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PRIMING AND THE POST-PRIME PAUSE IN MIXED FIXED-RATIO SCHEDULES

by

Larry Allen Alferink

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

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Larry Alferink

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Abstract

Priming and the Post-Prime Pause
in Mixed Fixed-Ratio Schedules

by

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The present study was designed to investigate the effects of a stimulus change inserted in the large component of a mixed fixed-ratio 10 fixed-ratio 100 schedule. In mixed fixed-ratio schedules, a run of responses which approximates the response requirement of the smaller fixed ratio occurs at the beginning of the larger fixed ratio. This run of responses and the pause it precedes is called a prime. In Experiment I, priming acquisition was compared in a mixed schedule in which a change in key-color followed completion of the first 10 responses of the fixed-ratio 100 component and a mixed schedule with no stimulus change. Primes were acquired more rapidly in the mixed schedule with the stimulus change and the number of responses in a priming run was less variable than occurred without the stimulus change. In Experiment II, the effect of the stimulus change on primes was further investigated by removal of the smaller fixed-ratio component or by varying the location of the stimulus change. Primes occurred only when the smaller fixed-ratio component was present. Varying the location of the stimulus change resulted in the transfer of control from the external stimulus to response-produced stimuli. Future investigation of this point of transfer should prove useful in the study of the proprioceptive stimulus control of homogeneous behavior sequences.

In Experiments III through VI, the variables controlling the length of the post-prime and the post-reinforcement pauses were investigated using the mixed FR x chained FR x FR y schedule. In this series of experiments, FR x was varied with FR y held constant at both high and low values. In addition, FR y was varied with FR x held constant at both high and low values. The results indicate that the post-prime pause is primarily a function of FR y, the number of responses required after the priming run. On the other hand, both post-reinforcement pauses were shown to be a function of FR x, the size of the small fixed ratio. An interaction between FR x and FR y and both the post-reinforcement and the post-prime pauses suggested that pausing in mixed schedules is a closed system. Taken as a whole, these results indicate the importance of mixed chained schedules in the investigation of the priming phenomenon.

(163 pages)

Introduction

Ferster and Skinner (1957) were the first to note that priming runs occurred in mixed (*mix*) schedules consisting of one large fixed-ratio (e.g. FR 190) component and one small fixed-ratio (e.g. FR 30) component. These priming runs occurred at the beginning of the large FR and consisted of a run of responses approximately the same length as the small ratio, followed by a pause. Since then, little additional work has occurred with primes although several other investigators (Bullock, 1960; Dews, 1958; Weissman, 1960) have noted their occurrence in mixed schedules and recently, several studies have presented quantitative evidence of changes in the frequency of primes as a function of the frequency of the small component (Alferink and Crossman, in press; Crossman and Silverman, 1973).

One possible reason for this scarcity of work on primes is the inability to control a prime precisely. The priming run corresponds only roughly to the size of the smaller ratio (Ferster and Skinner, 1957). Thus, attempts to study priming have been restricted to definitions which allow an investigator to determine the frequency of priming by examining cumulative records. For example, Crossman and Silverman (1973) and Alferink and Crossman (in press) studied priming in mixed FR 100 FR 10 schedules with a prime defined as a run of from 10 to 20 responses at the beginning of a ratio in the former study and from nine to 19 in the latter. In addition, both studies required this run of responses to be followed by a pause of at least 9 sec. However, these definitions imply considerable variability. In spite of this, behavior thought to be priming was often even more variable (Alferink and Crossman, in press).

Several studies have attempted to make definition of the priming run more explicit by using a response on a separate operandum (Mechner, 1958a, 1958b). Using a fixed consecutive number (FCN) or "counting" schedule, Mechner (1958a) required a minimum number of consecutive responses on lever A to be followed by a response on lever B prior to water delivery. Thus, a response on lever B defined run termination. Run termination has also been defined by an observing response which changed the schedule from a mixed to a multiple FR FR schedule (Hendry, 1969). However, neither the counting nor the observing response procedures eliminated the problem of variable run length.

The priming run has been described as responding which produces a stimulus condition that signals non-reinforcement and, hence, the animal pauses (Alferink and Crossman, in press). Whether this stimulus condition is based on the number of responses in the priming run or the time required to complete these responses is not important for the present analysis. However, it is important to note that these response-produced stimuli lie under the control of the animal. Earlier studies have suggested that giving the experimenter control of stimuli which were formerly under the animal's control produces more efficient responding. For example, Ferster and Skinner (1957) reduced the number of nonreinforced responses in a fixed-interval (FI) schedule by providing the animal with a clock which signalled the end of the interval.

In the present study, a change in the stimulus conditions sometimes occurred in the larger component following the completion of the response requirement of the smaller component. This stimulus change should signal nonreinforcement as much as the response-produced stimuli normally do. Thus, the pause which defines run termination should immediately follow this stimulus change.

While the variables controlling the length of the post-reinforcement pause have been extensively studied (Crossman, Heaps, Nunes and Alferink, 1974; Felton and Lyon, 1966; Ferster and Skinner, 1957; Killeen, 1969; Neuringer and Schneider, 1968; Powell, 1968), the variables controlling the length of the pause following the priming run (hereafter referred to as the post-prime pause) have not. Previously, the response preceding the pause was difficult to determine because of variability in the length of the priming run. If run length can be precisely controlled, the prime can be defined as a run of responses at the beginning of the large component equal to the response requirement of the small component. The interresponse time (IRT) between the last response in the priming run and the next response can then be determined. This IRT is the post-prime pause (PPP). In the present study, the length of the post-prime pause was measured and several variables which might be related to its length were examined.

Survey of the Relevant Literature

The Post-Reinforcement Pause

Simple fixed-ratio size. A number of studies have investigated the size of the fixed-ratio (FR) requirement on pause length. In one of the earliest studies, Skinner (1938) measured pause lengths from cumulative records obtained with rats on different fixed-ratio schedules. He found that pause length increased with increases in the fixed-ratio requirement. Ferster and Skinner (1957) and Barofsky and Hurwitz (1968) also observed increases in pause length with increases in the response requirement.

Similar effects have been found in studies with fixed-ratio escape. Kaplan (1956), using rats, investigated the effects of FR size on escape from a bright light. When the response requirement was varied from 1 to 31, the latencies increased. Winograd (1965) also found that latency tended to increase with increases in the response requirement for shock escape.

Most of these investigators have relied on examination of cumulative records. Other studies have reported more systematic measurements of pause length. For example, Thompson (1964) trained rats to respond on an FR 25. He then increased the response requirement in steps of 25 until ratio strain occurred. He found progressive lengthening of the post-reinforcement pause with increases in ratio size. As FR size increased, the frequency of pauses longer than 50 sec increased.

