This effect occurred even though each sequence length was followed by food presentation equally often, each stimulus preceded food presentation equally often, and 50 or more sessions of exposure occurred.

The behavior controlled by this variable-end clock is not surprising if the probability of food following each occurrence of each stimulus is emphasized rather than the probability of food following each sequence length. The stimuli were presented in a fixed order; as a result, the probability of food following each stimulus occurrence differed. The early stimuli occurred on virtually every trial and were rarely followed immediately by reinforcement. Following the first stimulus the probability of food was 1 in 10. After the second stimulus the probability of food was 1 in 9. After the final stimulus the occurrence of food was a certainty. It is plausible that the increasing rate to successively later stimuli in this procedure was a function of the increasing probability of food given the stimulus rather than time since food.

If probability of food presentation were the controlling factor in this procedure, it would appear that stimuli correlated with either increasing relative imminency or increasing relative probability of reinforcement control similarly increasing relative rates of responding. An interesting aspect of this similarity was that (with the exception of the first stimulus following food) only stimuli correlated with the upper half of the range came to control substantial responding.

A tangential but noteworthy result of the variable-end procedure was that exception. Both naive birds exhibited a high rate of responding to the first stimulus following food presentation. This responding is not typical of the behavior under interfood clock schedules and is a curious anomaly. A plausible conjecture is that occasional food presentation following a very short interval is disproportionately effective. This conjecture is consistent with data obtained in concurrent-chains choice procedures (Davison, 1969; Herrnstein, 1964; Rachlin & Green, 1972).

EXPERIMENT 3B

The previous experiment had shown a systematic increase in responding across the consecutive stimuli of a sequence when the probability of food presentation following each stimulus also increased. That finding suggested that a gradient of increasing relative probability of food may be equivalent to increasing relative imminence of food in controlling increasing response rates. The following two subexperiments were used to examine the plausibility of that explanation. In the first subexperiment, the probability of food presentation was constant for each of the 10 stimuli in a variable-length schedule. In the second, only the probability of food presentation differed for the various stimuli in a variable-length schedule.

METHOD

Subjects and Apparatus

Seven naive pigeons and two chambers were used.

Procedure

The first subexperiment exposed 3 naive birds to a modified analogue of the variable-end procedure of Experiment 3A. The subexperiment retained the fixed presentation order and the variable interfood interval, but in this case the probability of food given a stimulus was .10 for each occurrence of each of the 10 stimuli. In Phase 1, the birds were exposed to the standard sequence of 10 6-s clock stimuli. Following each stimulus, food occurred with a .10 probability; otherwise the next consecutive stimulus occurred. The next consecutive stimulus in the fixed sequence was also presented following food presentation rather than restarting the sequence from a constant initial hue after food presentation. Typically each session continued until 50 food presentations had been delivered. This phase was in effect for 76 sessions. Phase 2 implemented the standard 10-segment 60-s CFT schedule for 56 sessions. Phase 3 reinstituted the random-food procedure of Phase 1 and continued for 38 sessions.

The second subexperiment was also a modified analogue of the variable-end procedure of Experiment 3A. This procedure also provided a variable interfood interval and a different probability of food following each hue, but in this procedure the stimuli were not presented in a systematic order. Following food presentation a randomly selected one of the 10 stimuli was presented for 6 s. As with every occurrence of that stimulus, it was followed by

food with its respective probability. If food did not occur, one of the remaining stimuli was randomly selected and immediately presented. It was followed by food with the probability specified by that hue. Until interrupted by food, the sequence was a continuous series of random permutations of the 10 stimuli. Because the stimuli were not presented in any specific order, hue could not be correlated with time to, or time from, food presentation.

In the first phase, the probabilities of food following each of the 10 different stimuli were the same as those in the variable-end phase of Experiment 3A. The probabilities ranged from .10 (1 of 10 occurrences followed by food) to 1.0 (1 of 1). Phase 1 of this random-stimuli-with-probabilistic-food procedure continued for 50 sessions, each of which contained approximately 40 food presentations. In Phase 2 the probability of food following each stimulus was decreased. Reinforcement probabilities varied from .09 (1 of 11) to .50 (1 of 2). This manipulation altered the approximate average interfood interval from 20 s to 30 s. Therefore, at the expense of the probabilities of food given a stimulus this procedure now provided an interfood interval more similar to that in the variable-end phase of Experiment 3A (which was approximately 36 s). An additional naive bird was added with this phase. All birds were exposed to the conditions of Phase 2 for 35 sessions. Phase 3 increased the probability of food given the "last" stimulus in the probability gradient from .50 to 1.0 in an effort to increase response rates. All other probabilities remained the same as in Phase 2. The original birds were exposed to these conditions for 26 sessions, and the naive bird received 29 sessions. Appendix 1 presents the probability with which each stimulus was followed by food, for each bird, in the three phases of this experiment.

