SECOND-ORDER SCHEDULE PERFORMANCE: THE ROLE OF BRIEF STIMULI AND THE EFFECTS OF IMIPRAMINE

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SECOND-ORDER SCHEDULE PERFORMANCE:

THE ROLE OF BRIEF STIMULI AND THE EFFECTS

OF IMIPRAMINE

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SUMMARY

The present experiment was concerned with the analysis of performance under a second-order schedule involving brief-stimulus changes. Second-order schedules are schedules of reinforcement in which responding engendered by one schedule is treated as a unitary response which is then reinforced under some other schedule of unconditioned reinforcement. The component schedule performance may terminate either in a brief-stimulus temporally associated with the unconditioned reinforcer (S^{p}, a paired brief-stimulus) or one which is presented at the termination of each component, except the one in which food is presented (S^{np}, a non-paired brief-stimulus). The schedule under investigation was a multiple schedule in which one ply was a second-order schedule of the form: FI20-min(FR$\underline{n}$:S). The second ply was a simple fixed-interval schedule (FI20-min). Thus, comparisons could be made between the simple fixed-interval ply and the second-order schedule ply, as well as between paired and non-paired brief-stimulus conditions in the second-order schedule ply.

Patterns of responding characteristic of the within-component schedule (FR$\underline{n}$) were produced in both the paired and non-paired brief stimulus conditions. In both conditions, the performance engendered within-components acted as a unitary response in the over-component schedule (FI20-min). Imipramine had the same qualitative effect on the second-order schedule ply as it did on the simple fixed-interval ply. Under control conditions, there was some evidence of more distinct patterning in the paired condition; however, when imipramine was administered, there

were no differences in rates and/or patterns of responding engendered by the two brief-stimulus conditions.

CHAPTER I

INTRODUCTION

In the field of operant conditioning, an important variable under investigation is the role that stimuli play in modifying and controlling behavior. Whereas unconditioned stimuli elicit certain reflexes regardless of the organism's environmental history, most stimuli develop their functions as a result of interaction with the organism's behavior. That is, the roles that stimuli come to play are meaningful only in the light of the relationship they share with the organism's behavior. For example, food is generally a reinforcing stimulus only if the organism has been deprived. Likewise, a previously neutral stimulus may acquire reinforcing properties as a result of a history of temporal association with an unconditioned reinforcing stimulus. Such a stimulus is then designated a conditioned reinforcer.

When investigators discovered that a stimulus could acquire reinforcing properties through a history of pairing with an unconditioned reinforcer, they sought to study the effects of that stimulus in isolation from those of the unconditioned reinforcer. Some of the first attempts to separate the effects of a conditioned reinforcer from an unconditioned reinforcer involved extinction procedures, wherein after training, the unconditioned reinforcer is no longer presented. For example, Kelleher (1961) trained pigeons on a fixed-interval schedule (FI) of reinforcement, with an audible click preceding every food presentation. That is, the

first response after a fixed time from the previous food presentation produced the click followed by food presentation. To test the click as an effective conditioned reinforcer during extinction, the click alone was presented according to various schedules: (1) differential reinforcement of other behavior (DRO), i.e., if the organism had not responded for a specified length of time, the click was presented; if the time requirement had not been met, each response reset the timer and thus delayed click presentation; (2) a fixed ratio (FR), that is, the execution of a specified number of responses produced the click; and (3) the original fixed-interval schedule. When the click was scheduled on a DRO, a low or zero response rate was maintained, similar to that engendered when food is presented on a DRO schedule. When the click was presented on a fixed-ratio schedule, the characteristic pattern for that schedule developed; that is, a short pause followed by a high steady rate. When the click was presented under a fixed-interval schedule, the pattern consisted of a pause followed by positively accelerated responding similar to that engendered when food is presented according to the same schedule. Thus the click not only maintained responding, but also generated characteristic patterns of responding depending upon its schedule of presentation. As impressive as these findings are, the principal difficulty with the extinction method is that by no longer being paired with the unconditioned reinforcer, the conditioned reinforcer continually loses its effectiveness.

Kelleher and Gollub (1962) proposed a solution to this problem:

> Conditioned reinforcers might also have technical advantages for establishing and maintaining complex sequences of responding,

> i.e., a conditioned reinforcer, such as a click, could follow each component of a sequence, with a primary reinforcer terminating the sequence. In this way, components of the sequence could be reinforced without disrupting the entire sequence (p. 594).

Thus, a complex unit of behavior, comprising a series of responses could be grouped together by terminating each such unit with a distinct exteroceptive stimulus. These components could in turn be grouped together with food, for example, terminating the sequence of components. So, the smaller units could be studied when grouped together in certain ways but with food continuing to maintain the overall responding, unlike the extinction procedure. Thus Kelleher and Gollub laid the groundwork for the development of second-order schedules. "A second-order schedule is one in which the behavior specified by a schedule contingency is treated as a unitary response that is itself reinforced according to some schedule of primary reinforcement" (Kelleher, 1966a, p. 181). A response sequence (component schedule performance) is treated as if it were a single response and then is reinforced according to some schedule. Second-order schedules may thus be considered as schedules of schedules, and are designated by a characteristic notation. For example, if the component schedule were fixed interval (FI t-min), and the responding engendered by this schedule were treated as a unit which was then reinforced under a fixed-ratio schedule (FR n), the entire second-order schedule could be written as: FR n (FI t-min); that is, the nth fixed-interval-of-t-minute-component completed would result in food presentation. Following the suggestion of Kelleher and Gollub (1962), there is a class of second-order schedules, known as brief stimulus procedures, in which a brief stimulus terminates each schedule component.

> A brief stimulus may be described as an event of such duration that the primary focus of interest can conveniently be placed on the rate and pattern of responding terminating in, and/or subsequent to, its presentation. Also, such responses that might occur during its presentation have no programmed consequences (Marr, 1972, p. 1).

The brief stimulus might terminate all of the components except the final component ending in food presentation. In this case, the brief stimulus would not be directly associated with the unconditioned reinforcer, and would be designated a non-paired stimulus (S^{np}). If the brief stimulus followed all the components including the one terminating in the unconditioned reinforcer, it would be designated a paired stimulus (S^{p})

In dealing with second-order brief-stimulus procedures, three performance characteristics may be differentiated. The first is the temporal distribution of responses occurring between presentations of the brief stimulus, designated the within-component pattern. It is a function of the schedule under which the brief stimulus is presented, and perhaps by whether or not the brief stimulus is paired with the unconditioned reinforcer. The second pattern of interest is the temporal distribution of the within-component performances occurring between the presentations of the unconditioned reinforcer, designated the over-component pattern. This pattern is affected by the schedule under which the components are reinforced. Finally, these two patterns may interact (Marr, 1969).

As in the case of other stimuli, the role of a brief stimulus terminating second-order schedule components can be defined in relation to its effects on responding. Second-order schedules were developed, in part, to study the properties of conditioned reinforcers, so it was natural that the initial focus of the brief stimulus was on this function.

responding.

These effects were supposedly established by the temporal contiguity of the brief stimulus and the unconditioned reinforcer (Kelleher, 1966a; Marr, 1969). Almost all of the early studies compared rates and patterns of responding between a paired-stimulus condition (S^P) and a no-stimulus condition ($\overline{S}$), i.e., where no brief stimulus was presented. However, it became apparent that if the brief stimulus assumed its reinforcing properties by means of pairing with the unconditioned reinforcer, then its effects must be compared to those in a situation where the stimulus was not paired (S^{np}) before definitive statements could be made about the role of pairing.

A study by DeLorge (1971) showed evidence of differential effects of pairing and not pairing a brief stimulus with food. In this study, each ply of a multiple schedule was a second-order schedule. The only difference between the two plies was in the scheduling of the brief stimulus. The within-component schedule was a variable-interval-of-one-minute (VI 1-min); i.e., responding under this schedule produced a brief stimulus on the average of once per minute. At the completion of five of these components, food was presented. This schedule may be designated: MULT [FR5(VI 1-min:S)] [FR5(VI 1-min:S)]. Each condition was arranged so that a paired brief-stimulus procedure (S^P) in one ply was compared with either a non-paired brief-stimulus procedure (S^{np}) or no-brief-stimulus procedure ($\overline{S}$) in the other ply. DeLorge found that the plies which contained paired brief-stimuli engendered higher rates of responding and less pausing than eigher the S^{np} or $\overline{S}$ conditions. Further, when the conditions were reversed so that the stimulus which had been previously

paired was no longer paired with food, and the stimulus which had been previously non-paired was paired, there was a reversal of rates and patterns of responding for each stimulus.

The data with paired stimuli are clear: They exert control over responding by either increasing rates of responding and/or generating schedule-characteristic patterns of responding within-components. However, the data concerning non-paired stimuli are not as uniform. DeLorge (1971), along with others, found observable differences between the paired and non-paired stimulus conditions. However, some investigators have also found schedule characteristic patterning in the non-paired conditions (Kelleher, Fry & Cook, 1964; Neuringer & Chung, 1967) or have found no differences in responding generated by paired vs non-paired stimuli (Stubbs, 1971; Cohen & Stubbs, 1972). In the latter studies, both classes of stimuli engendered schedule-characteristic patterns of responding. In these cases, the discriminative functions of the brief stimuli are emphasized. A stimulus may acquire discriminative properties if it has been correlated with a schedule of either unconditioned or conditioned reinforcement; and its presence can therefore control a particular pattern of responding. For example, in the steady state, the presence of a stimulus associated with a fixed-interval schedule may control the performance of an initial pause followed by positively accelerated responding; a stimulus associated with a fixed-ratio schedule, a pause followed by a high, steady rate; and a stimulus associated with extinction, no responding.

Early evidence regarding discriminative roles of brief stimuli is

provided by a study of Ferster and Skinner (1957) who investigated the effects of percentage reinforcement upon fixed-ratio responding. They found that intermittent substitution of a 3-minute time out (TO) - a non-paired stimulus - for reinforcement under a fixed ratio (FR40) schedule, produced pauses after the time out, similar to that produced by reinforcement, i.e., the fixed-ratio schedule pattern was maintained.

Neuringer and Chung (1967) studied a percentage-reinforcement schedule involving very small response requirements in an attempt to determine the necessary and sufficient conditions for a brief stimulus to produce schedule-characteristic patterns of responding. They compared the performance of pigeons on a simple variable-interval (VI 60-sec) schedule with the performance under a schedule in which responding on a fixed ratio (FR11) was treated as a unitary response which was reinforced under a FI 60-second schedule. If the variable-interval reinforcement was available, then the fixed ratio terminated in food; if not, the fixed ratio terminated in a one-second blackout (a non-paired stimulus). Response rates doubled under the percentage reinforcement schedule compared to the standard variable interval, and there was evidence of fixed-ratio patterning. When the blackout was presented equally as often, but independently of responding, no rate enhancement occurred. Neuringer and Chung concluded that in order for within-component patterning to occur, there had "to be an identity between the required behavior sequence leading to primary reinforcement and the required behavior sequence leading to blackout" (Neuringer & Chung, 1967, p. 52).

Perhaps even more puzzling are the studies of Stubbs (1971) and

Cohen and Stubbs (1972) who used the same kinds of procedures as previous investigators, but obtained different results. Stubbs (1971) contrasted non-paired (S^{np}), paired (S^{p}), and no-stimulus conditions ($\bar{S}$) using three basic second-order schedules: VI T-min (FI t-min); FI T-min (FI t-min); and FR N(FR n), and found within-component patterning under both paired and non-paired stimulus conditions. All the within-component schedules used in these experiments were fixed; i.e., either fixed ratio or fixed interval, so either the number of responses (or the minimum time to execute the same number of responses) or the time between the last brief stimulus and food presentation was always fixed. Stubbs pointed out that the brief stimulus may be acting as a discriminative stimulus in both the paired and non-paired conditions. Since there is a fixed relation between the brief stimulus and food, the presentation of the brief stimulus could signal the beginning of a minimum time before food is presented. Thus, an occurrence of the brief stimulus would signal that reinforcement would not be available and therefore assume the property of an S^{Δ}, i.e., a stimulus associated with extinction.

Cohen and Stubbs (1972) studied this hypothesis further by means of a modified fixed-interval schedule. If the fixed-interval requirement had been satisfied, the first response after the specified interval resulted in food presentation. If the fixed-interval requirement had not been met, responses produced a brief stimulus under a variable-interval schedule. However, each brief stimulus presentation reset the fixed-interval clock, so while the interval between brief stimuli was variable, the interval between a brief stimulus presentation and food was fixed.

Cohen and Stubbs reasoned that if the brief stimulus developed discriminative properties signaling non-reinforcement, then a pause after the stimulus would be expected. If the brief stimulus developed reinforcing properties, then a constant rate characteristic of a variable-interval schedule would be expected. In one experiment, Cohen and Stubbs investigated paired and non-paired brief stimulus conditions and found that responding between presentations of brief stimuli was generally characterized by fixed-interval patterning for both the S^{p} and S^{np} conditions. They contend that independently of the pairing condition, maintaining a fixed minimum time between the brief stimulus and reinforcement can produce fixed-interval patterning, even if the brief stimuli were presented on a variable-interval schedule. Thus, it appears that Neuringer and Chung's (1967) condition of identity between sequences that produce the brief stimulus and sequences that produce reinforcement does not have to apply. All that is needed to engender schedule-characteristic patterning is a fixed relation between the response-produced brief stimulus and the response-produced reinforcement. So, at least in the case of the fixed-interval or fixed-ratio components, there is the possibility that the same type of schedule-characteristic patterns could be generated by stimuli not associated with unconditioned reinforcement; but rather associated with the absence of unconditioned reinforcement. Any conditioned reinforcing effects the brief stimulus might come to have in the paired condition could be overshadowed by the discriminative function that develops in both the paired and non-paired conditions.