Felton and Lyon (1966) varied the response requirement from FR 25 to FR 150. In addition, several points were recovered. As the fixed-ratio requirement increased, so did the mean post-reinforcement pause-length. Powell (1968) used small sequential increases in the response requirement of an FR to investigate changes in pause length. He found that the post-reinforcement pause distributions became more variable and that the frequency of longer pauses tended to increase as the ratio requirement was raised. Likewise, Powell (1970) showed that the mean post-reinforcement pause consistently increased with increases in ratio size.

When the response requirement is raised in simple FR schedules, several things are directly effected. The number of responses between reinforcements increases and since responding takes time, the time between reinforcements (the interreinforcement interval or IRI) also increases. The length of the post-reinforcement pause could be a function of either the IRI, the number of responses, or both.

Killeen (1969) examined some of these variables. Four pigeons were trained to respond on various fixed-ratio schedules. Four additional pigeons were subsequently yoked to these FR birds such that the yoked birds were reinforced following the first response after the FR bird had completed its response requirement. Thus, the yoked birds were on an interval schedule which approximated an FI, since reinforcement depended on the time taken by the FR bird to complete the FR. Pauses tended to be longer at larger fixed ratios for both the FR and the yoked birds. Killeen suggested this was evidence for the control of pause length by the interreinforcement interval.

Earlier, Neuringer and Schneider (1968) also suggested that pause-length is controlled by the interreinforcement interval. They held the interreinforcement interval constant on an FI 30 sec schedule while indirectly varying the number of responses the animal could emit in the interval. In a fixed-ratio 15 schedule, they held the number of responses constant and manipulated the interreinforcement interval. In both cases, this was accomplished by imposing a short blackout after each response and varying the length of the blackout. As the length of the blackout increased, the number of interreinforcement responses which could occur in the FI decreased from approximately 20 to five responses while the interreinforcement interval in the FR increased. Using this technique, they found that pause length did not vary as a function of number of responses in a fixed interval, but pause length increased in the fixed ratio as the interreinforcement interval increased. Based on this evidence, they concluded that the post-reinforcement pause was a function of the interreinforcement interval but not the number of interreinforcement responses.

However, Crossman, Heaps, Nunes and Alferink (1974) presented data which suggested that the post-reinforcement pause was a function of the number of interreinforcement responses. In this study, two fixed-ratio components were alternated in a multiple schedule. One component was a simple FR while the other component, the FR 2 + TO, required two responses which were separated by a timeout. In one experiment, the length of the timeout was equated with the length of time between the first and last responses in the simple FR component. In a second experiment, the interreinforcement interval of the FR 2 + TO component was yoked to the interreinforcement interval of the preceding FR. In both experiments, the post-reinforcement pause increased more in the simple FR than in the FR 2 + TO component as the simple FR requirement was increased. Thus, these authors concluded that the post-reinforcement pause was a function of both the number of interreinforcement responses and the interreinforcement interval.

Multiple fixed-ratio schedules. Post-reinforcement pause-length has also been investigated in multiple fixed-ratio schedules. In multiple schedules, each schedule is associated with a different exteroceptive stimulus. Ferster and Skinner (1957) studied a *mult* FR 60 FR 200 in which the components alternated every session. Post-reinforcement pauses were short in the FR 60 component and long in the FR 200 component. Similar results were obtained when more than two components were used. A *mult* FI 2 min FI 11 min FR 50 FR 250 schedule produced characteristic FI behavior with pauses which varied with the length of the interval and FR behavior with longer pauses before the larger ratio (Ferster and Skinner, 1957). Likewise, Mintz, Mourer and Gofseyeff (1967) used a *mult* FR 50 FR 50 FR 20 FR 20 schedule. Pauses preceding FR 20s were short while pauses before FR 50s were long.

Since multiple schedules produce responding which resembled that of the components programmed in isolation, they have considerable promise as a means of comparing schedules within the same session. Schuster (1959) examined the effects of ratio size in a mult FR FR schedule. As the ratio requirement of one component increased from FR 10 to FR 80, the pause in front of this component increased while the pause before the constant FR 20 component decreased. This increase in the pause for one component with an accompanying decrease in the pause for the other component was one of the earliest examples of behavioral contrast. Crossman (1971) also manipulated the size of the ratio in one component while holding the other constant. Using a mult FR L FR 10 in which the components simply alternated, Crossman found that as the FR L increased from FR 15 to FR 55, the pause before that component increased while the pause before the FR 10 component decreased. This confirmed the contrast obtained in Schuster's (1959) study.

A second implication of Schuster's (1959) experiment is terminological in nature. The term "post-reinforcement pause" may imply that the pause is controlled by the ratio it follows (Griffiths and Thompson, 1973). Schuster's (1959) study suggests that the pause is controlled by the upcoming ratio and should be called a pre-ratio pause. The concept of a pre-ratio pause was supported in a series of experiments by Findley (1962). In one of these experiments, in the presence of a green light, the subject was reinforced for responding on each of three different ratios. These ratios progressively increased from FR 33 to FR 132 to FR 528. In the presence of a red light, these same ratios occurred in decreasing order. Mean pause length increased in the green sequence and decreased in the red sequence. Thus, pause length was a function of the size of the next ratio. A second experiment by Findley (1962) showed similar results. In the presence of a red light, the animal completed a sequence of ratios consisting of FR 33, FR 132 and FR 528. In the presence of a green light, the subject completed three FR 132s. Pauses following the FR 132 in the green light were uniform in length but were longer following the 132 (preceding the FR 528) in the presence of the red light. Again, this showed pause length was a function of the next rather than the last ratio. Crossman (1968), Davison and Over (1966) and Griffiths and Thompson (1973) have also shown that pauses are long preceding large ratios and short preceding small ratios.

Mixed fixed-ratio schedules with short repetitive sequences. In mixed FR schedules, a change in the schedule is not accompanied by a change in the stimulus conditions. In the simplest type of mixed schedule, the components simply alternate. Under these conditions, the pattern of responding is similar to that obtained in a multiple schedule. Crossman (1971) found similar effects in mixed and multiple schedules with fixed-ratio components when the size of one component was varied. However, larger changes in the FR requirement in the mixed schedule were necessary to produce changes in behavior similar to those obtained in the multiple schedule. Patrikou and Keehn (1964) found longer pauses preceding the FR 45 component than before the FR 15 component of a mixed schedule.