Results and Discussion

Figure 6 depicts the results of the first subexperiment. The mean response rate to each third of each stimulus across the last five sessions of each phase is presented as a continuous function for each bird. The stimuli are depicted in the same order as they were presented in the CFT procedure of Phase 2 irrespective of the occurrence of food presentation. The left frame shows that variable-length sequences containing stimuli with an equal probability of being followed by food failed to establish responding. The center frame shows that the standard interfood clock generated and supported the typical increasing response rate to the early stimuli in the second half of the interval. The right frame demonstrates that the reinstitution of an equal probability of food presentation following each stimulus failed to maintain the responding established in Phase 2.

Figure 7 presents the results of the second subexperiment. It shows the mean response rate to each third of each stimulus across the last five sessions in each phase for each bird. The leftmost stimulus in each frame was followed by food least often. Each stimulus to the right had a successively higher probability of being followed by food presentation. The left column of frames depicts the results of Phase 1, which varied the probability of food from .10 to 1.0. The second column depicts the results when the probabilities were reduced. The third column presents the results of Phase 3 when the probability of food presentation for the stimulus with the highest probability of being followed by food was increased to 1.0. Within each procedure, response rates generally increased as the probability of food increased. Little or no responding occurred to the stimuli in the lower half of the range, whereas successively higher rates occurred to the stimuli in the higher portion of the range.

The alteration in the probabilities of food presentation across phases failed to affect the distribution of responding. The strong effect of probability of reinforcement within a phase and the weak effect of probability of reinforcement across phases suggest that relative probability of food is the critical variable in determining response rate. This is consistent with a wide variety of findings (Herrnstein, 1970; Timberlake, 1982). It also lends additional support to the view that relative probability of food is equivalent to relative delay to food (Rachlin, Castrogiovanni, & Cross, 1987).

GENERAL DISCUSSION

The main findings of these six experiments were as follows. (a) Chronic pecking occurs to clock stimuli that have never been contiguous with food. (b) The effect occurs when response–reinforcer contiguities are allowed, required, or precluded. (c) An interfood clock is

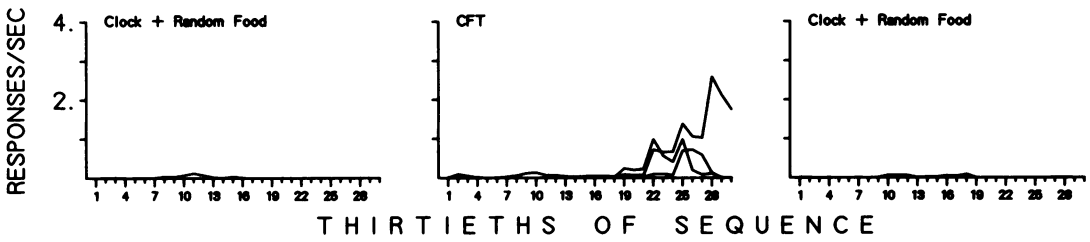

Fig. 6. Asymptotic distribution of responding for each bird to the stimuli in each of the three phases of the first subexperiment of Experiment 3B. The data, depicted as a continuous function for each of the 3 birds, are the mean response rates in each third of each of the 10 stimuli averaged over the last five sessions. Data for the fixed-clock sequence with food following each stimulus equally often (which was implemented in Phase 1 and reinstituted in Phase 3) are presented in the leftmost and rightmost frames, respectively (Clock + Random Food). Data for the clocked fixed-time schedule (CFT) implemented in Phase 2 are presented in the center frame.

sufficient to establish and maintain a characteristic distribution of pecking in the interfood interval in the absence of a response requirement. In addition, that distribution does not occur or is not maintained in the absence of the interfood clock. (d) The response rate to the final stimulus and the distribution of responding prior to the final stimulus do not covary. (e) A fixed interfood interval is unnecessary for increasing rates to successive stimuli. (f) Stimuli correlated with successively higher probabilities of food produce a distribution of responding similar to that produced by a gradient of relative delays to food presentation. (g) Responding increases only across the upper half of the range and not across the entire gradient.