Kelleher (1966a) has suggested another possible discriminative function of the brief stimulus, namely that it may help to maintain the

unity of the component behavior by signaling the completion of each unit. Dews (1965) has also emphasized the unifying function a brief stimulus may have and characterizes the within-component responding as a "macro-response," with the brief stimulus serving to set it apart as a unit. Thus, even though the brief stimulus is not temporally paired with reinforcement, occasionally that macroresponse terminates in food presentation. This intermittent reinforcement of the unit serves to maintain it throughout the sequence.

There have been a number of studies which suggest the extent to which the "macroresponse" acts as a unit. For example, Kelleher (1966a) treated the responding engendered under a fixed-ratio schedule (FR20) as a unitary response and reinforced this schedule component performance under a fixed-interval schedule (FI 10-min) of food presentation: FI 10-min (FR20:S^P). Each FR20 completed produced a brief stimulus change, and the first FR20 completed after the interval had elapsed was followed by a brief stimulus and food. Pauses followed the presentation of each brief stimulus, followed by an abrupt change to a high rate until the next brief stimulus presentation. The pause-run pattern within components was similar to that produced by a fixed-ratio schedule of food. In general, the within-component pauses were longest at the beginning of the 10-minute interval and became shorter as time passed; that is, the number of FR20s completed per unit time was positively accelerated throughout the interval, so the complex response (FR20) was similar to a single response when scheduled under a fixed interval.

Shull, Guilkey, and Witty (1972) also studied this same basic

schedule, and manipulated the size of the response unit. The fixed ratio requirement was either 10 or 20 responses, and the fixed-interval requirement was also varied from 3-, to 6-, to 12-minutes. Completing the fixed-ratio component produced a paired brief stimulus that resulted in short pauses immediately after the stimulus which were related to the fixed-ratio unit size; that is, the FR20 resulted in longer pauses than did the FR10. Shull et al. found that the overall fixed-interval pattern was not disturbed by manipulating the response unit at these values.

Byrd (1973), using squirrel monkeys, scheduled a fixed-ratio component performance on a fixed-interval schedule for electric shock, i.e., each fixed-ratio (FR n) component completed resulted in the presentation of a brief stimulus, and the first fixed-ratio component completed after 8 minutes produced shock: FI 8-min(FR n:S^P). Byrd found, as did Kelleher (1966a) and Shull et al. (1972), that the number of fixed-ratio components completed was least during the first minute of the interval, and increased during subsequent minutes, again giving the overall pattern of a scallop. Within-component patterning consisted of a period of little or no responding, followed by high steady rates until the next brief stimulus, i.e., a typical fixed-ratio performance.

All these investigators (Kelleher, 1966a; Shull et al., 1972; Byrd, 1973) have found within-component patterning much like a fixed ratio maintained under food, and the over-component pattern characteristic of a fixed interval, with the fixed-ratio component performance acting like a single response. However, only the paired brief-stimulus procedure has been studied. The present experiments, using pigeons as subjects, investigated further a schedule of the form FI T-min(FR n:S), under both

paired and non-paired brief stimulus conditions. Furthermore, the intervals used and ratios employed were larger than those investigated in previous studies of this form of second-order schedule. The schedule was probed by varying the parameter values of the fixed-ratio components to ascertain the effect this had on unifying the within-component performance, as well as the effect this had on the fixed interval. In all conditions of the second-order schedule, comparisons were made with performance under a simple fixed-interval schedule (FI T-min).

Pharmacological analyses have proved to be useful in the past in the study of behavior engendered by schedules of reinforcement. In the present experiment a pharmacological analysis was executed, in part, to compare effects a drug had on the performance under the second-order schedule with that under the simple fixed-interval schedule. Thus, the drug was used to probe further the performance under the second-order schedule to ascertain similarities with the simple fixed-interval schedule. The simple fixed-interval ply may be viewed as a second-order schedule of the same form as the other ply, but without a brief stimulus, and with the fixed-ratio requirement being only a simple keypeck: FI20-min(FR n:$\overline{S}$), where n = 1. (In the second-order ply, n > 1.) To the extent that the ratio in the second-order schedule ply is acting as a unit, then the effect of the drug on this schedule performance should be similar to that when a single response is the unit. In addition, Thomas (1966) and McKearney (1970) have demonstrated that a pharmacological analysis may reveal differential effects in performance which were similar under nominally different stimulus conditions. So, a drug procedure also

provided the possibility of distinguishing between the paired and non-paired brief stimulus conditions, if the performance under both conditions was similar. In previous experiments, the fixed interval has proved to be especially sensitive to behaviorally active drugs. In part, it has been useful since a large range of response rates are generated within each interval, and the effects of drugs are easily seen through changes in response rates.

Marr (1970) has previously demonstrated that drugs may be of value in the analysis of schedule and stimulus control in second-order schedules including brief stimuli. The performance under a fixed-interval-of-one-minute (FI 1-min) schedule was treated as a unitary response and reinforced under a fixed-ratio 20: FR20(FI 1-min:S^P). The first response after one minute produced a brief stimulus, and the twentieth fixed-interval component completed produced the brief stimulus followed by food delivery. Using chlorpromazine, rate dependency was found for both over-component responding and within-component responding, i.e., the control rate of responding was the primary determinant of the rate of responding under the drug (see Kelleher and Morse, 1968). Chlorpromazine showed its rate-dependent effects by increasing the low rate during the components early in the fixed ratio, and, to a lesser extent, decreasing responding in the components later in the ratio. Rate dependency was also found within the fixed-interval components; the rate was increased during the early quarter of the fixed-interval component, and to a lesser extent, decreased in the final quarter of the one-minute intervals. However, the within-component pattern was altered less than the over-component pattern, "...thus suggesting that the presentation of the brief stimulus

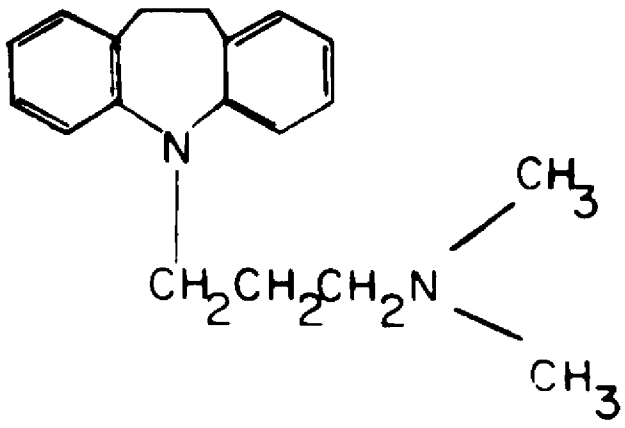
exerted more control over responding within-components than did food presentation over the sequence of components" (Marr, 1969). In general, Marr found that the effect of chlorpromazine on fixed-interval responding which terminates in a paired brief-stimulus presentation was similar to that on fixed-interval responding maintained by food presentation.

Hill (1970, 1972) has provided evidence that psychomotor stimulants, such as pipradrol, can exert their effects on behavior by enhancing the reinforcing strength of a conditioned reinforcer. Hill (1970) trained rats to press a lever in order to produce sweetened milk on a variable-interval schedule (VI 2-min). For one group of rats, lever presses during extinction produced the sound of the empty feeder mechanism (the conditioned reinforcer) under the same schedule that was in effect during training. For the second group of rats, lever presses had no scheduled consequences during extinction. Half the rats from each group were injected with pipradrol, and the other half were injected with a placebo (the control groups). Hill (1970) found that in the group in which responses produced the conditioned reinforcer during extinction, lever presses occurred at a higher rate and extinguished more slowly than the comparable control group. In the group in which responding had no scheduled consequences during extinction, rats injected with pripradrol extinguished more rapidly than the controls. Also, when the rats were returned to the home cage and given free access to the sweetened milk, rats injected with pipradrol drank 40% less than control rats. Hill concludes

> ...the high response rates that were obtained among some of the rats of that experiment suggest that a CR [conditioned reinforcer],

> enhanced by pipradrol, may be a stronger determinant of behavior than the primary reinforcer from which the CR originally derived its reinforcing properties (1970, p. 792).

The drug whose effects are to be studied in the present experiment is imipramine. Figure 1 shows the chemical structure of imipramine, a tricyclic antidepressant. It is thought that imipramine has its effect on behavior in part by blocking the active re-uptake of norepinephrine by the pre-synaptic junction (Longo, 1972). Any drug which has the behavioral effect of increasing rates would have been of interest in comparing the effects of the drug on rates and patterns of responding engendered under the simple schedule and the second-order schedule. Imipramine falls under the general category of drugs whose effect is to increase low and moderate rates of responding. However, imipramine was chosen for additional reasons. First, imipramine shows structural similarity to chlorpromazine. Since the effects of chlorpromazine under a second-order schedule have already been investigated in this laboratory (Marr, 1970), it was of interest to compare the behavioral effects of imipramine with the effects of a chemically-related compound, chlorpromazine. Second, under certain conditions, imipramine shows behavioral effects similar to the psychomotor stimulants investigated by Hill. Studies from Hill's laboratories (Hill, 1972) indicated that in pigeons, when responses (keypecks) produced a conditioned reinforcer (the presentation of the empty feeder magazine and the loud noise of the solenoid), imipramine facilitated responding during extinction. Furthermore, the "pigeon model" followed Hill's previous findings with rats in that when the conditioned reinforcer was withheld during extinction, imipramine produced more rapid extinction of responses.



IMIPRAMINE

5-(3-DIMETHYLAMINOPROPYL)-10,
11-DIHYDRO-5-H-DIBENZAZEPINE

Figure 1. The Chemical Structure of Imipramine.

A number of investigators in addition have found rate-dependency effects using imipramine (Smith, 1964; Valliant, 1964), i.e., different rates were differentially affected by the drug. Smith (1964) studied a multiple schedule in which responding was reinforced under a fixed-interval schedule in the presence of one stimulus, and reinforced under a fixed-ratio schedule in the presence of another stimulus. By scheduling reinforcement in this manner, the multiple schedule provided relatively low rates in the fixed-interval ply and high rates in the fixed-ratio ply. Doses of 0.3 - 10.0 mg/kg increased the fixed-interval rate but decreased the fixed-ratio rates. Furthermore, examination of the rates within the fixed-interval schedule revealed that the relatively high rates during the last minute of the fixed interval were decreased and the relatively low rates occurring during the first minute of the fixed interval were increased. Thus, the particular second-order schedule being studied here offered intriguing possibilities for drug effects, since fixed-ratio responding is affected in an opposite manner than fixed-interval responding: Imipramine increases fixed-interval responding, but it decreases fixed-ratio responding.

To summarize, the purpose of the present experiment was to:

1. Compare rates and patterns of responding under a simple fixed-interval schedule with those under a second-order schedule in which the components were reinforced under an interval schedule.

2. Compare the effects of pairing vs not pairing a brief stimulus with the unconditioned reinforcer in controlling performance under a second-order schedule.

3. Investigate the possibility that a component schedule performance

could acquire properties of a unitary response.

4. Explore the effects of imipramine on a simple fixed-interval schedule vs a second-order schedule.

5. Investigate the possibility that drugs might be useful in analyzing performance characteristics in second-order schedules.

CHAPTER II

METHOD

Subjects

Three male White Carneaux pigeons served as subjects for all conditions. Pigeons 287 and 289 had previous experience with various schedules, including second-order schedules, as well as experience with drugs. Pigeon 70 was naive at the onset of the experiment. Pigeons 287 and 289 were approximately 10 years old and P70 was approximately one year old at the onset of the experiment. All three birds were obtained from the Palmetto Pigeon Plant, Sumter, South Carolina. Birds 287 and 289 were reduced to 80% of their free-feeding weight and P70 was reduced to 75% of its free-feeding weight for the duration of the experiment.

Apparatus

The experimental chamber was a standard 3-key unit (Ferster & Skinner, 1957) in which the two side keys had been covered. The center response key, 2.0 cm. in diameter, could be operated with a minimum force of 0.18 N and could be transilluminated from the rear by either a red, blue, or amber light. A white GE10C7D 120VAC chamber lamp was mounted behind a translucent screen on the key panel and could provide general illumination. The food magazine aperture was 5.1 cm. x 4.4 cm. located 13.5 cm. below the center key and could be illuminated by a white GE10C7D 120VAC lamp during the feeder cycle. White noise in the experimental chamber masked extraneous noises. Standard relay programing equipment

operated all clocks, counters, and timers in a separate room. A cumulative recorder provided a permanent record of the rates and patterns of responding. A cumulative recorder is a device which moves a strip of paper at a constant rate. Each time a response is made, a recorder pen moves a small, constant increment orthogonal to the direction of movement of the paper. This generates a continuous record of the organism's behavior in which the relation between responses and time, e.g., rate, may be easily seen.