Apparently, in mixed schedules in which the components simply alternate, the subject relies on cues arising from the ratio just completed to govern its behavior. It has been shown that animals can respond on the basis of stimuli which are no longer present. Ferster and Skinner (1957) demonstrated this finding in a mult FR 50 primed FI 10 min schedule. No differential stimuli were associated with either schedule except during the beginning of the FI. During this period, a stimulus paired with the FI was briefly presented but the subject continued to produce an FI pattern after the differential stimulus was removed. Mabry (1965) also presented differential stimuli briefly at the beginning of FRs and FIs. He found that appropriate performance was maintained when these differential stimuli were no longer present. Likewise, Kendall (1969) presented a stimulus paired with either an FR 10 or an FR 100 for 30 sec. After 30 sec, this cue was turned off and the response key was illuminated with the same stimulus for both FRs. Pauses were short before the FR 10 and long before the FR 100. These studies suggest that trace stimuli arising from the ratio just completed may result in performances on alternating mixed schedules which are similar to multiple schedules.

An even more striking example of this occurred in a four component mix FR 15 FR 45 FR 15 FR 135 schedule (Keehn, 1965). Pauses were longer before the FR 135 than before the FR 45 even though both of these schedules followed an FR 15. Since no differential cues were provided by the experimenter, the subjects apparently were discriminating an FR 15 following an FR 135 from one following an FR 45. If this were the case, it would indicate that rats can rely on cues arising from the previous two components to govern their current behavior.

Rilling (1968) investigated the effects of timeouts on discrimination between an FR 25 and an FR 50 using this procedure. When the timeout followed the first response on both the FR 25 and the FR 50, the discrimination was not affected. When the timeout followed the first response on the FR 25 and the 26th response on the FR 50, the discrimination fell to chance levels as the duration of the timeout was increased. The effect of the timeout was to increase the errors on the FR 50 while little effect was observed on the FR 25. Thus, independent of the schedule, the subjects tended to peck the left key. Rilling interpreted these findings as showing that the timeout disrupted the chaining of response-produced stimuli within the larger ratio.

Pliskoff and Goldiamond (1966) investigated FR discrimination using a two-key procedure. One of the two fixed ratios was programmed on a red key. This red key alternated position in an unsystematic fashion. When the ratio was completed, both keys were illuminated with a white light. If the ratio was large, a response on the left key was reinforced. If the small ratio had been in effect, reinforcement followed a response on the right key. Errors were followed by a 15 sec intertrial interval. The following FR pairs were used: 95-5, 75-25, 65-35, 60-40, 58-42, and 50-50. Thus, the mean response requirement was held constant at 50 responses. Accuracy above 90% was maintained with the 65-35 pair. When the difference was decreased still further, accuracy rapidly diminished. With probe conditions in which the size of either the large or small FR was varied, accuracy on the large FR decreased as the large FR size decreased from 95 to 10. Accuracy on the small FR decreased as the size of the small FR was increased from 5 to 40. When a delay was imposed between the completion of the ratio and the occurrence of the choice response, accuracy decreased with increases in the delay.

Primes

Primes and the post-reinforcement pause.

If random alternation is used to program the components in mixed FR schedules, primes or priming runs generally result. A priming run is a run of responses at the beginning of the large FR approximately equal to that of the schedule with the shortest inter-reinforcement interval. This priming run is followed by a pause. As Ferster and Skinner (1957, p. 580) noted, "The emission of approximately the number of responses in the smaller ratio 'primes' a pause appropriate to the larger ratio."

Ferster and Skinner (1957) investigated mixed schedules using primarily random alternation. A comparison of *mix* FR 50 FR 300 and *mult* FR 50 FR 300 schedules with random alternation revealed that the multiple performance was more difficult to maintain. According to Ferster and Skinner (1957), a *mix* FR FR schedule has the effect of averaging the two ratios to produce a mean ratio. The multiple schedule does not have this effect. This mean ratio controls pause length in a mixed schedule containing primes. Thus, a stimulus associated with a large ratio in a multiple schedule may produce an extremely long post-reinforcement pause while such long post-reinforcement pauses do not occur in a comparable mixed schedule.

Frequently, primes in mixed FR FR schedules are preceded by short pauses typical of the smaller ratio (Ferster and Skinner, 1957). In a mix FR 190 FR 30, both ratios were preceded by short pausing. The large ratio contained frequent priming runs in which the subjects emitted about 30 responses followed by a pause appropriate to the longer ratio. In a mix FI 10 min FR 125, both the FR and the FI component began with a pause and a high rate of responding appropriate to the FR. The ratio pattern (priming) in the FI component was followed by a gradual scallop after about 125 responses.

Dews (1958) examined a mix FR 50 FI 15 min schedule in which the schedules occurred according to a pseudorandom sequence. Fixed-interval components began with a short pause and a high rate typical of the FR 50. After the completion of about 50 responses, this pattern was followed by a gradual scallop typical of the FI.

Priming also occurred when one component of the mixed schedule was extinction. In a mix FR 50 EXT 20 min schedule in which components were separated by a 10 sec timeout, a priming run occurred at the beginning of each extinction component (Ferster and Skinner, 1957). Likewise, Weissman (1960) noted priming runs in a mix FR 24 EXT 10 min schedule. The sequence used in this study consisted of nine FR 24s followed by a single extinction period. The beginning of the extinction component was characterized by a priming run followed by a long pause. Occasionally, the subjects emitted runs of less than 24 responses followed by a pause in the FR component. Primes were also obtained when 20 FR 10s were followed by extinction for 60 min in a mixed schedule (Bullock, 1960).

Priming can be brought under stimulus control. Ferster and Skinner (1957) found that a multiple schedule in which one component was a simple FR 160 and the other a mix FR 20 FR 160 produced appropriate component performances. The FR 160 component was preceded by long pauses and no priming while the mix FR 20 FR 160 component produced short post-reinforcement pauses and frequent primes.

In the first study which quantified changes in priming frequency, Crossman and Silverman (1973) investigated a mixed schedule in which a fixed sequence of FR 100s were followed by a single FR 10. They varied the proportion of FR 100s to FR 10s from 99:1 and 1:1. As FR 10s became relatively more frequent up to 4:1, the post-FR 100 pause shortened and the frequency of primes at the beginning of the FR 100 increased. When the proportion of FR 100s to FR 10s were reduced to about 4:1, priming became relatively infrequent in the first FR 100 after an FR 10 and the overall frequency of priming decreased. Alferink and Crossman (in press) studied a mix FR 10 FR 100 schedule in which the FR 10 occurrence was based on the superimposed FI contingency. In this study, an FR 10 occurred following the first FR 100 completed after the fixed interval elapsed. The first FR 100 after an FR 10 contained few primes and was preceded by a long pause while the other FR 100s contained frequent primes and were preceded by a short pause which was approximately equal to the pause preceding FR 10s.