Several types of behavior may occur during an interfood interval and may change systematically in probability across the interval (Staddon & Simmelhag, 1971). The current research dealt only with key pecking and was not focused on determining whether that behavior is best considered operant or Pavlovian. The point of the current research was to examine the factors controlling the distribution of pecking across an interfood interval.

An FI schedule typically maintains an increasing rate of the operant as the interval elapses and supports many responses per reinforcer. The acquisition and maintenance of this responding are generally seen to be a function of the elements contiguous with reinforcement (Zeiler, 1977, 1979). The importance of the context of reinforcement is illustrated by pointing out that when that context is altered the resulting behavior changes. The present paper examined three aspects of the context of reinforcement on the distribution of key pecking in an interfood interval. The relationships among reinforcement and key pecking, explicit stimuli, and the time since the prior food presentation were manipulated.

The current research did not study the process or processes underlying the origin of key pecking. That task may be problematic in any case, in that it appears unlikely that a procedure could contain only a stimulus–reinforcer or only a response–reinforcer contingency (Hearst, 1975). However, the present data did suggest that either an explicitly programmed response–reinforcer contingency or an explicitly programmed stimulus–reinforcer contingency is sufficient to establish key pecking as the dominant behavior in the second half of the interval in a context that provides food presentations as the reinforcer and keylights as the stimuli to pigeons. As a result, it is difficult to argue that the contiguity between key pecking and food presentation is essentially involved in the distribution of responding across an FI schedule, because similar distributions were acquired and maintained in the face of an omission dependency. This view is corroborated by the independence of the distribution and the rate of responding to the final stimulus of an interfood clock segmented by discriminably different stimuli.

It is also unlikely that the distribution of behavior in an interfood interval can be understood adequately by appeals to confusion, generalization, or inability to discriminate. Responding was chronically maintained by stimuli discriminably different than the stimulus in effect at food presentation. The clocked interfood interval can be viewed as simply formalizing the theoretical stimuli typically used to explain interval performance (Zeiler, 1977).