Procedure

Pigeon 70 was first trained to eat from the food magazine and then the behavior shaped so the bird pecked a lighted key, and was reinforced for each response (FR1). The schedule was then changed to a small fixed-interval (FI) schedule, i.e., the first keypeck occurring after a fixed-interval of time operated the feeder; keypecks occurring before the elapsed time had no scheduled consequences. The fixed-interval parameter was gradually increased to 20 minutes (FI20-min). After several weeks of training, the condition for P70 was changed to Multiple (MULT) FI20-min FI20-min. Pigeons 287 and 289 were introduced immediately to a MULT FI20-min FI20-min schedule. Under the multiple schedule, the first response after 20 minutes in the presence of a red keylight resulted in 10-sec. access to mixed grain. In the presence of the blue keylight, the first response after 20 minutes also resulted in 10-sec. access to mixed grain. The birds were placed in the darkened experimental chamber 30 minutes before the onset of the session. There were eleven fixed intervals in each session. The first interval was always associated

with the blue keylight. The second interval was either red or blue; thereafter the remaining intervals alternated regularly throughout the session. All responses during the initial blue-stimulus interval were recorded on a separate counter. The responses from the remaining ten intervals were recorded cumulatively under either the red or blue condition. If the bird did not respond within 5 minutes of the end of an interval, that interval terminated without the delivery of a reinforcer and was followed by the succeeding schedule condition (limited-hold 5-minutes).

All experimental conditions were maintained until visual observation of the cumulative records indicated no consistent trend in the performance. After responding had stabilized under the MULT FI20-min FI20-min schedule, a dose-response curve was obtained for imipramine.[1] Imipramine was dissolved in physiological saline (0.9%) and injected into the breast muscle 30 minutes before the start of a session. The injection volume never exeeeded 0.5 cc. The drug was administered only once per week. When imipramine was administered during a condition, the order of the dose of the drug was randomized, with the added condition that two doses of the same value would not follow each other. The drug was administered only after responding had stabilized under each condition.

Doses under the MULT FI20-min FI20-min condition were 1.0, 3.0, 6.0, 10.0, and 17.0 mg/kg for Pigeons 287 and 289, and 0.1, 1.0, and 3.0 mg/kg for P70. Doses which were the same level as injected in P287 and P289 completely suppressed behavior for P70. Physiological saline alone

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[1]Kindly supplied by Geigy Pharmaceuticals, Ardsley, New York.

was occasionally injected, and it was found that responding did not differ from control days (see below, p. 29).

Table 1 gives the sequence of conditions, drug doses, and number of sessions conducted during the experiment. After all doses were administered under the MULT FI20-min FI20-min schedule for all three birds, sessions were continued until responding had stabilized as measured by visual observations of the cumulative records and comparisons of various quantitative indices (see below). Subsequently, the schedule associated with the red stimulus light was changed to a second-order schedule, beginning with MULT [FI20-min (FR30:S^{np})] [FI20-min]. That is, in the presence of the red stimulus light, every thirtieth keypeck (FR30) produced a 0.75-sec. brief stimulus composed of a key color change from red to amber and the onset of the chamber light (S^{np}); the first fixed-ratio 30 completed after 20 minutes (FI20-min) produced food. Thus the responding under an FR30 schedule was treated as a unitary response that was reinforced under a FI20-min schedule of food presentation. The second ply of the multiple schedule accompanied by the blue keylight remained a simple fixed-interval 20-minute schedule, i.e., the first keypeck after 20 minutes resulted in food presentation. The brief stimulus did not accompany the feeder cycle during this ply of the multiple schedule.

The various fixed-ratio components in the second-order schedule were always reinforced under a fixed-interval schedule (FI20-min), and the simple fixed-interval ply remained the same (FI20-min) throughout the experiment. Thus, in order to simplify schedule descriptions, only

Table 1*. Sequence of Experimental Conditions

Bird	Condition	Schedule	Drug (in mg/kg)	Number of Sessions
70	1	MULT FI20 FI20	1.0, 3.0, 6.0	102
	2	FR30:S^{np}		34
	3	FR60:S^{np}	0.1, 0.3, 1.0, 3.0	124
	4	MULT FI20 FI20		14
	5	FR100:S^{np}	0.1, 0.3, 1.0	44
	6	FR100:S^{p}	0.6, 1.0, 3.0	64
	7	FR100:S^{np}		19
	8	FR100:S^{p}	0.6, 1.0, 3.0	32
	9	FR100:S^{np}		5
	10	FR60:S^{np}		8
	11	FR60:S^{p}	0.6, 1.0	27
	12	FR60:S^{np}		4
	13	MULT FI20 FI 20		12
	14	FR30:S^{np}		6
	15	FR30:S^{p}		14
	16	MULT FI20 FI20		21

*Since the over-component schedule was the same (FI 20-min) for all second-order schedules, and the fixed-interval ply remained unchanged (FI 20-min) throughout the experiment, only the second-order schedules are listed.

Table 1
(continued)

Bird	Condition	Schedule	Drug (in mg/kg)	Number of Sessions
287	1	MULT FI20 FI20	1.0, 3.0, 6.0, 10.0, 17.0	150
	2	FR30:S^{np}		34
	3	FR60:S^{np}	1.0, 3.0, 10.0, 17.0	116
	4	MULT FI20 FI20		14
	5	FR100:S^{np}	6.0, 17.0, 30.0	40
	6	FR100:S^{p}	6.0, 17.0, 30.0	61
	7	FR100:S^{np}		16
	8	FR100:S^{p}	6.0, 10.0, 30.0	28
	9	FR100:S^{np}		5
	10	FR60:S^{np}		8
	11	FR60:S^{p}	6.0, 10.0, 30.0	26
	12	FR60:S^{np}		4
	13	MULT FI20 FI20		12
	14	FR30:S^{np}		6
	15	FR30:S^{p}		14
	16	MULT FI20 FI20		21

Table 1
(continued)

Bird	Condition	Schedule	Drug (in mg/kg)	Number of Sessions
289	1	MULT FI20 FI20	1.0, 3.0, 6.0, 10.0, 17.0	150
	2	FR30:S^{np}		34
	3	FR60:S^{np}	1.0, 3.0, 10.0, 17.0	120
	4	MULT FI20 FI20		12
	5	FR100:S^{np}	6.0, 17.0, 30.0	44
	6	FR100:S^{p}	6.0, 17.0, 30.0	63
	7	FR100:S^{np}		17
	8	FR100:S^{p}	6.0, 10.0, 30.0	28
	9	FR100:S^{np}		5
	10	FR60:S^{np}		8
	11	FR60:S^{p}	6.0, 10.0, 30.0	29
	12	FR60:S^{np}		4
	13	MULT FI20 FI20		12
	14	FR30:S^{np}		6
	15	FR30:S^{p}		14
	16	MULT FI20 FI20		21

the second-order schedule component will be referred to hereafter, e.g., FR60:S^{np}, FR100:S^{p}. In the sequence of second-order schedules that follow, the size of the ratio component was first increased, then decreased. The brief stimulus associated with the second-order schedule was first a non-paired stimulus (S^{np}) for all three levels of the fixed-ratio size, and then the stimulus was paired (S^{p}) for all three levels of the fixed ratio. Under the paired condition, the first fixed-ratio of size n completed after 20 minutes changed the key color from red to amber and illuminated the chamber light for 0.75-seconds preceding food presentation. In the non-paired condition, the food was presented with no accompanying key color change or chamber light. Thus, the same stimulus was used in both the paired and non-paired conditions. One of the criticisms of some of the initial studies where differences were found between paired and non-paired conditions was that different brief stimuli were used for the two conditions. It was suggested that perhaps different nominal stimuli affected behavior differently (Stubbs, 1971; Stubbs & Cohen, 1972). By using the same nominal stimuli in both conditions, differences found between the paired and non-paired conditions could not be attributed to different stimuli. Furthermore, the non-paired conditions were initially studied under all ratio values before pairing was instituted. Some evidence suggests that a history of pairing a brief stimulus can produce at least partially irreversible effects (DeLorge, 1967; Kelleher, 1966b; Marr & Zeiler, 1974).

When responding had stabilized under the FR30:S^{np} condition, the fixed ratio size was increased to FR60:S^{np}. Imipramine was administered

for P287 and P289 at doses of 6.0, 10.0, and 30.0 mg/kg. For P70, the doses were 0.1, 0.3, and 1.0 mg/kg. The number of dose levels were reduced at this time, and 30.0 mg/kg was added for P287 and P289 so that a ceiling effect could be seen. Thus, 6.0, 10.0, and 30.0 mg/kg represented a low, medium, and high dose for P287 and P289, and 0.1, 0.3, and 1.0 represented the same relationship for P70.

The schedule was then returned to the original MULT FI20-min. FI20-min. until responding had stabilized. The baseline was reinstated in order to ascertain if the second-order schedule affected responding when the condition was returned to the simple fixed interval.

The schedule sequences studied four general types of transitions. Conditions 2, 3, and 5 (Table 1) investigated the transition of increasing the size of the fixed-ratio component under the non-paired conditions. Conditions 8, 11, and 15 investigated the transition of decreasing the fixed-ratio unit under the paired brief stimulus condition. Conditions 6, 7, 8, 9, 19, 11, 12, 14, and 15 investigated the effects of switching directly from the non-paired consitions to the paired conditions or vice versa. Conditions 4, 13, and 16 were studied to ascertain the effects of changing the second-order ply to a standard fixed-interval ply under the red stimulus condition, as well as to re-establish baseline responding.

Conditions 1, 3, 5, 6, 8, and 11 were used to investigate the effect that certain doses of imipramine had on responding under all schedules, except FR30:S^{np} and FR30:S^{p}.

Measurement of Fixed-Interval and Fixed-Ratio Responding

Total responses under the red and blue stimulus light conditions

were accrued for each session so that overall rates could be calculated. Also, each 20-min. interval was divided into 10 equal segments for both the red and blue stimulus light conditions. In this way, rates could be calculated for each segment, providing a measure of patterning across the 20-min. interval. In addition, a printout counter recorded the time taken to complete each ratio during the second-order schedule ply, and the number of ratios completed per segment was determined. The total postreinforcement pause was cumulated for both plies of the multiple schedule.

Measurement of Drug Effect

The day before each injection was used as a control day. If responding on the regularly scheduled control day fell outside the range of the previous control days of that condition, the injection was postponed. Two measures may be considered when investigating the effects of drugs. First is the dose response, or dose-effect curve, where some measure of responding is plotted as a function of dose levels to determine the effect that a particular dose has on responding. Although overall rates were considered in generating the dose-effect curves for fixed-interval responding, this measure tended to show considerable variability from day to day. This appears to be a fundamental property of fixed-interval responding (Dews, 1970; Herrnstein & Morse, 1958). A more stable parameter, the quarter-life (Herrnstein & Morse, 1957), was used primarily in determining a dose-effect curve. Herrnstein and Morse (1957) showed that several doses of pentobarbital had a more orderly effect on the quarter-life than on rate. The quarter-life measure is somewhat similar

to the median; it is the time (expressed as percentage of the interval value) taken to emith one-fourth of the total number of responses for any interval. The responses being recorded in equal segments throughout the interval allows the distribution of rates to be determined. To obtain the quarter-life, the number of responses in each segment of the schedule was added until one-fourth of the total number of responses was obtained.

The second measure of drug effect is somewhat more refined and indicates the proportional increase or decrease in responding under drug rates when compared to control rates. Rate dependency functions were plotted with the abscissa showing the distribution of the logarithms of the control rates, and the ordinate the logarithms of the ratio of the drug rate to the control rate times 100, e.g., log (drug rate per segment/ control rate per segment x 100). Regression lines were fitted to the data by the method of least squares. By determining the extent of rate-dependency, one may predict to a certain extent the effect of the drug depending upon the ongoing control rates, and also further compare the simple fixed-interval schedule to the second-order schedule, as well as the paired brief-stimulus to the non-paired brief-stimulus conditions. Rate-dependency functions were obtained from the distribution of over-component fixed-interval rates and by counting the number of fixed-ratio components completed per segment of the interval. The mean, range, and standard error of the mean were calculated for both rates and quarter-life values.