The relation between primes and observing responses. Several lines of evidence suggest that primes and observing responses serve a similar function. In observing response procedures, a mixed schedule can be changed to a multiple schedule by responses on a separate "observing" operandum (Wyckoff, 1952). Observing responses produce discriminative stimuli which govern behavior in their presence. Likewise, according to Ferster and Skinner (1957) the bird's own behavior functions as a stimulus in a prime. Like the exteroceptive stimuli produced by an observing response, the response-produced stimuli resulting from the priming run also provide information about the schedule in effect. Therefore, primes and observing responses might be expected to occur under similar conditions.

Auge (1973) trained pigeons to produce stimuli paired with each component of a mix FR 50 FI 2 min schedule using an observing response procedure. The observing responses changed the color of the food key to red if the FR was in effect and to green if the FI was in effect. When these differential stimuli were no longer presented following observing responses, observing responses extinguished. In addition, one bird ran off more than 50 responses at the beginning of each FI component, and then paused. These data suggest that when observing responses are no longer effective, they may be replaced by primes.

Hendry (1969) provided pigeons with the opportunity to make an observing response on an observing key. This observing response had the effect of changing the schedule on the food key from a mix FR 20 FR 100 schedule to a mult FR 20 FR 100 schedule. Following observing responses in the multiple schedule, Hendry found a short pause prior to the FR 20 and a longer pause before the FR 100. If no observing response occurred, the pause was short before both ratios in the mixed schedule. Observing responses were most likely following reinforcement, but were also probable after 16 to 40 responses in the FR 100 had occurred. Since this is approximately the length of the short ratio, observing responses were apparently replacing or supplementing priming runs. Thus, the observing response had essentially the same function as a prime.

According to Hendry (1969), observing responses are maintained by the information they provide. The observing response can provide information in the large FR only after the response requirement of the small FR has been completed. In Hendry's (1969) study, completion of about 20 responses on the food key already provided information as to which schedule is in effect. Any information provided by an observing response was redundant and should not maintain observing behavior (Egger and Miller, 1963).

Based on their data, Crossman and Silverman (1973) questioned the information hypothesis of priming. To counter this hypothesis, they noted the formal similarity between a priming run and an FR 10 and claimed that the prime is essentially a large unit of behavior which is intermittently reinforced by food delivery on the FR 10 schedule. Thus, as the presentation of FR 10s increased, the number of primes increased. Alferink and Crossman (in press) provided additional evidence for the formal similarity between a prime and an FR 10. They noted that those FR 100s which contained primes also, like an FR 10, were preceded by a short pause.

Counting Schedules

Run lengths on counting schedules. An attempt to simplify the definition of a priming run was first begun by Mechner (1958a). On a fixed consecutive number (FCN) or "counting" schedule (Mechner, 1958a), a fixed minimum number of consecutive responses were required on operandum A followed by a response on operandum B. Reinforcement followed a response on operandum B only if the fixed consecutive number of responses on operandum A had occurred. A response on lever B always reset the "count" on lever A. Thus, the response on operandum B defined termination of the run. The number of consecutive responses on operandum A defined run length.

While Mechner (1958a) clearly couched his investigation of the counting schedule in terms of the primes which are produced on mixed FR FR schedules, other historical precedents are evident. Clearly, the double alternation temporal maze (Hunter, 1920) attempted to examine if rats could discriminate or "count" their own behavior. In this maze, the animals were required to make two right turns followed by two left turns. The maze was constructed such that alleys following right turns and left turns led to the same choice point. Thus, the exteroceptive stimuli accompanying right and left turns were the same. Attempts at producing reliable double alternation in this maze using the white rat have consistently failed (Hunter, 1930; Hunter and Hall, 1941; Hunter and Nagge, 1931; Karn and Patton, 1941). However, Schlosberg and Katz (1943) successfully trained rats to push a lever twice in one direction and twice in the other direction. This is analogous to a modified Mechner procedure in which more than one lever B response is required.

Mechner (1958a) first examined the effect of the number of consecutive responses required in the FCN schedule on run length. Six rats were trained to lever-press on a mix FCN FR schedule in which the probability of an FCN component was 0.50. The response requirements of the FCN and the FR schedules were varied simultaneously from four to 16. The distribution of run lengths were generally bell shaped. In addition, the number of responses in a run tended to exceed the response requirement by two to three responses independent of the requirement.

A second experiment examined the effect of component probability on run length (Mechner, 1958a). Again, a mix FCN FR schedule was used. The response requirement for both components was fixed at eight responses but the probability of the FR component was varied from 0.00 to 0.75. Run length in the FCN component increased as the probability of the FR component increased.

Mechner (1958b) also investigated the sequential effects on run length of the length of the preceding run. Run length was measured in extinction following FCN training. Run lengths tended to be longer following a long run than a short run. In addition, the variability of the length of a run increased in extinction over the variability obtained in training periods.

Although run length was sensitive to the response requirement and to the probability of the component being an FCN schedule, run length was not sensitive to deprivation. Mechner and Guevrekian (1962) varied the hours of water deprivation in an FCN procedure. While run length did not systematically vary with deprivation, the post-reinforcement pause tended to decrease with increases in deprivation.

Millenson (1962) studied counting behavior in mice. Using an FCN schedule with a response requirement of four, he found that mice produced run length distributions comparable to those previously found with rats (Mechner, 1958a). Comparable run length distributions were maintained for two of three subjects even when correct run lengths were reinforced according to a fixed-interval 1 min schedule in which only the first correct run after 1 min produced water. For the third subject, runs of 2, 3, 4, 5, 6 and 7 responses occurred with approximately the same frequency.

Ferster (1958) trained a chimpanzee to press the left response key three times before a right-key-response was reinforced. If runs consisted of either more or less than three left-key-responses, they were followed by time-outs. Counting behavior was maintained even when correct responses were reinforced according to an FR 34. While the behavior was maintained, runs of both more and less than three responses were frequent.

Schafer (1963) developed a technique in which a rhesus monkey was trained to respond on an FCN schedule in which the number of required responses depended on the visual number symbol displayed. The numbers from one to five were geometrically represented. Overruns as well as underruns resulted in timeouts. Reinforcement occurred after a fixed ratio of correct responses. Accuracy increased with both the length of the timeout and the FR requirement.

More errors occurred as the number value increased and runs which were too short were more common than runs which were too long. Using a similar procedure, Levison and Findley (1967) found that baboons could respond correctly more than 90% of the time.

Adams and Walker (1972) trained rats to respond on a multiple schedule in which one component was a counting schedule in which runs of three or four responses were reinforced. In the other component, runs produced food only if the run length exceeded 10 responses. Runs in the large component approximated 10 responses and approximated three to four responses in the small component. In probe conditions in which the stimuli associated with each component were removed, the differences in performance tended to diminish. When the stimuli were reversed, the run length distributions were the same independent of the component. Thus rats, like monkeys, also can behave according to stimuli which signal which of two counting schedules are in effect.