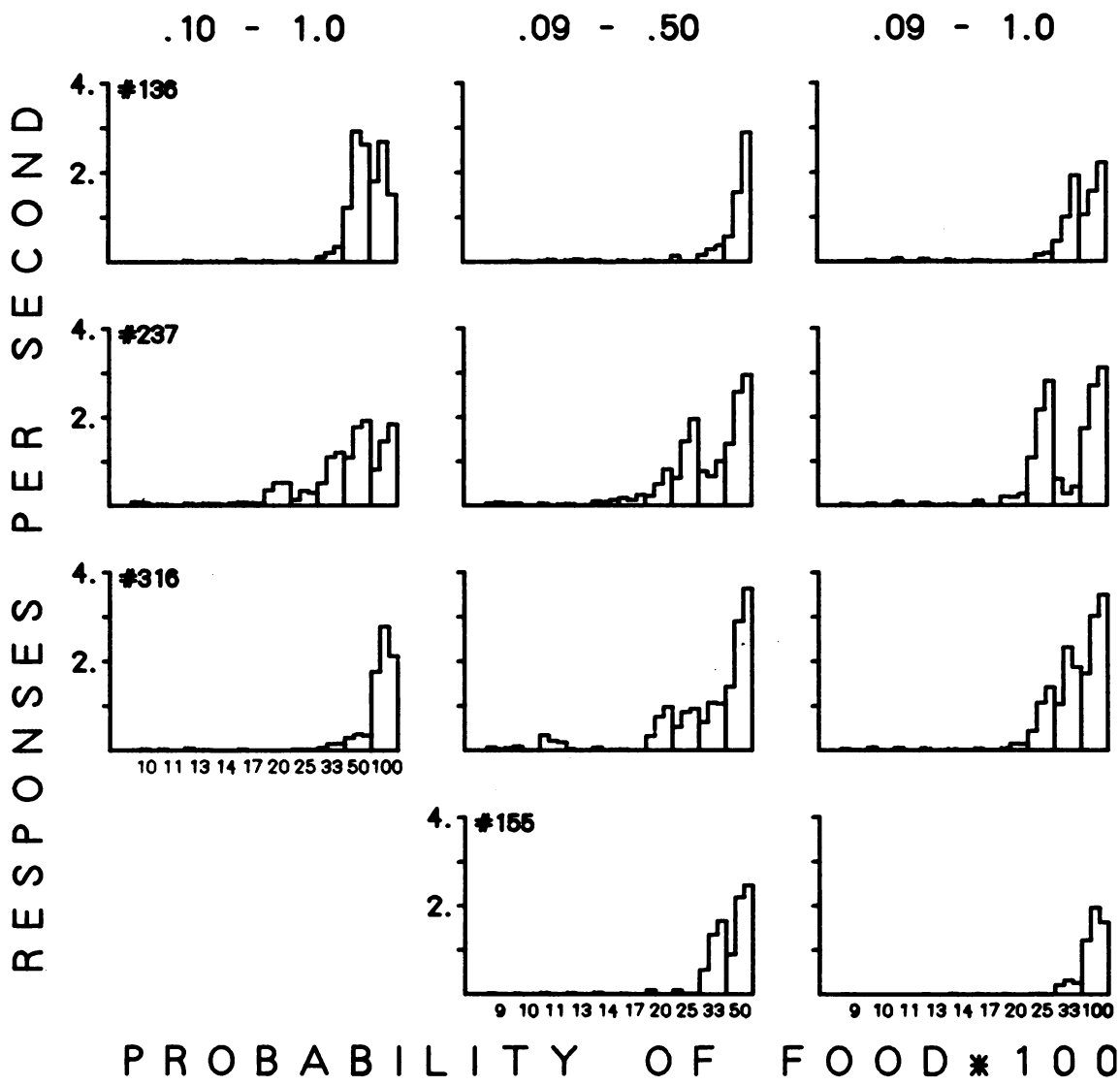

Fig. 7. Asymptotic distribution of responding for each bird to the 10 stimuli in each phase of the second subexperiment of Experiment 3B. The data are the mean response rates in each third of each of the 10 stimuli (or consecutive 30ths of the interval) averaged over the last five sessions. The leftmost stimulus in each frame was followed by food least often. Each stimulus to the right had a successively higher probability of being followed by food presentation. The left column of frames depicts the results of Phase 1, which varied the probability of food from .10 to 1.0. The second column depicts the results when the probabilities were reduced (.09 to .50). The third column presents the results of Phase 3, when the probability of reinforcement for the last stimulus was increased to 1.0 (.09 to 1.0).

Although the clock stimuli did reduce the overall amount of responding in the middle and early portions of the interval, substantial responding was maintained. Perspectives suggesting that responding occurs in an FI because the changes in implicit stimuli over the course of a fixed interfood interval are too subtle to come to control precise discriminative control are therefore obligated to account for why the very different stimuli of an explicit clock are also insufficient to eliminate early responding. Although a process of higher order conditioning or conditioned reinforcement may be extended to account for responding in the interval, it is necessary to alter those mechanisms in a substantive way. At present both

mechanisms suggest an absolute process that is thought to strengthen earlier members in a sequence. These processes are thought to lose effectiveness across successive stages. The stimulus contiguous with food presentation is thought to be the strongest, the penultimate stimulus is weaker, and the stimulus preceding that one is weaker yet. Data obtained with clocked interfood intervals corroborate the ability of earlier stimuli to support responding and the decrement in successively earlier instances, but they also indicate that responding is chronically maintained to the approximate midpoint of the interval regardless of the number of steps or the absolute delay to food presentation (Palya & Pevey, 1987). The implied acute and absolute decremental process underlying higher order conditioning (Gormezano & Kehoe, 1975) and conditioned reinforcement (Kelleher & Gollub, 1962) is not easily integrated with either a permanent or a relative effect.

The findings from the present research are consistent with interpretations of FI performance that suggest that the response pattern of an operant is the result of the placement of reinforcement in time (Dews, 1966; Staddon, 1977; Zeiler, 1977). The extant data suggest that the duration of the interfood interval determines the distribution of the operant, whereas the elements contiguous with food presentation govern the selection and the maximal rate of that operant.

The present data suggest that these principles can be extended to include both respondent and operant behavior in explicitly clocked interfood intervals. Although pecking is the prototypical operant, it is not necessarily an operant. Pecking is easily established. It will occur as the result of an explicit operant–reinforcement dependency for key pecking, or as the result of an autoshaping dependency with a keylight preceding food (Hearst & Jenkins, 1974). Because an increasing rate across the second half of the interval occurs in intervals that prohibit the contiguous occurrence of a key peck and food presentation, that factor cannot be solely responsible for the obtained distribution. Because the response pattern occurs in intervals that provide an explicit clock, generalization or perceptual capacities are not applicable explanations either.