CHAPTER III

RESULTS

Within- and Over-Component Patterning

Figures 2, 3, and 4 show representative cumulative records of the performance of the three birds at all values of the fixed-ratio component under the paired and non-paired brief stimulus conditions. At FR30 and FR60 there were no consistent differences between the paired and non-paired conditions either in the overall rate of responding or the extent of characteristic fixed-ratio patterning. While there are indications of patterning at all values of the fixed ratio, manifestation of within-component patterning increased as the size of the fixed ratio was increased. The within-component patterning was seen most clearly in the FR100 conditions. The records from all three birds at FR100 indicate that the fixed-ratio patterning was somewhat more distinguishable and occurred slightly more often in the paired condition. If there were a difference in patterning, then it would be expected that it would take longer to complete the fixed ratio in the paired condition, if the pauses were longer and occurred more often than in the non-paired condition. The average time taken to complete a fixed-ratio of size n was calculated (omitting the highly variable first ratio of each interval) for all conditions. Under the FR100 condition, the average time taken to complete a fixed ratio was greater in the paired condition than the non-paired condition. However, at other levels of the fixed ratio, this trend was not observed. For example, under the FR60 conditions, P70's average time to complete a fixed ratio was greater in the

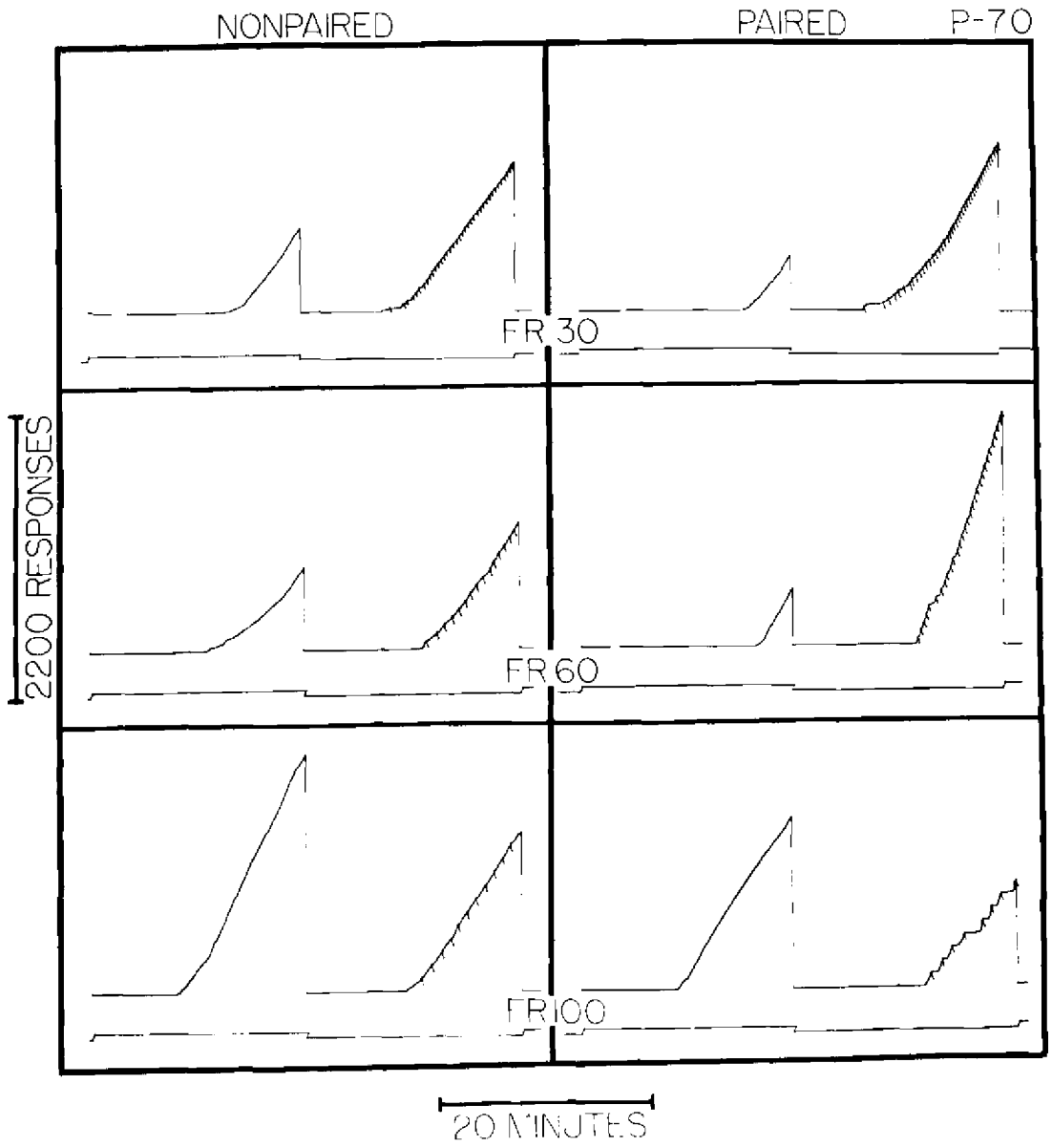

Figure 2. Performance Under All Levels of the Fixed Ratio for P70. Requiring a Fixed Ratio of Size n Did Not Disrupt the Over-Component Fixed-Interval Patterning.

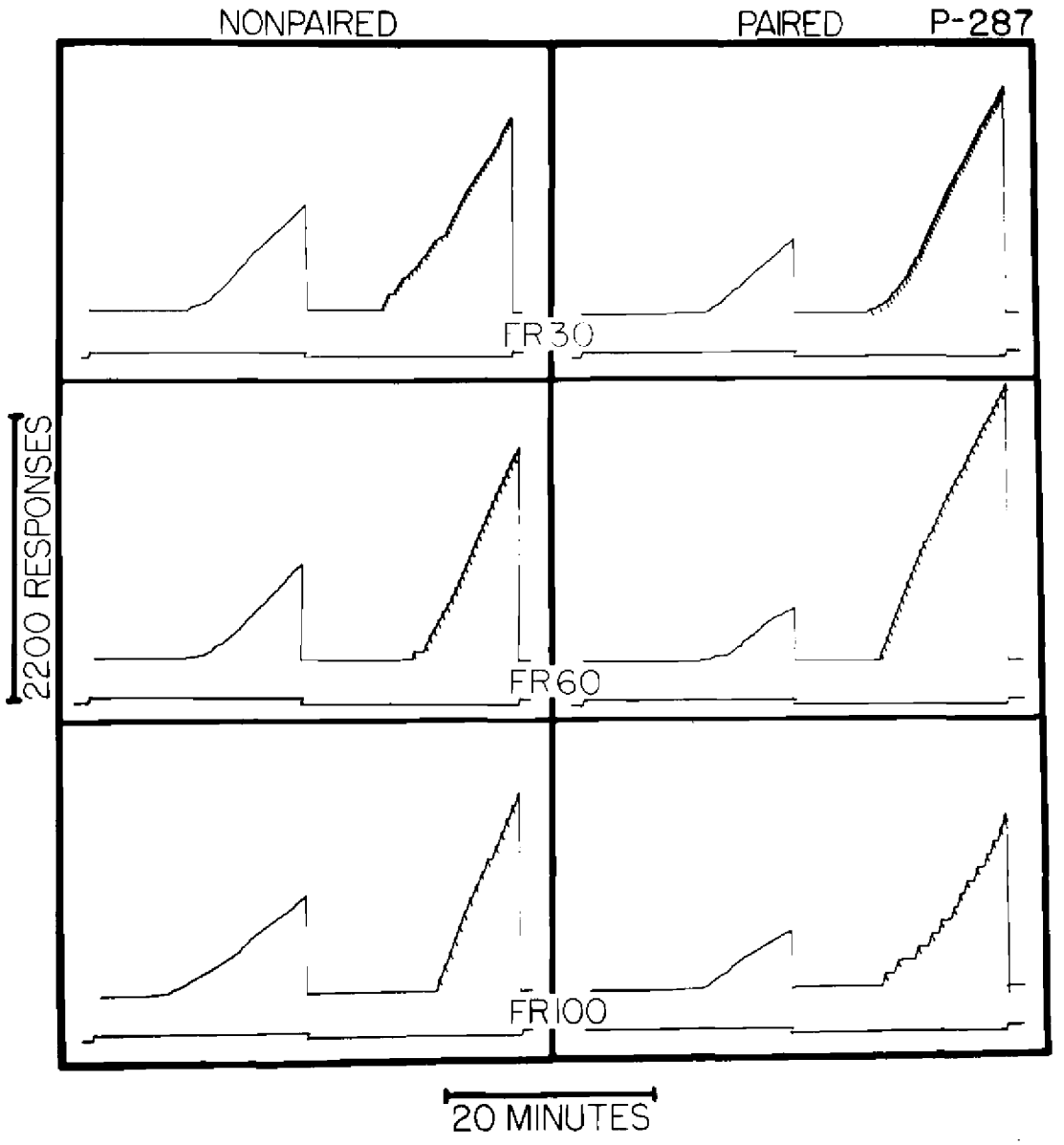

Figure 3. Performance Under All Levels of the Fixed Ratio for P287. Within-Component Fixed-Ratio Patterning Was Seen Distinctly Under the FR100 Conditions; There Was Some Indication of This Pause-Run Pattern Under the FR60 and FR30 Conditions.

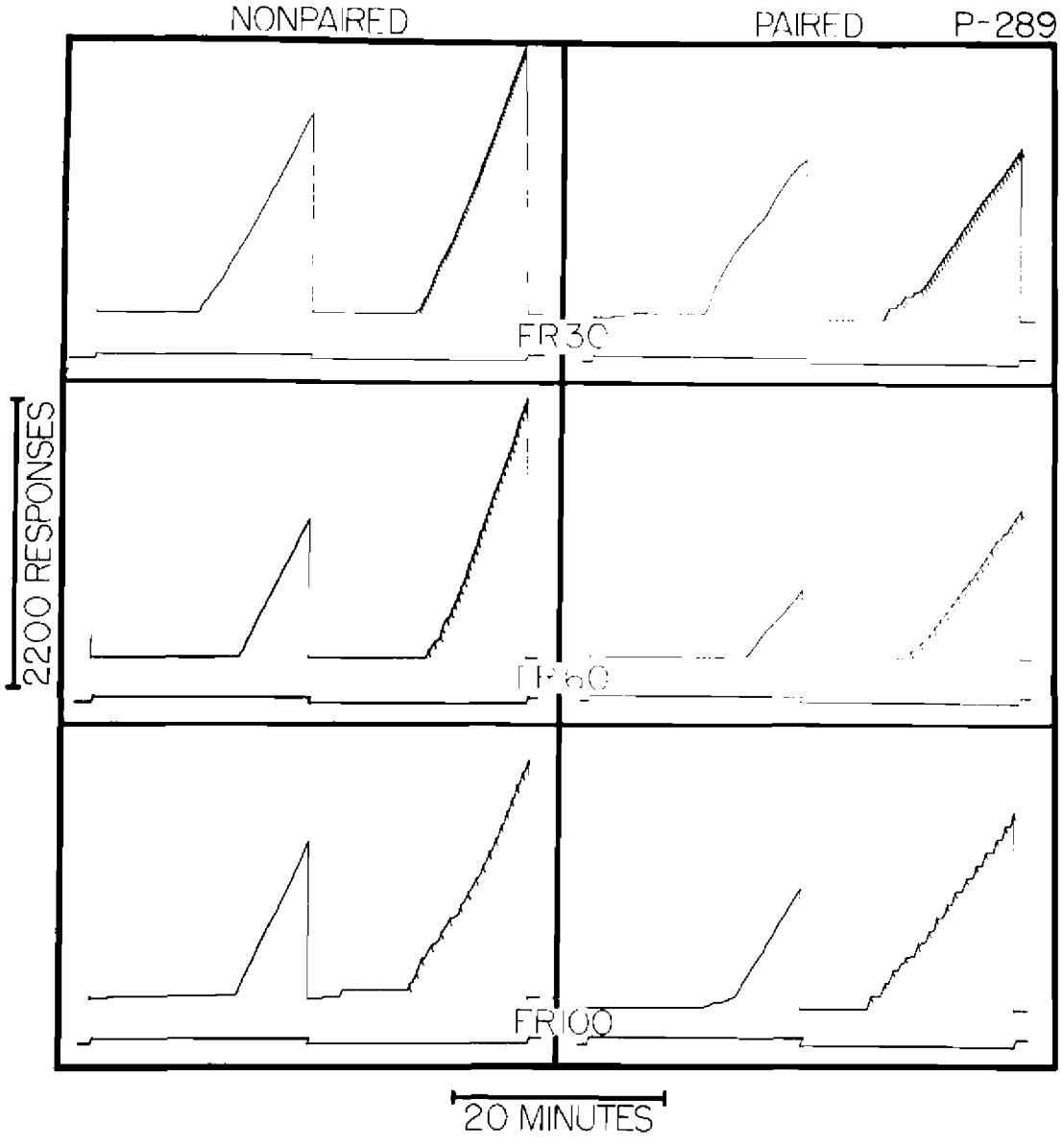

Figure 4. Performance Under All Levels of the Fixed Ratio for P289. In Both the Simple Fixed-Interval Ply and the Second-Order Schedule Ply, There Was a Pause After Reinforcement, Followed By Responding Increasing in a Positively Accelerating Manner Until the Next Reinforer.

non-paired condition; the average time was the same for P287 for both conditions; and P289's average time was greater in the paired condition. In both the second-order schedule ply and the simple fixed-interval ply, a pause occurred after food presentation with the rate of responding increasing until the next food delivery. In the second-order schedule the number of fixed-ratios completed was the least during the early segments of the fixed-interval and increased during the later segments. Thus, imposing a fixed ratio requirement did not disrupt the overall pattern of increased responding characteristic of the fixed-interval schedule.