Blackman and Scruton (1973) studied the effects of a conditioned suppression procedure on counting behavior in rats. With FCN 20 or FCN 27 schedules, 2 min periods of white noise were presented every 10 min. Unavoidable shock followed this period. Modal run lengths equaled or exceeded the response requirement in the absence of the pre-shock stimulus. During the pre-shock stimulus, modal run lengths were shorter than the response requirement. The counting responses on lever A were suppressed proportionately more than lever B responses.

Hurwitz (1962) compared performance on a fixed-ratio schedule with that on a counting schedule. The FR schedule was modified such that entry into a food tray following completion of the FR requirement produced food. For both schedules, entrance into the food tray defined run termination. The FR schedule only reset upon the completion of the response requirement followed by a tray entry, while the counting schedule reset whenever a tray entry occurred. Hurwitz found that animals trained on the counting schedule emitted more responses per run than did the subjects on the FR schedule.

Hurwitz (1963) investigated the effects of several types of cues on this modified FR 4 schedule. When a buzzer sounded on every lever-press, the rat alternated between the lever and the tray, although extended training produced some runs of two, three, or four lever-presses. When the buzzer sounded on every fourth lever-press, generally only one tray-entry occurred per reinforcement. No data were provided for run length and this procedure was not used with an FCN schedule.

Platt and Johnson (1971) compared the FCN and FR schedules used by Hurwitz (1962) and attempted to separate the factors responsible for the differences in run length. Following the convention adopted by Platt and Johnson, Hurwitz's modified FR schedule will hereafter be referred to as a fixed-number (FN) schedule since food followed tray entries rather than simply the completion of a fixed ratio. The FN procedure also differed from an FR schedule in that the response-to-reinforcement ratio for an FN schedule was not necessarily constant.

Using a trial procedure with an intertrial interval of 10 sec, Platt and Johnson (1971) presented error-contingent timeouts of 10 sec duration for some FN and FCN groups but not for others. Errors were defined as non-reinforced tray entries. Run lengths tended to increase in direct proportion to the response requirement for the FCN groups. The main effect of the timeout was to produce slightly longer runs following errors. Run lengths after food for the FN groups increased in direct proportion to the response requirement only if an error-contingent timeout occurred. In both FN groups, runs after errors were shorter than runs after food and no systematic changes occurred as a function of increases in the response requirement.

Brandon (1969) also examined the effects of error-contingent timeouts on a modified FCN procedure in which only runs of seven to nine responses were reinforced. Runs of other lengths were followed by timeouts. It was found that timeouts increased the proportion of reinforced runs. Brandon discounted a punishment interpretation of the timeout effect. Although timeouts decreased errors, runs following timeouts tended to be of the same length as the run which produced the timeout.

Platt and Johnson (1971), taking Brandon's (1969) results into account, discussed the effects of the timeout in terms of directional feedback. In a standard FCN procedure, timeouts provide feedback that the current run was not long enough, and as Platt and Johnson's results showed, the run following the timeout in the FCN schedule tended to be longer than runs following food.

In Brandon's (1969) study, no directional feedback was given since identical timeouts followed runs which were too short and runs which were too long.

Chaining vs response unit accounts of counting. Platt and Johnson (1971) also suggested two possible interpretations for the development of particular run lengths in the FN and FCN procedures. First, runs of n responses in length could develop as a unitary response on the FCN procedure. However, a unitary response account becomes considerably more complex when applied to the FN procedure. They suggested that two units would be required, a long response unit following food and a short unit following errors.

The alternative interpretation, the chaining hypothesis, assumes that stimuli associated with fewer than n responses were discriminative for lever-pressing while stimuli associated with n or more responses were discriminate for tray entry. According to Platt and Johnson (1971), differences between performances on the FCN and FN schedules would be due to differences in the reference, or zero, points for the response dimension. On an FCN schedule, the zero point would be the occurrence of the last tray response and/or food delivery. On the FN schedule, the zero point would be the occurrence of food. Thus, subjects should match run lengths to the response requirement of the FCN schedule and match total lever-presses since the last food delivery to the response requirement in the FN procedure.

Platt and Johnson (1971) gloss over what the unitary responses in the FN schedule might be. They suggested that the existence of two response units is quite complex. However, runs are reinforced independent of run length provided that the sum of the number of responses in the runs since food equals or exceeds the response requirement. Except immediately following food delivery, short runs have a high probability of being reinforced. Thus, one might well expect two (or more) units to develop since runs of different lengths result in reinforcement.

On the other hand, the chaining hypothesis suggests an even more complex task for the subject. Since the zero point on the FN schedule is the last food delivery, the subject should vary the length of a run as a function of the total number of responses in the previously non-reinforced run. Thus, if a subject has only made two responses since food delivery, the subsequent run should be eight responses in length given a response requirement of 10 responses. If the previous total run length was eight responses, the subsequent run should be two responses in length. The subject is expected to keep track of this "count" in spite of the tray entries which intervene. These tray responses might be expected to disrupt the count much as timeouts do in FR discrimination procedures (Pliskoff and Goldiamond, 1966; Rilling, 1968).

A sequential analysis is required to show that the predictions of the chaining hypothesis are verified. Such an analysis was not presented. However, the medians for runs following reinforced and non-reinforced tray entries suggest that the chaining hypothesis is not correct. The FN group timeouts tended to progressively undershoot the response requirement of the FN schedule. Thus, runs after non-reinforced tray entries should tend to increase in length with the response requirement if the animal is to match total output since reinforcement with the response requirement. Instead, runs after nonreinforced tray entries remained relatively constant in length, suggesting a second response unit.

Given that the chaining account is correct, more than a change in the zero points is required to account for differences in the FCN and FN performance. Both FCN groups generally had larger run lengths than either FN group at identical response requirements. Such a difference must be related to the difference in the reset contingencies. Given that the subjects will make errors on both the FN and FCN procedures, different patterns of responding emerge as the most efficient in terms of response output per reinforcement. The FCN subjects might be expected to emit slightly more responses per run than the response requirement, given an approximately normal distribution of run lengths. Estimates of mean number of responses per reinforcement taken from Platt and Johnson's (1971) data showed that, given the same distributions, a shift of the modal run length either right or left by one response resulted in less efficient responding. Similar results would be obtained for the FN schedule. This preliminary analysis suggests that it might be possible to build a model based on this efficiency ratio to predict the mean number of responses per reinforcement.

An analysis of counting schedules in terms of efficiency ratios would not hold for all procedures. For example, Millenson (1966) studied "counting" schedules in which R_1 responses set the occasion for an R_2 to be reinforced according to a constant probability of 0.02, 0.04 or 0.05. This procedure minimizes the effect of the reset contingency. In addition, runs of 25 or more responses were sometimes reinforced with a probability of 1.0. Run lengths tended to approximate five responses independent of whether or not runs of 25 or more responses were reinforced with a probability of 1.0. Optimization of output per reinforcement would predict a shift toward longer run lengths. However, intermittent reinforcement of short runs may well overcome the effect of an efficiency ratio. Short runs, like short IRT's (Anger, 1956), may be more susceptible to reinforcement.