The current data may be seen in a more molar perspective. The placement of food in time could establish a gradient from the point of maximum imminence immediately preceding food presentation back to the point of minimum imminence at that point furthest removed from subsequent food presentation. This gradient could then be seen as controlling types of behavior appropriate to those relative conditions. The beginning of the interval would be expected to control avoidance and low rates of the behavior typical of the end of the interval; subsequently, the reverse would be true.

This general description can be cast in either an optimality framework (Krebs & Davies, 1978) or a matching framework (Herrnstein, 1970). An optimality perspective would emphasize the evolutionary utility of avoidance or nonfood behavior when food was not available and increasing approach or preparatory behavior when food was increasingly imminent. The variability would have obvious long-range utility in that it provides novel instances of reinforceable behavior (Segal, 1972; Skinner, 1969; Staddon & Simmelhag, 1971).

The matching perspective would emphasize the allocation of behavior as a function of the relative ratio of available reinforcers. In this case the gradient can be conceptualized as a function of the ratio of the reinforcement available for terminal and nonterminal behavior (Nevin, 1981). Immediately following food, nonterminal behavior is most reinforced. Immediately preceding food, terminal behavior is most reinforced. The distribution of behavior across the interval would therefore be the matching equilibrium between terminal and nonterminal behavior. Preceding the midpoint, other behavior should predominate; following the halfway point, food behavior will predominate.

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Appendix 1

EXPERIMENT 1A

BIRD	STIMULUS ORDER
167	GR PU YE TU AM RD OR BL PK WH
248	PU RD PK OR WH AM GR TU BL YE

EXPERIMENT 1B

Immediate Trial Termination		Food Loss Only	
BIRD	STIMULUS ORDER	BIRD	STIMULUS ORDER
187	OR AM RD YE GR TU PK PU BL WH	140	OR AM RD YE GR TU PK PU BL WH
44	WH PK RD OR AM YE GR TU BL PU	149	PK OR GR BL TU WH YE AM PU RD
122	PK OR GR BL TU WH YE AM PU RD	181	WH PK RD OR AM YE GR TU BL PU

EXPERIMENT 2B

Subexperiment 1

Clocked Fixed-Time		Single Stimulus Fixed-Time	
BIRD	STIMULUS ORDER	BIRD	STIMULUS ORDER
197	RD TU PU PK WH GR BL AM OR YE	197	YE
206	OR TU RD PK YE AM WH PU GR BL	206	BL
223	RD PK TU GR WH PU AM OR BL YE	223	RD
231	PU AM TU OR PK GR YE BL WH RD	231	RD
234	TU PU RD GR AM PK WH YE OR BL	234	TU
241	BL GR OR PK YE RD WH PU AM TU	241	BL
243	OR PK RD YE TU PU BL GR AM WH	243	OR
314	PK RD OR AM YE WH GR PU BL TU	314	TU

Subexperiment 2

Single Stimulus Fixed-Time		Clocked Fixed-Time		Single Stimulus Fixed-Time	
BIRD	STIMULUS ORDER	BIRD	STIMULUS ORDER	BIRD	STIMULUS ORDER
186	GR	186	PU TU BL YE PK AM RD WH OR GR	186	GR
210	YE	210	RD BL OR WH PU PK AM GR TU YE	210	YE
263	OR	263	PK RD GR PU TU WH YE BL AM OR	263	OR

EXPERIMENT 3B

Subexperiment 2

Probability of Food									
	.10	.11	.13	.14	.17	.20	.25	.33	.5	1.0
136	WH	PK	RD	OR	AM	YE	GR	TU	BL	PU
237	RD	GR	AM	TU	PK	PU	OR	YE	BL	WH
316	AM	TU	YE	PU	WH	BL	PK	RD	OR	GR

Probability of Food										
	.09	.10	.11	.13	.14	.17	.20	.25	.33	.50
136	WH	PK	RD	OR	AM	YE	GR	TU	BL	PU
237	RD	GR	AM	TU	PK	PU	OR	YE	BL	WH
316	AM	TU	YE	PU	WH	BL	PK	RD	OR	GR
155	BL	GR	WH	TU	YE	PU	OR	RD	AM	PK
173	RD	WH	GR	BL	OR	PK	YE	TU	PU	AM

Probability of Food										
	.09	.10	.11	.13	.14	.17	.20	.25	.33	1.0
136	WH	PK	RD	OR	AM	YE	GR	TU	BL	PU
237	RD	GR	AM	TU	PK	PU	OR	YE	BL	WH
316	AM	TU	YE	PU	WH	BL	PK	RD	OR	GR
155	BL	GR	WH	TU	YE	PU	OR	RD	AM	PK
173	RD	WH	GR	BL	OR	PK	YE	TU	PU	AM