Figure 5 shows the overall control rates for all three levels of the fixed ratio in both paired and non-paired conditions, as well as the simple fixed-interval ply of the multiple schedule. The data were obtained from the control sessions preceding those in which imipramine was administered and comparable days at the FR30 value. When the fixed-ratio value was increased, there was no consistent trend in overall rates for either the second-order schedule or its associated simple fixed-interval ply. Also, overall rates of responding during the second-order schedule ply were not consistently higher than the overall rates of responding during the simple fixed-interval ply. For example, P289 had higher rates in all the second-order schedule plies than in the simple fixed-interval plies, but P287 showed higher rates in the second-order schedule ply only for the paired conditions. Pigeon 70's rates of responding were higher in the simple fixed-interval ply for almost all the conditions. Rates for the second-order schedule ply for P70 showed little or no change as the fixed ratio was increased. Pigeon 289's rate during this ply increased and then decreased as the size of the fixed ratio was increased. As the

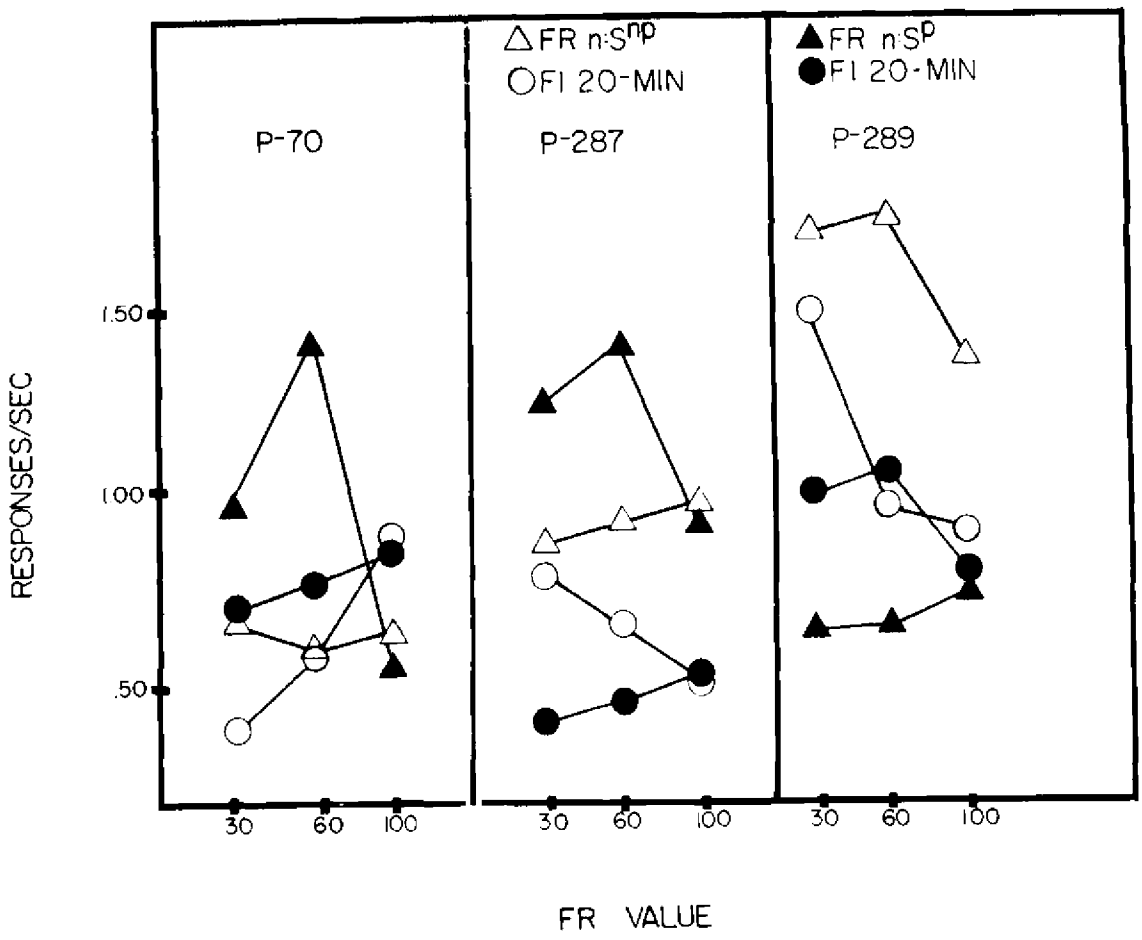

Figure 5. Overall Rates Of Responding in the Fixed-Interval Ply and the Second-Order Schedule Ply, Including Paired and Non-Paired Brief-Stimulus Conditions for All Three Birds.

ratio was increased for P287, the responding in the second-order schedule ply of the non-paired conditions increased slightly, while responding in the paired condition decreased slightly.

Figure 6 shows the number of fixed ratios completed per two-minute segment for each of the six FR$\underline{n}$ conditions for P287. The printout counter which recorded the time in seconds taken to complete each ratio permitted the calculation of the data shown in Figure 6. The time taken to complete each fixed ratio was summed and divided into 2-minute segments, just as the distribution of single responses had been recorded in 2-minute segments across the 20-minute interval. The number of fixed ratios completed in each two-minute segment was then averaged across intervals. Plotting the complex unit in this manner enabled one to determine the extent to which the fixed-ratio performance had characteristics of a single keypeck during the fixed interval. The patterns indicate that few or no fixed ratios were completed during the first few 2-minute segments of the interval, then the number of fixed ratios completed per segment increased in a positively accelerated manner until the terminal segment, thus giving a pattern appropriate to fixed-interval responding for the fixed-ratio components, just as was seen for the single response in the simple fixed interval in Figures 2, 3, and 4.

The schedule under the red-stimulus light was returned from the second-order schedule to a simple fixed-interval schedule during conditions 4, 13, and 16. Figure 7 shows cumulative records from three different sessions of MULT FI20-min. FI20-min. for P287. The event marking pen was down for the red-stimulus ply and up for the blue stimulus ply. The top record was taken from Condition 1, the original multiple schedule, before

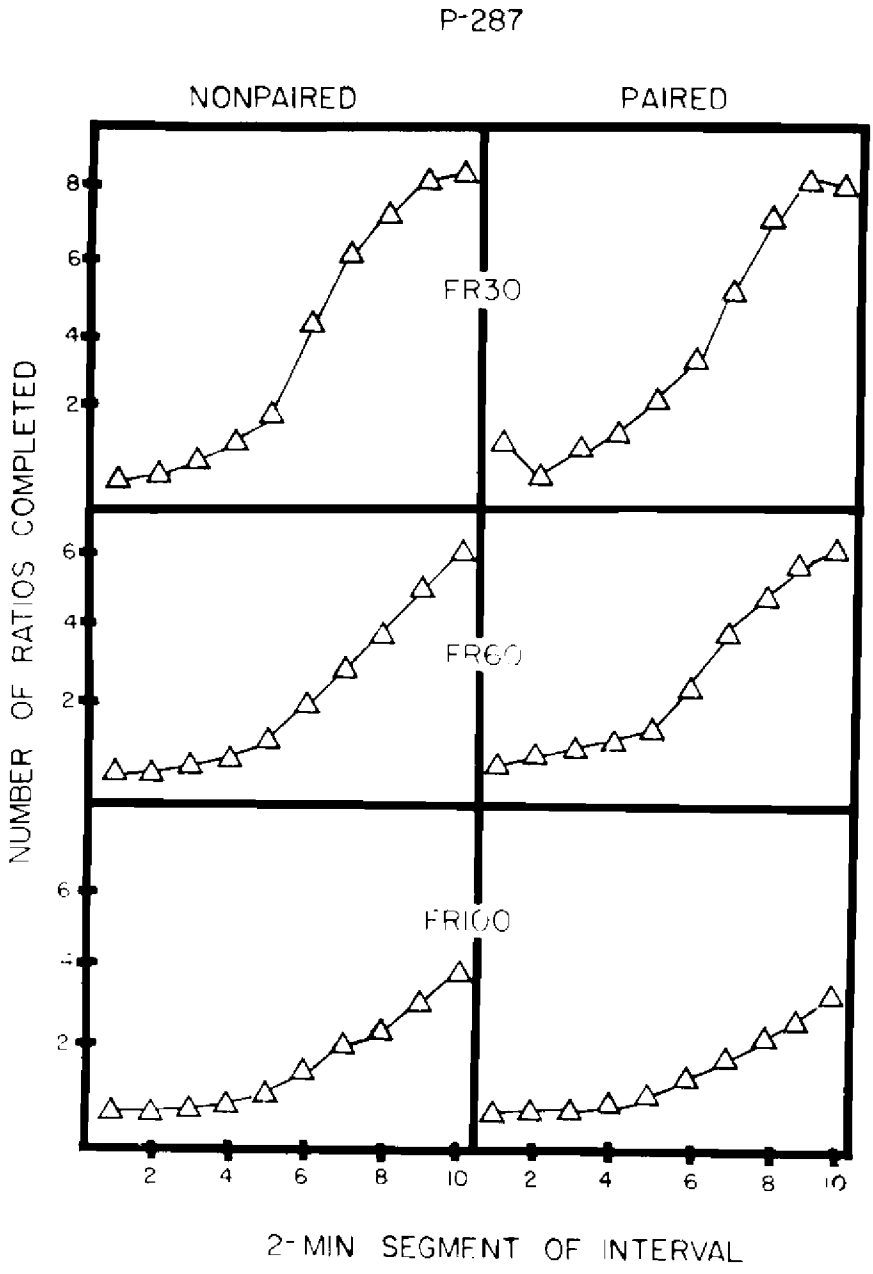

Figure 6. Ratios Completed Per Segment for P287. The Within-Component Fixed Ratios Acted as a Unitary Response In the Over-Component Fixed-Interval Schedule.

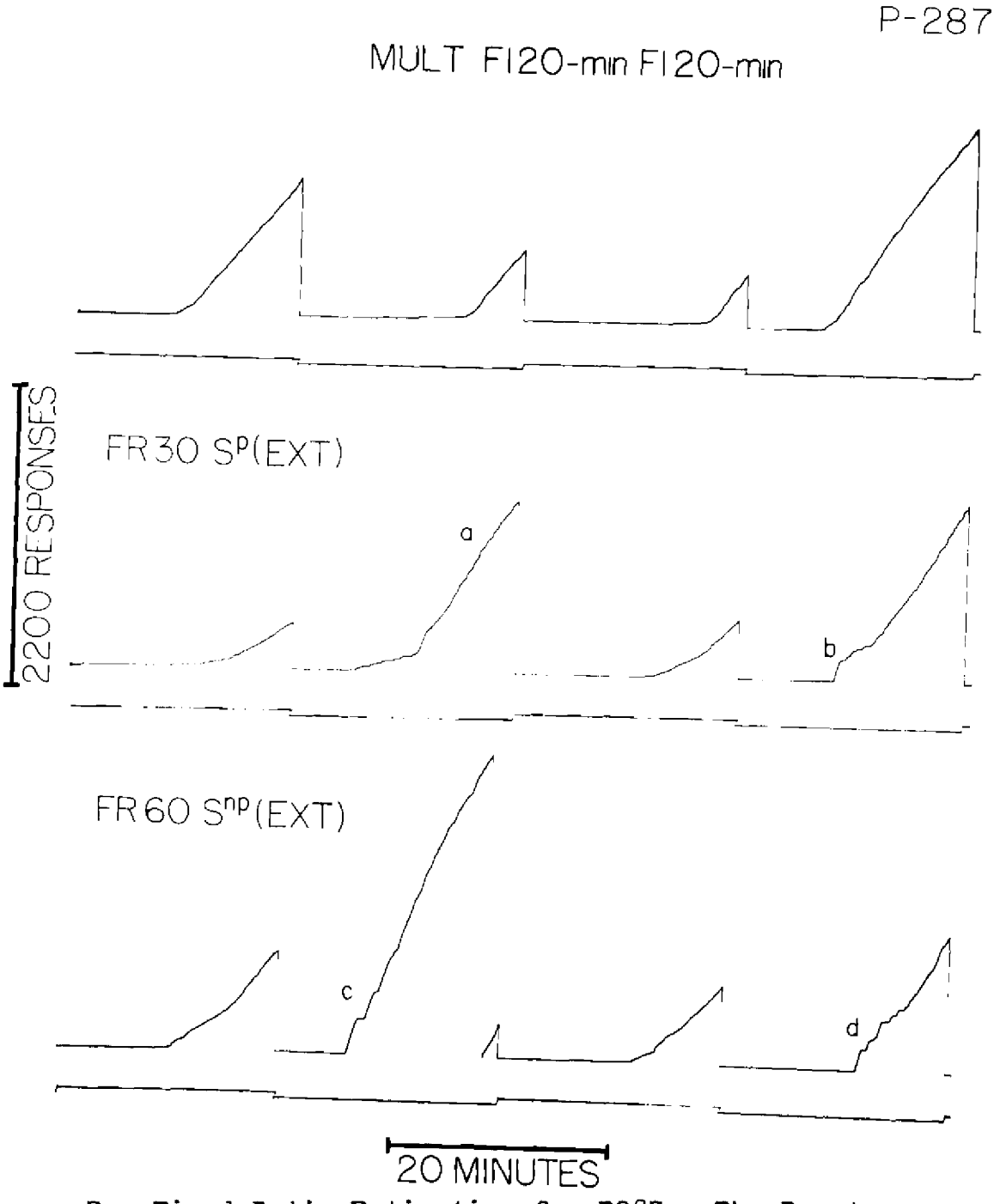

Figure 7. Fixed-Ratio Extinction for P287. The Bursts of Responding at (a) and (b) Are Smaller Than the Bursts at (c) and (d).

the second-order schedule was introduced in the red-stimulus ply. The rates of responding were about equal for both plies, and the pattern of responding was typical of that seen in fixed intervals. The second record is from the first day of Condition 4, again MULT FI20-min. FI20-min., which was reinstated after the second-order schedule FI20-min ($FR60:S^{np}$). The bottom record shows the first day of return to the simple multiple fixed-interval schedule (Condition 16), which occurred after the $FR30:S^{p}$ condition. While the top record indicates a smooth pattern of increased responding in both plies, with about equal rates in the two plies, the middle and bottom records show bursts of responding (for example, at a, b, c, and d) during the red-stimulus ply (event marker in the down position) and higher overall rates, both characteristics of fixed-ratio extinction. The length of the bursts of responding corresponded with the previously established fixed-ratio requirement; they were longer following FR60 than FR30. Both the middle and bottom records show the same effect, even though one occurred after a non-paired condition and the other occurred after a paired condition.