A comparison of counting and priming. This analysis suggests several limitations of extrapolation from FCN and counting schedules to priming. Reinforcement is contingent on run termination in both the FN and FCN procedures. Reinforcement is delivered independent of run termination (i.e., a pause) in mixed schedules. In addition, reinforcement is delayed after most primes but immediately follows termination of runs of appropriate lengths in FCN procedures.

Both FN and FCN procedures provide penalties in terms of wasted responses. In the FN procedure, responses prior to run termination that exceed the minimum response requirement are wasted and have no specified consequences. In the FCN procedure, the penalty is even more stringent due to the reset contingency. Not only are responses in addition to the minimum response requirement wasted but runs terminated before the minimum response requirement has been completed leave the subject no closer to reinforcement than before run initiation. In a standard mixed schedule, since food is not dependent on priming, no penalty in terms of food loss occurs if a priming run is too long or too short. Given these differences, it is not surprising that run length is generally shorter in FN and FCN procedures than in primes.

The Effects of Added Stimuli

The data on priming and counting indicate that run lengths are quite variable. Hurwitz (1963) found that the variability of run lengths could be reduced if a stimulus were added signalling the completion of the response requirement on an FN schedule. Added stimuli in the form of clocks and counters also control responding on FI and FR schedules.

Added clocks.

Responding on a fixed-interval (FI) schedule has been characterized as being an increasing function of time in the interval (Ferster and Skinner, 1957). Ferster and Skinner (1957) have discussed this pattern in terms of a clock based on the subject's behavior. They noted that this behavior was a poor clock and attempted to study the degree of control exercised by this behavior by adding an exteroceptive clock under the control of the experimenter.

The added clock in Ferster and Skinner's experiments consisted of a slit of light projected on a response key. This slit of light was lengthened or shortened as the interval progressed. On fixed intervals of 10 and 30 min, the added clock produced a longer pause than was obtained without the clock. An abrupt transition to a rapid rate of responding occurred near the end of the intervals in both of these FIs.

While the clock used by Ferster and Skinner (1957) changed continuously over time, discrete clocks which change in steps have also been used. For example, Segal (1962) varied the color of the response key over successive quarters of the interval. During the first quarter of the interval, the key was green, during the second quarter the key was orange, the third quarter blue and the final quarter red. The effects of this discrete clock were compared to a constant red key on fixed intervals of 1, 5 and 12 min. Segal consistently found that the discrete clock produced lower percentages of responding in the earlier and higher percentages in the later quarters of the interval than occurred with a constant red key.

Segal (1962) made the brief occurrence of these key colors dependent on pecking the response key. Except for the brief duration in which these colors were present, the key remained dark. The behavior generated by this technique was intermediate between the behavior generated by the response-independent discrete clock and the constant red light. The increase in rate early in the interval was taken as evidence of the reinforcing properties of the change in key color.

Kendall (1972) also presented brief stimulus changes following responses on the food key. On an FI 2 min schedule, differential stimuli associated with each sixth of the interval were presented following responses (clock condition). Comparison of performance on this schedule with the same schedule in which the brief stimulus changes were red-light flashes independent of their location in the interval (constant stimulus condition) showed that the response rates were ower and the post-reinforcement pauses longer with the clock stimuli. These results thus confirm those obtained by Segal (1962) with a response-dependent clock.

Hendry and Dillow (1966) separated the response maintained by the occurrence of the clock stimuli by making production of the clock dependent on pecking a separate response key. One of three stimulus changes, each associated with successive thirds of an FI 6 min schedule, occurred on the clock key for 0.5 sec following a response on the clock key. Responding on the food key was positively accelerated while responding on the clock key was positively accelerated with a decrease in responding on the clock key slightly before reinforcement.

Farmer and Schoenfeld (1966) varied the location of a 6 sec key-color change in an FI 1 min schedule. When the stimulus change occurred in the last 6 sec of the interval, responding occurred at a low rate in the interval preceding the change in key color and a high rate during the 6 sec key-color change. In other locations in the interval, the key-color change tended to decrease responding over what had been obtained in the interval preceding the stimulus change or the comparable location in a schedule without the stimulus change.

Donahoe, Schulte and Moulton (1968) ran rats on an FI 50 sec schedule using a trial procedure with an intertrial interval of 90 sec. For one group, the intensity of a stimulus light increased every 5 sec. For the other group, the intensity remained constant at the maximum illumination. The group with the added clock consistently responded faster throughout the interval than the group with the constant stimulus intensity.

Donahoe (1970) extended these findings by tracing the development of the control by the added clock over sessions. An FI 60 sec schedule was used with an intertrial interval of 60 sec. Generally, the group with the added clock had a lower rate in the initial portion of the interval and a higher rate in the later portions of the interval than the group without the added clock. However, these differences in rate between the two groups tended to diminish with continued training. Caplan, Karpicke and Rilling (1973) confirmed Donahoe's (1970) finding that differences between groups with and without an added clock tended to disappear with extended training.

Ferster and Skinner (1957) also studied the effects of an added clock on the FI 10 min component of a <u>mix</u> FI 10 min FI 2 min schedule. Performance tended to be poorly controlled by the addition of the clock. Sometimes a high rate prevailed during that portion of the clock associated with the first 2 min of the FI 10 min schedule. This was abruptly followed by a period of zero rate and a gradual scallop for the remainder of the interval. At other times, the transition after the first 2 min of the FR 10 min schedule consisted of a lowering of the rate to a value intermediate between a zero rate and the high terminal rate.

<u>Added counters</u>. Like clocks which vary with time, exteroceptive stimuli may also covary with responding. Such stimuli are called added counters (Ferster and Skinner, 1957).

Ferster and Skinner (1957) studied the effects of a small spot of light which lengthened after each response (up to a maximum) on FI schedules. On FI 5 min, FI 10 min and FI 20 min, the added counter tended to produce a pause after reinforcement followed by a rapid acceleration to a high terminal rate. With extended training, the terminal rate tended to decrease slightly, especially on the FI 20 min schedule.

A counter was also added to a mix FI 10 min FI 2 min schedule (Ferster and Skinner, 1957). This counter reached its maximum setting after 300 responses. This counter produced breaks in the FI 10 min schedule after approximately twice the number of responses in the shorter interval had been emitted. A counter which reached its maximum setting after 1200 responses showed a similar effect.