RD=RED;GR=GREEN;PU=PURPLE;YE=YELLOW;TU=TURQUOISE;AM=AMBER;OR=ORANGE;BL=BLUE;PK=PINK;WH=WHITE

Appendix 2

BIRD	IOC (RESP)	IOC (RESP)	IOC (RESP)	IOC (RESP)
EXPERIMENT 1A				
	CFT	CFI	CFT	
65	.703 (19.20)	.709 (18.34)	.708 (17.84)	
995	.443 (33.98)	.584 (32.74)	.640 (28.64)	
998	.487 (14.66)	.833 (12.16)	.783 (9.32)	
167	.410 (59.30)	.521 (57.62)	.393 (36.14)	
180	.662 (28.38)	.711 (36.68)	.706 (37.72)	
248	.759 (17.72)	.748 (13.40)	.744 (10.10)	
EXPERIMENT 1B				
	TT			
4	.572 (14.22)			
14	.620 (7.98)			
64	.557 (26.20)			
51	.900 (0.04)			
92	.750 (3.46)			
62	.612 (3.32)			
187	.040 (3.54)			
44	.614 (2.76)			
122	.675 (27.60)			
	FLO			
58	.395 (8.22)			
982	.635 (5.02)			
3	.505 (4.02)			
17	.330 (15.62)			
18	.613 (6.48)			
78	.306 (15.48)			
181	.266 (6.28)			
140	.449 (1.98)			
149	.470 (2.30)			
EXPERIMENT 2A				
	CFT	SSFI	CFI	RCFI
36	.682 (22.54)	.276 (46.40)	.668 (42.04)	.333 (58.74)
50	.460 (15.00)	.336 (61.54)	.527 (33.30)	.388 (63.14)
89	.611 (37.12)	.112 (91.28)	.712 (46.14)	.112 (106.50)
EXPERIMENT 2B				
		Subexperiment 1		
	CFT	SSFT		
332	.350 (6.06)	.157 (0.14)		
243	.544 (2.16)	-.233 (0.02)		
314	.693 (6.96)	.000 (0.00)		
203	.758 (40.46)	-.178 (0.60)		
209	.602 (7.40)	.000 (0.00)		
239	.692 (8.76)	.000 (0.00)		
223	.683 (2.96)	-.067 (0.04)		
206	.472 (8.34)	-.107 (0.18)		
231	.708 (14.98)	-.488 (0.32)		
197	.699 (1.68)	-.800 (0.04)		
234	.717 (27.28)	-.278 (0.12)		
241	.277 (17.20)	.000 (0.00)		
		Subexperiment 2		
	SSFT	CFT	SSFT	
186	.489 (0.36)	.366 (6.24)	.634 (1.64)	
210	.000 (0.00)	.621 (15.80)	-.529 (2.52)	
263	-.421 (0.84)	.813 (3.84)	-.226 (0.38)	

IOC=Index of Curvature; RESP=Responses per Minute

Appendix 2 (continued)

BIRD	IOC (RESP)	IOC (RESP)	IOC (RESP)	IOC (RESP)
EXPERIMENT 3A				
	CFT	VSCFT	CFT	VECFT
90	.512 (33.70)	.484 (56.64)	.523 (38.12)	.517 (30.72)
978	.781 (24.42)	.714 (39.42)	.776 (32.68)	.860 (20.98)
26	.731 (41.28)	.645 (48.22)	.750 (27.70)	.799 (18.24)
31	.828 (14.10)	.738 (17.66)	.847 (5.96)	.929 (6.46)
43				.349 (30.32)
55				.541 (43.38)
EXPERIMENT 3B				
		Subexperiment 1		
	CRF	CFT	CRF	
126	-.303 (0.82)	.693 (25.72)	.833 (0.02)	
171	.000 (0.00)	.544 (5.54)	-.168 (0.96)	
227	.000 (0.00)	.489 (8.26)	.000 (0.00)	
		Subexperiment 2		
	.10-1.0	.09-.50	.09-1.0	
136	.777 (27.02)	.839 (12.34)	.794 (17.52)	
237	.604 (28.82)	.684 (31.92)	.696 (31.56)	
316	.832 (16.44)	.651 (32.40)	.750 (34.02)	
155		.818 (18.86)	.873 (11.22)	

IOC=Index of Curvature; RESP=Responses per Minute