Drug Effects

Figure 8 shows representative cumulative records from the $FR100:S^{np}$ and $FR100:S^{p}$ conditions for P289. The fixed-ratio patterning was more demonstrable in the paired condition than in the non-paired condition. However, when imipramine (6 mg/kg) was administered there were no discernible differences in the effect on the rate or pattern of responding engendered in the paired and non-paired conditions. In both the paired and non-paired conditions the low rates during the first few segments of the interval were

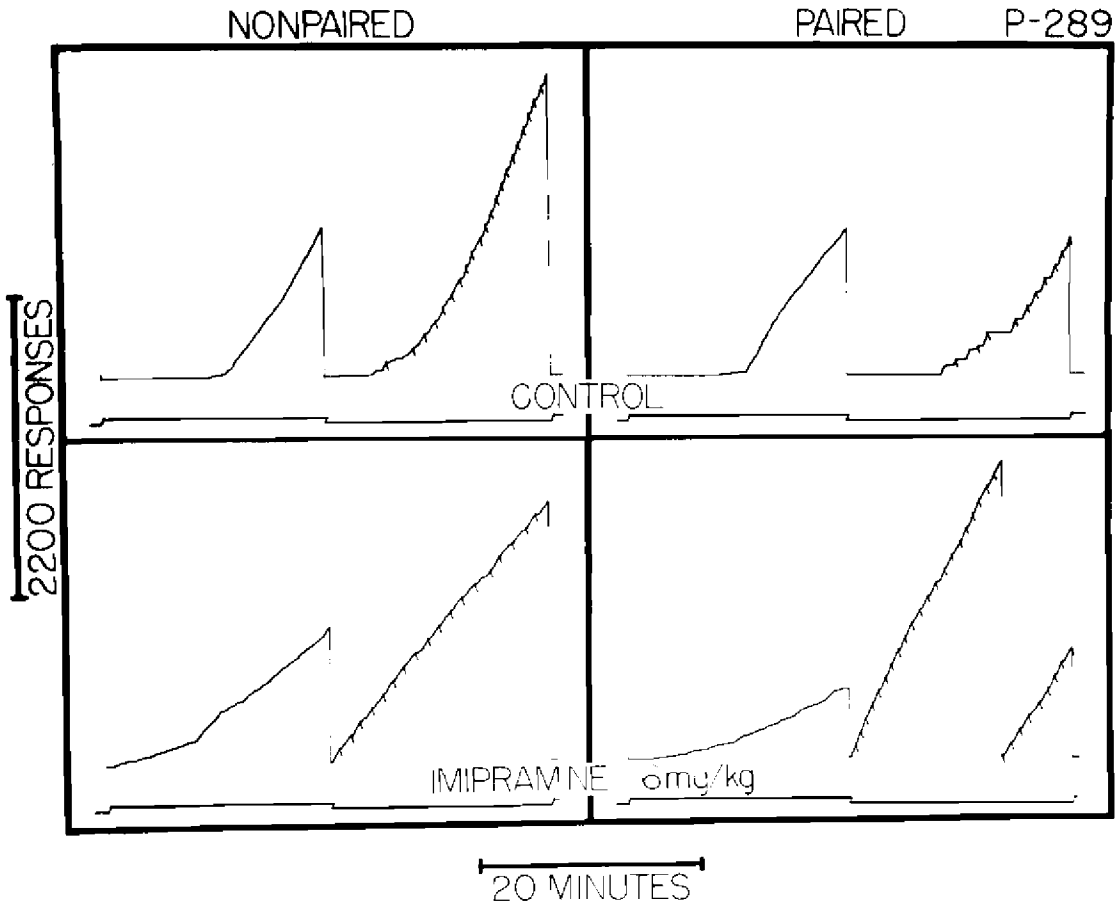

Figure 8. Responding Under the FR100 Condition for P289. The Top Record Shows Typical Responding Under the FR100 Conditions; The Fixed-Ratio Within-Component Pattern is More Distinct Under the Paired Condition. However, When Imipramine Was Administered (Bottom Record), These Differences Disappeared.

greatly enhanced, while the terminal high rates were slightly decreased. While the effect of the drug was qualitatively similar between the second-order schedule and the simple fixed-interval plies, it differed quantitatively. The rates in the second-order ply were enhanced more than the rates in the fixed-interval ply. In the second-order schedule ply, all post-stimulus pauses disappeared in both the paired and non-paired conditions, and responses were emitted in a steady high rate throughout the interval.

A rate-dependency function was obtained for P289 at 6.0 mg/kg at the FR100 conditions. Figure 9 presents a quantitative analysis of the control days and drug days from which the cumulative records of Figure 8 were chosen. The abscissa is divided into three sets of ten 2-minute intervals representing the distribution of the logarithm of the mean control rates of responding for the control sessions. The second-order ply control rates for both the paired and non-paired conditions at FR100, and the simple fixed-interval ply for the FR100:S^P condition are displayed here. The ordinate represents the logarithm of the ratio of the rate of responding under the drug to the control rate of responding, multiplied by 100. If the points all fell along the horizontal dotted line, it would indicate that the drug exerted no influence in rates of responding. Points which lie above the "no change" line indicate those control rates of responding were increased by the drug; points which lie below the "no change" line indicate those rates of responding were decreased. Figure 9 shows that the low rates of responding occurring during the early segments were greatly enhanced by imipramine while the high rates of responding occurring

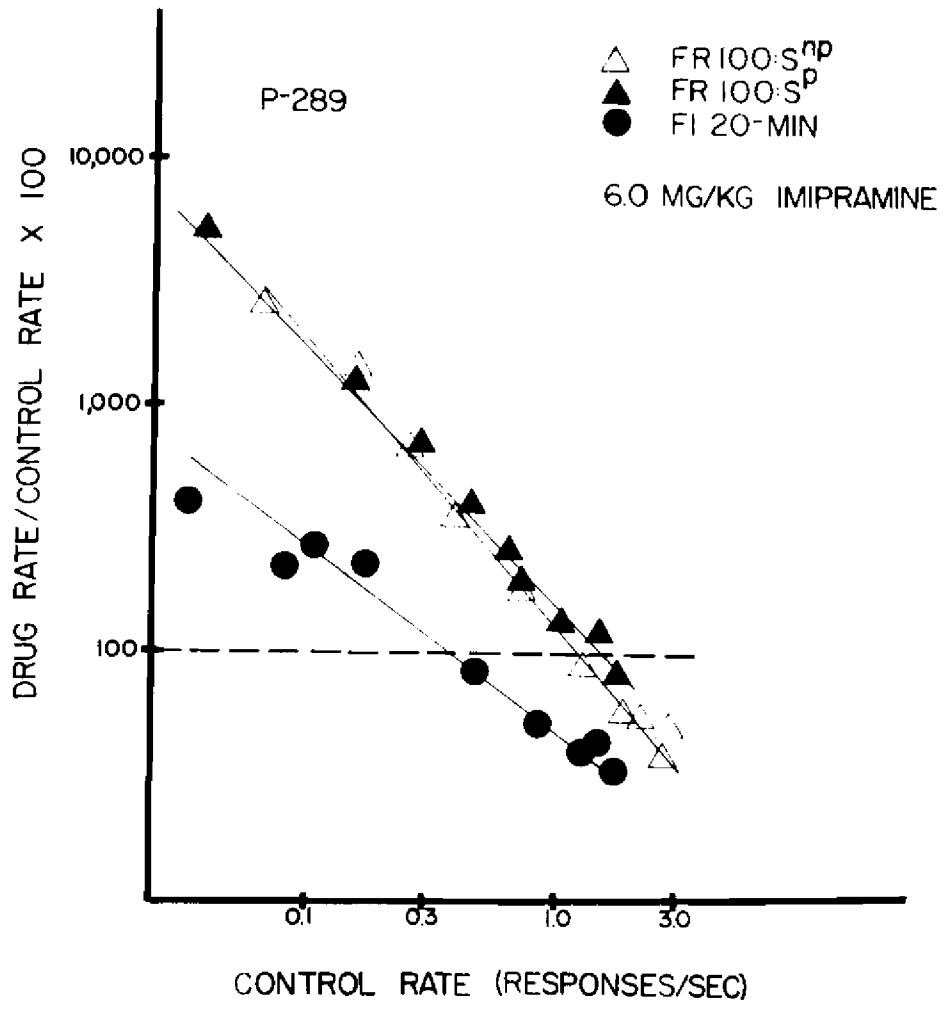

Figure 9. Rate Dependency Function For P289 at 6.0 MG/KG Of Imipramine. The Filled Circles Represent Rates From The Simple Fixed-Interval Schedule In The Paired Condition. Data Points Falling Along The Dashed Line Would Indicate The Drug Had No Effect On the Control Rates.

later in the interval were somewhat decreased. There was no consistent difference between the paired and non-paired brief stimulus conditions in the effect the drug had on responding. The slope of the rate dependency function for the second-order ply in the FR100:S^{np} condition was -1.1709; the slope for the second-order schedule ply in the FR100:S^{p} condition was -1.0575. This graph again indicates the quantitative difference between the effect of the same dose of the drug under the second-order schedule ply and the simple fixed-interval ply. Control rates during the fixed-interval ply which were the same (fell in the same position along the abscissa) were not enhanced as much as the same rates during the second-order schedule ply, and the higher rates of responding during the simple fixed-interval ply were decreased more than the same rates during the second-order schedule ply. The slope of the regression line for the simple fixed-interval ply in the paired brief stimulus condition was -0.6508; the slope of the regression line (not shown) of the fixed-interval ply of the nonpaired condition was -0.6320. Thus, while during the second-order schedule plies in the paired and non-paired brief stimulus conditions responding did not differ greatly, responding under the drug was quantitatively different in the second-order plies when compared to the simple fixed-interval ply.

By using the same procedure as was used in calculating the data shown in Figure 6, another type of rate-dependency analysis was made possible. The number of fixed ratios completed per 2-minute segment was first obtained for the control days and that number multiplied by n, where n was the size of the fixed ratio in that condition. The control rates are plotted on

the abscissa of Figure 10 and are thus the logarithm of average control rates per interval, rather than per session, as shown in Figure 9. The control rates for the fixed-interval ply were obtained by dividing the mean session rates per 2-minute segment by the number of seconds in that segment, resulting in responses completed per second. The ordinate is again the logarithm of drug rate divided by the control rate times 100. Figure 10 shows the rate dependency function for P70 at 1.0 mg/kg of imipramine under the FR60:S^P condition, using the ratio as the unit of analysis for the second-order ply, rather than the single response, and the average response rates per interval for the simple fixed interval rather than the average session rates. Pigeon 70 proved to be more sensitive to imipramine than the other two birds. Rate-dependency functions and dose-effect curves were similar, but were obtained at lower doses than the other two birds. Other investigators (e.g., Dews, 1962) have reported this wide range of sensitivities. One possible explanation for the present finding is that P70 was much younger, had no previous drug history, and was experimentally naive at the onset of the experiment. The slope of the regression line using the ratios completed per segment was -0.9521 for the second-order schedule ply; the slope of the regression line (not shown) using single responses per 2-minute sgement for the second-order schedule ply was -0.9463. The slope of the simple fixed-interval was -0.7924 using the rate of responding per interval, while the slope of the regression line (not shown) using rate of responding per session was -0.7987. Thus, the fixed ratio may be used as the unit of analysis to determine a rate-dependency function.