Ferster and Skinner (1957) also studied the effect of an added counter on fixed ratios. On FR 70 and FR 100, the added counter tended to increase the running rate on the ratio. In addition, the pause after reinforcement on the FR 70 tended to disappear.

Ferster and Skinner (1957) studied the effects of a block counter on FR performance. Rather than advancing with each response, the block counter consisted of a change in key color with each fraction of the ratio completed. After reinforcement on an FR 125 schedule, the key was colored yellow which changed to blue after the completion of 35 responses. After 70 responses in the ratio had been completed, the key-color was changed to white and after 105 responses, was changed to green. The block counter produced longer pauses after reinforcement and a higher terminal rate in contrast to the condition in which the key-color changes were uncorrelated with the number of responses when the key remained blue throughout the ratio. Changes in key-color were not followed by pauses.

Chained fixed ratio schedules. Block counters are special cases of chained FR schedules. In a chained FR FR schedule, completion of the first FR requirement in the presence of one stimulus, S_2, produces a second stimulus, S_1, in the presence of which completion of the second FR requirement is followed by food. Ferster and Skinner first investigated a variety of chained schedules such as this.

For example, on a chain FR 15 FR 100 schedule, 15 responses on a red key produced a blue key. One hundred additional responses on this blue key produced food. Ferster and Skinner found long pauses preceding responding in red and short pauses preceding responses in blue.

Likewise, a chain FR 30 FR 30 FR 30 FR 30 schedule tended to produce a short pause after each stimulus change. The pause after a stimulus change was generally shorter than the pause after reinforcement. Ferster and Skinner also noted that the pause after the stimulus change tended to disappear with continued training.

Crossman (1968) investigated the continuum between multiple and chained FR 10 FR 100 schedules by varying the percentage of FR 10s which were followed by food. As the percentage was varied from 0 (chained) to 100 (multiple) %, the pre-FR 100 pause gradually increased and the pre-FR 10 pause decreased. As the percentage was varied from 100 to 0%, the pre-FR 100 pause decreased and the pre-FR 10 pause increased. Thus, the pre-FR 10 pauses were long and the pre-FR 100 pauses were short on the chained schedule while the multiple schedule produced short pauses before the FR 10 and long pauses before the FR 100 schedule.

In a chain FR 5 FR 70 schedule which alternated with an FR 75 schedule, the pause before the FR 5 was generally longer than the pause before the FR 75 (Crossman, 1969). Little pausing was present before the FR 70. However, when food was presented after the FR 5, the pause before the FR 5 became shorter than any other pause and a substantial pause, longer than the pause preceding the FR 75, developed before the FR 70.

Findley (1962) also investigated chained fixed-ratio schedules. In these experiments, three response keys were used. During grain delivery, all three keys were illuminated by white light. Following grain delivery, the left key changed to blue. After the completion of the fixed-ratio requirement on the left key, its color changed from blue to white and the color of the center key changed from white to green. After the completion of the fixed-ratio requirement on the center key, its color changed from green to white and the color of the right key was changed from white to red. After the completion of the fixed-ratio requirement on the red key, grain was delivered.

With Bird 1, the response requirement on the green and red keys were held constant at FR 10 while the response requirement on the blue key was varied from FR 10 to FR 160. For Bird 5, the requirement on the blue and red key was held constant at FR 10 and on the green key, was varied from FR 10 to

FR 160. For Bird 256, the response requirement was held constant at FR 10 on the blue and green keys and varied from FR 10 to FR 160 on the red key. For Bird CRS, the response requirement on all three keys was raised simultaneously from FR 10 to FR 80.

When the response requirement was raised for the first component, the pause before that component increased but performance in the other components was not affected. When the response requirement of the second component was increased, the pause before the second component increased slightly. The pause before the first component increased and some ratio strain occurred. Little effect on the third component occurred. When the response requirement of the third component was increased, the primary effect was to increase the pause before the first component and to a lesser extent, the pause before the second component. Only slight effects on the pause before the third component were evident. As the response requirement was increased in all components, the primary effect was to increase the pause before the first component and to a lesser extent, the second component. Little effect was evident on the third component until ratios of FR 60 or FR 80 were obtained. Thus, the primary effect of raising the response requirement of a component in a chained FR schedule was to increase the pause after reinforcement. This effect was independent of the location of the component in which the response requirement was raised.

Thomas (1964) studied a chained FR x FR x FR x schedule in a multiple schedule in which the other component, a tandem FR x FR x FR x, controlled for the effects of the stimulus changes in the chained schedule. Using FR x values of FR 20, FR 60 and FR 80, Thomas found that rates were lower in the first component, intermediate in the second component and highest in the third component. Long pauses often occurred in the first chained component while brief pauses sometimes occurred in the second component.

Jwaideh (1973) investigated the effect of the response requirement and of the number of components on the post-reinforcement pause in chained FR schedules. When response requirements of 12, 60, 90, 120, 180 and 240 were divided into three equal components, the post-reinforcement pause increased components, the post-reinforcement pause increased with increases in the response requirement. In another portion of this study, the response requirement was held constant and the chain was divided into one, three or five components. As the number of components increased, the post-reinforcement pause increased. Rate changes were inconsistent and no mention was made of between-link pausing.

Sheldon (1971) varied the component requirements in a chained FR FR schedule with the total requirement held constant at 100 responses. Using chained FR 2 FR 98, chained FR 50 FR 50 and chained FR 98 FR 2 schedules, Sheldon found shorter pauses before the initial link when the response requirement in that link was FR 2 rather than FR 50 or FR 98. Measurable pauses before the terminal link occurred only if the response requirement in the initial link was FR 2.

These data indicate that the stimulus change in chained schedules is not necessarily followed by a pause. However, the data with stimuli added to mixed schedules suggest that an added stimulus in the context of mixed FR schedules might control pausing. Unfortunately, mixed chained schedules with FR components have never been investigated.

Statement of the Problem

In mixed fixed-ratio schedules, the priming run provides information about whether the large or the small ratio is in effect. In this sense, the information provided by the priming run is similar to that provided when an observing response changes a mixed schedule to a multiple schedule (Hendry, 1969). In both cases, the animal pauses following information which indicates that the large ratio is in effect.

However, primes have been difficult to study both because of objectively recording the occurrence of a prime and the variability of the length of the priming run. Because of this, little work has been done with primes. Few investigators have done more than simply note the occurrence of primes in mixed schedules.

In an attempt to solve the problem of objectively defining run length, Mechner (1958a) developed the counting procedure. In this procedure, termination of the run was defined by a response on a separate operandum. This procedure was successful in objectifying the study of run lengths but did not eliminate the variability associated with the priming run.