As with the overall control rate of responding (see Figure 5),

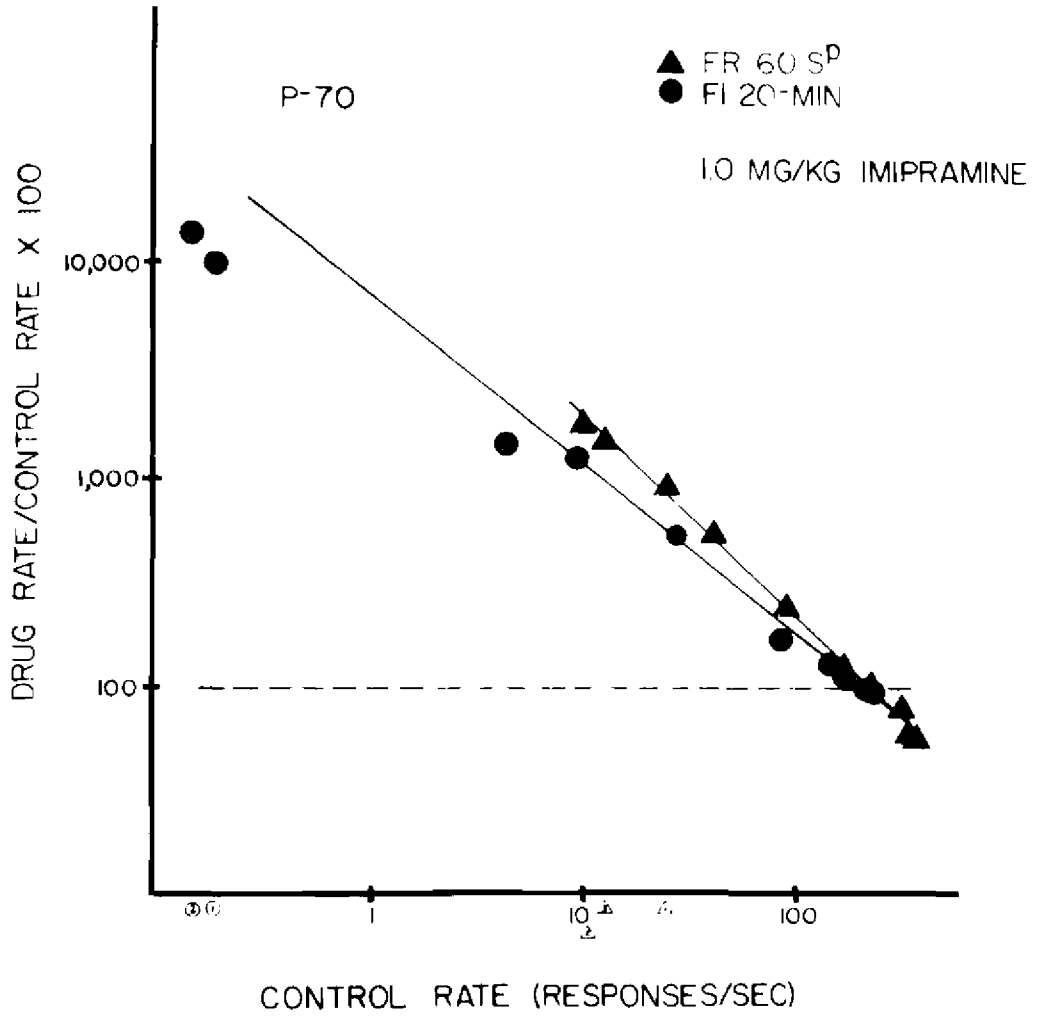

Figure 10. Rate Dependency Function For P70. The Simple Fixed-Interval Schedule Is From The Paired Condition. Only The 2-Minute Segments Which Did Not Fall In Sequential Order Are Numbered Across The Abscissa.

overall rates of responding under the drug were highly variable, and there was no consistent trend indicating differences between the paired and non-paired conditions. The drug had greater rate enhancing effects on the second-order schedule ply than the simple fixed-interval ply at the same dose levels. In general, responding in both plies increased when the drug was administered, until the maximum dose (17.0 mg/kg for P287 and P289 and 1.0 for P70) and then decreased. However, rate enhancement was not expressible as a simple monotonic relationship. At higher doses, the disparity of responding between plies under the drug was more clearly distinguishable, as seen in the cumulative records of Figure 8 and the rate dependency curves in Figures 9 and 10.

The quarter-life values (i.e., the percentage of the interval taken to emit one-quarter of the responses) were stable across all conditions for both the second-order schedule ply and the fixed-interval ply. Table 2 shows the control data for all three birds at all levels of the fixed-ratio component. Included in the table are the means of the quarter-life values, as well as 2 standard errors of the mean.

The drug decreased the quarter-life value, reflecting the very large rate enhancement during the early segments of the interval, and the slight decrease of responding during the terminal segments. Figure 11 shows the dose-response curve obtained using quarter-life values for P287 at FR60:S^{p} and FR60:S^{np} for dose levels of 1.0, 3.0, 6.0, 10.0, 17.0, and 30.0 mg/kg. The data from Figure 11 indicate that in general, the higher the dose, the lower the quarter life value for the second-order schedule.

Once the quarter-life value had reached 25% (which occurred around 6.0 mg/kg), a "floor effect" was seen, i.e., the quarter-life was not

Table 2. Quarter-Life (Q. L.) Values and Standard Error of Mean (SEM) for All Conditions

	P70			
	FRn:S^{np}	FRn:S^{p}	FI20(S^{np})	FI20(S^{p})
FR30				
Q.L.	58.01	65.82	62.97	64.33
2 SEM	8.43	7.98	9.30	8.40
FR60				
Q.L.	67.66	60.70	64.51	67.65
2 SEM	2.64	8.00	3.75	3.06
FR100				
Q.L.	71.19	66.68	62.21	64.68
2 SEM	6.56	2.64	5.48	6.86
	P287			
FR30				
Q.L.	62.64	56.16	60.43	65.78
2 SEM	6.70	7.80	8.12	7.49
FR60				
Q.L.	68.03	60.18	62.65	61.24
2 SEM	3.30	4.98	1.78	6.34
FR100				
Q.L.	63.84	66.91	56.80	63.57
2 SEM	3.05	6.71	5.14	5.92

Table 2 (Continued)

	P289			
	FRn:S^{np}	FRn:S^{p}	FI20(S^{np})	FI20(S^{p})
FR30				
Q.L.	51.86	65.02	51.50	60.72
2 SEM	8.50	8.89	5.81	7.40
FR60				
Q.L.	59.60	61.68	63.99	56.11
2 SEM	2.43	8.99	3.44	6.28
FR100				
Q.L.	61.81	64.69	62.73	63.26
2 SEM	3.52	7.66	4.48	5.09

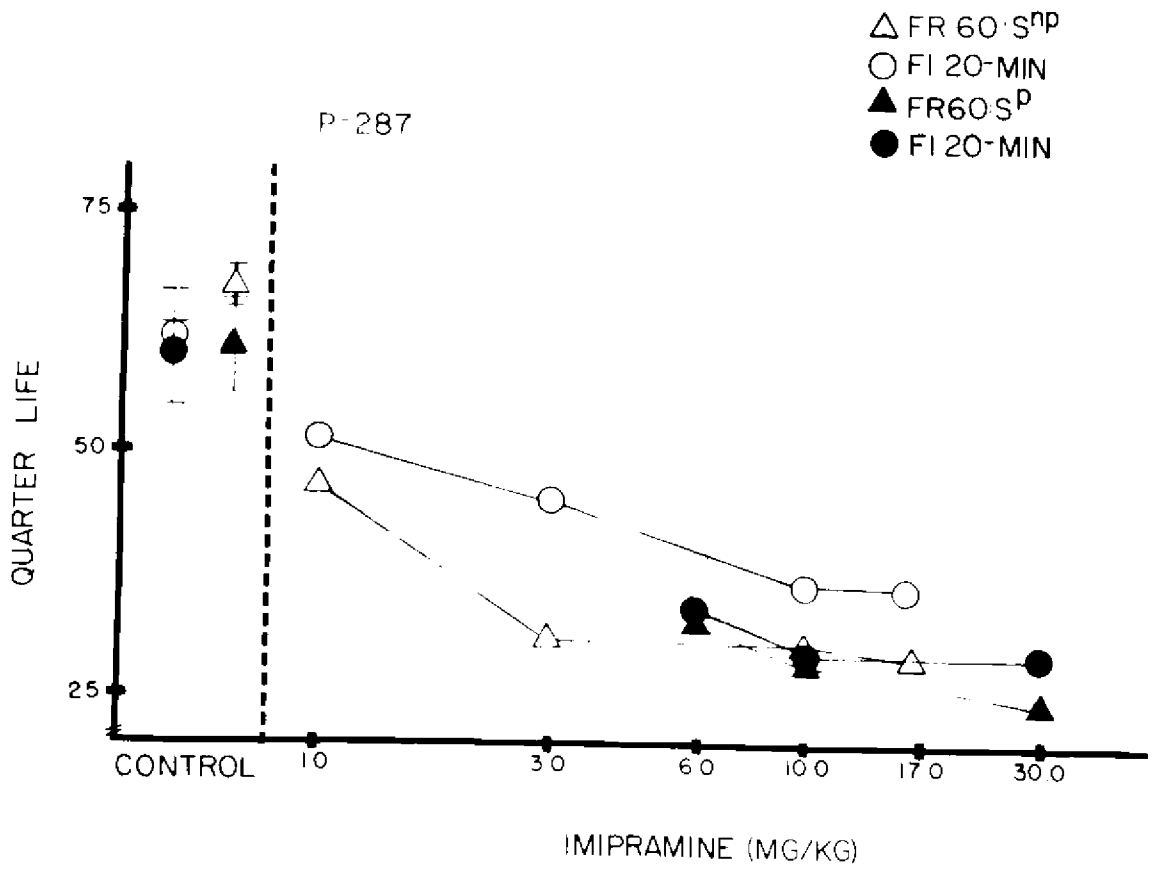

Figure 11. Dose-Response Function for P287. Approximately Three Determinations at Each Level Were Made. Vertical Lines Signify ± 2 Standard Error. The Abscissa is a Logarithmic Scale.

decreased further with increased doses (Figure 12). A quarter-life value of 25% indicates that the bird is responding equally throughout the interval. Figures 11 and 12 also indicate that the effect of the quarter-life values for the second-order schedules (both paired and non-paired) were more similar to each other than they were to the simple fixed-interval ply of each schedule. The hatched triangles are a second dose-response curve, obtained during the second establishment of the FR100:S^P condition (condition 8). These points closely replicate the initial dose-response curve for the paired condition. In general, the drug decreased the quarter-life value more for the second-order schedule ply than the simple fixed-interval ply, except at the highest doses (3.0 mg/kg for P70 and 30.0 mg/kg for P287 and P289). Responding under these very high doses was often highly variable.

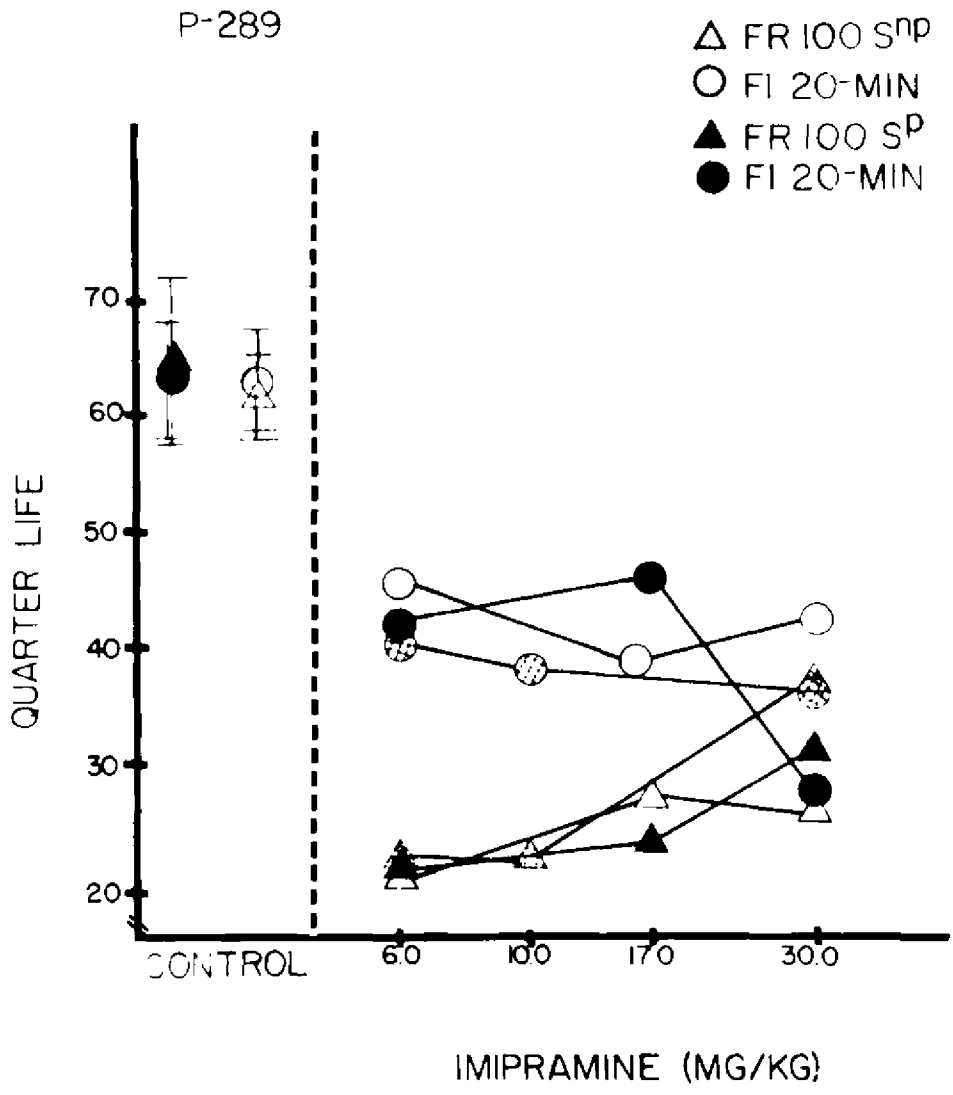

Figure 12. Dose-Response Function for P289. Vertical Lines Signify ± 2 Standard Error. Hatched Points Are a Re-determination of the Doses Under the Paired Condition.

CHAPTER IV

DISCUSSION

In the present experiment, patterns characteristic of fixed-ratio schedules were produced within the components of both the paired and the non-paired brief stimulus conditions. The within-component pattern consisted of a short pause after the brief stimulus, followed by high steady rates until the next brief stimulus was presented. The cumulative records showed that the pre-ratio pause was proportional to the fixed-ratio requirement; the pauses which developed at the FR30 condition were noticeably shorter than those seen in the FR100 conditions. Once the response sequence had begun, there were few pauses until the fixed-ratio requirement was completed. The records for the first day following the change from the second-order schedule to the simple fixed-interval schedule under the red stimulus (Figure 7) indicate clear evidence of fixed-ratio extinction (Ferster & Skinner, 1957) after both the paired and non-paired conditions. In order for the responding to occur in bursts, as it did, it was first necessary that responding characteristic of fixed-ratio schedules had been established within the components of the second-order schedule. Further evidence of fixed-ratio patterning was revealed by the effect of imipramine on within-component responding. When the drug was administered, the pauses and the high steady rates were altered so that responding was emitted at slower steady rates, with no pauses after the brief stimuli. Comparison of the cumulative records obtained from days in which the drug was administered with those from control days made the pause-run pattern

of the fixed-ratio component more evident.

The within-component patterns which developed and were maintained at all levels of the fixed ratio may have been the result of the brief stimulus assuming properties of either a conditioned reinforcer or a discriminative stimulus. In studies which have found distinct differences between the two conditions, i.e., characteristic patterns and/or enhanced rates in the paired condition which did not develop in the non-paired condition (Byrd & Marr, 1969; DeLorge, 1967; Kelleher, 1966b; Marr, 1969; Thomas & Stubbs, 1969; Zimmerman, 1969) those differences have been attributed to the conditioned reinforcing properties of the paired brief stimulus. Patterning could also result from acquired discriminative functions of the brief stimulus. Stubbs (1971) suggested that when fixed within-component schedules (e.g., FR, FI) are used, there is a fixed period of time between the occurrence of the last brief stimulus and food presentation, and the brief stimulus may thus acquire S^{Δ} characteristics. During the first part of the component, food is never presented, so the animal pauses before responding. If the first part of the FR component developed S^{Δ} properties or if the brief stimulus assumed reinforcing properties controlling schedule-characteristic patterns, the end result might be similar; a pause followed by high steady rates. The S^{Δ} hypothesis would explain the within-component pattern in both the paired and non-paired conditions.

A second role of a discriminative stimulus which could have contributed to the patterning in both the paired and non-paired conditions has been suggested by Dews (1965). The brief stimulus could serve to mark the ending of the response requirement, thus setting it apart as a

"macroresponse." Thus, with brief stimuli in both conditions signaling the completion of the fixed-ratio requirement, fixed ratio patterning might develop because the brief stimulus serves to unify each component, the component performance, in turn, maintained by the fixed-interval schedule for food presentation. Under these conditions the brief stimulus might be deemed a "quasi-reinforcer" (see Neuringer & Chung, 1967) in both paired and non-paired conditions. Since the food and the brief stimulus both terminated the same sequence of responses then the brief stimulus could assume functional reinforcing properties and thus have generated fixed-ratio patterns in both conditions.

It appears that confusion will remain regarding the properties of paired and non-paired stimuli as long as no consistent difference in within-component patterning occurs between these two conditions. In the present experiment, however, some differences were evident, particularly at the FR100 level. Observation of the cumulative records in the present study revealed a tendency for patterning to occur more often, and the pauses after the brief stimulus to be longer in the paired stimulus condition of FR100 for all three birds. Although all the birds showed a tendency for more within-component patterning under the paired condition at certain other levels of the fixed ratio, the most convincing examples were at the largest ratio (FR100). Overall rates of responding were less in the paired condition than the non-paired condition at FR100 for all three birds. As Byrd and Marr (1969) point out, a conditioned reinforcer may not always have a rate-enhancing effect. In the case of a within-component schedule that is fixed-ratio or fixed-interval, the brief

stimulus may even decrease rates by acting as a conditioned reinforcer, since the pattern produced includes a pause at the beginning of the schedule component serving to decrease the overall rate. In the present experiment, the evidence for differential responding between the paired and non-paired conditions was not very compelling, however, since the patterning looked very similar at other levels of the fixed ratio and there were no consistend trends in the average time to complete a fixed ratio, except under the FR100 condition. Although there was a slight indication of more patterning within the paired conditions, administering imipramine at a variety of dose levels revealed no differences in responding between the two conditions. The rate-dependency functions (Figures 9 and 10) demonstrated that comparable rates in the paired and non-paired conditions were affected similarly by the drug.

In terms of Dews' (1965) analysis, the fixed-ratio component performance may have acquired properties of a macroresponse displaying a schedule-characteristic pattern because the brief stimulus functioned to unify each fixed ratio. Once the response sequence had begun, it was generally completed without further pauses, i.e., the number of responses required in the fixed ratio seems to have been executed as a unit. The run of responses along with the initial pause result in the characteristic fixed-ratio pattern. Ferster and Skinner (1957) investigated mixed schedules with fixed-ratio components. A mixed schedule is similar to a multiple schedule except that there are no distinguishing exteroceptive stimuli associated with each ply. Ferster and Skinner found that when the two plies of a mixed schedule consisted of a large and a small fixed

ratio, responding in the large fixed-ratio ply was characterized by a high rate of responding until about the same number of responses which were required in the small fixed-ratio ply had been executed. Thereafter, the bird paused for a period of time, then completed the response requirement and obtained food. When a Mixed Fixed-Ratio-Extinction schedule was studied, responding in the extinction ply was characterized by bursts of responding about the same size of the fixed-ratio requirement. Kelleher (1966a) suggests that the length of the response sequence is controlled by response chaining. Weiss and Gott (1972) offer evidence to the contrary but nevertheless agree that "...the most outstanding property of the FR pattern is its coherence or cohesiveness" (p. 201). Whether or not the response sequence is maintained by a chaining process, there is some characteristic of the fixed ratio such that when the reinforcer is not presented, responding occurs in a burst of the size appropriate to the fixed ratio requirement. In the present experiment, the size of the bursts during fixed-ratio extinction (when the schedule under the red stimulus light was switched from a second-order schedule to a simple fixed interval) correlated with the size of the previous fixed-ratio component. Thus, the response sequence length was controlled by the previous fixed-ratio requirement, indicating a cohesive property of the within-component performance. This provided strong evidence that fixed-ratio schedule control had been engendered within the second-order schedule components.

With the indication that within-component responding under both the paired and non-paired conditions was characterized by fixed-ratio

schedule control, it is of significance to establish whether or not this component performance was acting as a unitary response in the overall fixed-interval schedule. That is, to what extent was the over-component pattern appropriate to a fixed-interval schedule. Observation of the cumulative records revealed similar over-component patterns for both the simple fixed-interval ply and the second-order schedule ply. In the simple fixed interval, few responses were emitted at the beginning of the interval, with the number of responses increasing in a positively accelerated manner. Likewise, responding under the second-order schedule was characterized by few fixed-ratio components being completed at the beginning of the interval; thereafter the number increased in a positively accelerated manner until food presentation occurred. Further, when the ratios were plotted as units, the distribution of "responses" was identical to that of single keypecks maintained under a simple fixed-interval schedule.

An interesting aspect of the present study is that requiring a fixed-ratio of as much as 100 to be completed did not reduce responding or seriously alter the shape of the fixed-interval pattern. Herrnstein and Morse (1958) added a fixed-ratio requirement to a fixed interval to make a conjunctive schedule. A conjunctive schedule specifies that both requirements must be met before reinforcement is delivered. So, a conjunctive FIt FRn would indicate that the first response after a fixed time (t) had elapsed (FI requirement) would be reinforced only if $n - 1$ responses had already been emitted (FR requirement). If not, reinforcement would follow completion of the ratio requirement. Herrnstein and Morse found

that requiring as few as 10 responses seriously disrupted responding under a FI 15-min. schedule, even though the subjects were emitting an average of 300 responses per interval. An important feature of an interval schedule is that while many responses ordinarily occur during the interval, only one response following the elapsed time is required. In Herrnstein and Morse's experiment, even though the subjects were responding an average of 300 times during the interval, the range was from one response to three or four times the average number. As the size of the fixed-ratio requirement was increased, the number of times the subjects came into contact with the fixed-ratio requirement increased. Responding subsequently decreased so that the number of responses emitted became equal to the fixed-ratio requirement. At larger values of the fixed ratio the pausing greatly exceeded the interval value. In the present experiment, increasing the size of the fixed-ratio component did not disrupt overall fixed-interval responding. This may be relevant to the issue of the within-component performance acting as a unitary response. The second-order schedule required that only <u>one</u> response sequence be executed, analogous to the simple fixed-interval schedule requiring only a single keypeck. Increasing the size of this complex response did not disrupt behavior, thus providing further evidence that the fixed-ratio performance was acting as a unitary response.

The differences in performance between the second-order schedule and the fixed-interval schedule when imipramine was administered might be interpreted on the basis of the unitary characteristic of the within-component performance. The rate-dependency functions indicated that rate

enhancement under the drug was greater for a given rate in the second-order schedule ply than it was in the simple fixed-interval schedule. If the results are interpreted in terms of the fixed-ratio component performance acting as a unitary response in the overall fixed-interval schedule, then the unit of analysis would be the number of fixed-ratios completed per segment. Thus, the number of fixed ratios completed per segment in the second-order schedule ply would be relatively less than the individual keypecks completed per segment in the simple fixed-interval ply. Since imipramine demonstrated its rate-dependency effect by increasing low rates of responding, the rates of component execution in the second-order schedule ply being lower than the rates of keypecks in the fixed interval ply, the drug would be expected to enhance the former more than the latter.

Weiss and Gott (1972) investigated the effect which imipramine had on FR30 responding by scrutinizing the interresponse time (IRT, the pause between each response). They found that imipramine greatly increased the post-reinforcement time (the first IRT) and thereafter increased to a lesser extent the subsequent IRTs. Since the pausing was increased, the overall rates were decreased. Weiss and Gott found the major contributor to the IRT changes and the decrease in rate was the interruption of the steady rapid rates of responding typical of fixed ratio schedule. In the present experiment, imipramine enhanced responding both within components and over components. When imipramine was administered, not only did the birds begin responding sooner in the interval, but the pause within the component disappeared as well, and responding occurred at a

slower steady rate. This is contrary to Weiss and Gott's findings, for instead of increasing the initial IRT, imipramine greatly reduced the initial IRT. Weiss and Gott concluded that the drug had its effect by breaking up the response sequence, increasing all the IRTs. However, in the present experiment, all pauses within the component were omitted. Thus, even though the within-component fixed-ratio showed characteristics of a fixed ratio, such as patterning and properties of fixed-ratio extinction, when the drug was administered, the within-component unit performance was qualitatively similar to the single response in the simple fixed interval.

Hill (1970, 1972) has found that certain psychomotor stimulants, including imipramine, increased responding which produced a conditioned reinforcer during extinction. Hill attributed these rate enhancing effects to the increased effectiveness of the conditioned reinforcer. However, Hill did not distinguish between the possible conditioned reinforcing effects and the discriminative properties of the stimulus. To the extent that his results apply to the present experiment, one must conclude that any stimulus which functions to unify response sequences might be enhanced in effectiveness by the psychomotor stimulant agents designated by Hill.

CHAPTER V

RECOMMENDATIONS FOR FUTURE RESEARCH

New experiments have been suggested by the present results. One such experiment would involve Hill's hypothesis concerning psychomotor stimulants producing rate enhancement by increasing the effectiveness of the reward value of the conditioned reinforcer. It would be of interest to administer the drugs in a condition in which the functions of the discriminative stimulus and the conditioned reinforcer would be separated. An example of this would be a case in which responding engendered by a paired brief stimulus clearly and reliably differed from that produced by a non-paired brief stimulus. If the drug had rate-enhancing effects on the paired condition, but not the non-paired condition, then it would be concluded that the drug was increasing the effectiveness of the conditioned reinforcer but not the discriminative stimulus.

A second experiment is suggested by comparing the results of Herrnstein and Morse's (1958) study of conjunctive FI FR schedule performance with the present experiment. If the brief stimulus is serving to unify the fixed-ratio component performance as a single response, then omitting the brief stimulus in the second-order schedule (but still having the same response requirement) should disrupt the overall fixed-interval responding, just as it did in Herrnstein and Morse's study. Increasing the within-component fixed-ratio size should further decrease fixed-interval responding. Also, one should be able to replicate Herrnstein and Morse's (1958)

results by requiring more than a single FR component to be executed per interval.

A problem inherent in using a second-order schedule with a fixed within-component schedule is that the schedule relationships between brief stimuli, and between a brief stimulus and food presentation are the same. Thus, the within-component may be acting as a unit which is intermittently paired with food, which in turn maintains responding and schedule-characteristic patterns. Neuringer and Chung (1967) referred to this by indicating all that was necessary for patterning to take place was an identity between the responses which produced the brief stimuli and responses which produced reinforcement. This problem could be eliminated by using a conjoint schedule. A conjoint schedule is one which programs two independent schedules simultaneously on the same key. So, while the brief stimulus could be scheduled on a fixed-interval, the unconditioned reinforcer could be produced under a variable-interval schedule. In this way, the time between the last brief stimulus and the unconditioned reinforcer would always vary from reinforcer to reinforcer (see Zimmerman, 1969).

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