The similarity between priming and observing suggests that both the recording difficulties and the run-length variability can be eliminated by providing a more reliable source of information than primes normally produce by themselves. In mixed schedules, the stimuli which control the initiation of the pause which terminates the priming run are produced by responding. Experiments with added clocks (Ferster and Skinner, 1957) show that behavior can be brought under the control of an external stimulus change. The purpose of the first two experiments in the present study was to investigate the effect on priming of a stimulus change in the large ratio following completion of the response requirement of the small ratio. This stimulus change should control the initiation of the pause and eliminate the variability in the length of the priming run. Moreover, varying the location of this stimulus change in the large ratio would make the control of behavior by response-produced variables more amenable to investigation.

The pause which terminates the priming run is unusual because of its location within a ratio. Normally, pauses in fixed-ratio schedules immediately follow reinforcement. The length of these post-reinforcement pauses has been shown to increase with increases in the upcoming ratio requirement. Based on this relationship, the post-prime pause would also be expected to increase with an increase in the upcoming response requirement. The role of the number of responses in the priming run in controlling the length of the post-prime pause are more difficult to predict because of the lack of data under similar conditions. In addition, the length of the post-reinforcement pause in mixed schedules with random component alternation is not related to the size of the upcoming ratio as is true in all other fixed-ratio schedules. The present series of studies will attempt to determine the variables which control the length of both the post-reinforcement and the post-prime pauses in mixed fixed-ratio schedules. More specifically, the number of responses preceding and following the post-prime pause will be manipulated in Experiments III through VI.

Experiment I

The purpose of Experiment I was to develop a better technique to control priming in *mix* FR FR schedules. This control should decrease the variability of the number of responses in a priming run and should also result in more rapid acquisition of priming as compared to a standard *mix* FR FR schedule. Thus, a comparison was made between priming acquisition in a standard *mix* FR FR schedule and a *mix* FR FR schedule in which a key-color change occurred in the large component following the completion of the response requirement of the small component.

Method

Subjects. Four White King pigeons, maintained at approximately 80% of their free-feeding weight, served. Two subjects (K-9 and K-12) had previous experience with fixed-ratio schedules, while the other two subjects (K-11 and K-53) had been exposed to an automaintainence procedure. The age and sex of the pigeons were undetermined.

Apparatus. Two identical three-key pigeon chambers were used. The inside dimensions of the chambers were 53 x 47 x 59 cm. Reinforcement consisted of 3 sec access to an illuminated hopper containing Purina Pigeon Chow. The center response key, located 10.5 cm above this food hopper was transilluminated by a colored light during each session, except during reinforcement. Pecks on this illuminated key resulted in a click from a feedback relay. The remaining two keys were not used and remained dark. The chamber was illuminated during experimental sessions by two 7.5 w bulbs located near the top of the front panel on which the response keys were mounted. White noise was present in the room at all times to mask extraneous sounds. The experiment was controlled and data were recorded by electro-mechanical equipment housed in an adjacent room. Primes were defined and recorded by an on-line, PDP-8 digital computer (Digital Equipment Corporation).

Procedure. Birds K-9 and K-12 were already trained to respond on fixed ratio schedules and, following exposure to a chained FR FR schedule (see Experiment II), were placed on a mix FR 10 FR 100 schedule. This schedule is diagrammed in Figure 1. As this figure shows, the key remained red during both FR 10 and FR 100. Birds K-11 and K-53 were trained to respond on an FR 100 schedule by gradually increasing the response requirement. Following this training, K-11 and K-53 were placed on a mix FR 10 chain FR 10 FR 90 schedule. This schedule is diagrammed in Figure 2. As this figure shows, sometimes the first 10 responses in a ratio were followed by food delivery and sometimes by a change in the key color from red to green. In the presence of the green key, an additional 90 responses produced food.

The probability of an FR 10 occurring in either mixed schedule was fixed at approximately 0.25 and was determined by either of two pseudo-random sequences which specified that no more than three consecutive FR 10s could occur. These sequences were LSLLLLSLSLLLLLSSLLSLLLLLSLLLLLLL SSSLLLLLLLSLSLL or LLLSLLLLLSSSLLLLSLLLSLSLLLLLSLLLLLLLSLLL

Figure 1. A diagram of the mixed FR 10 FR 100 schedule. The top line is a stylized cumulative response record. Reinforcement is identicated by the pen resetting. The key remains red during both FR 100 and FR 10.

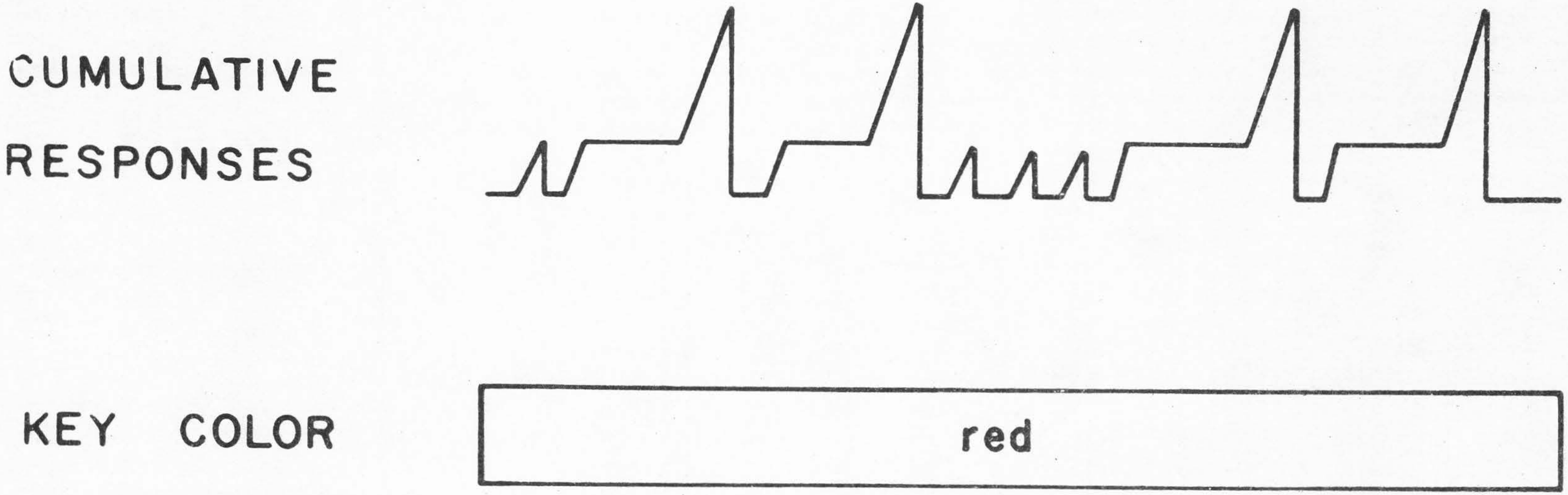
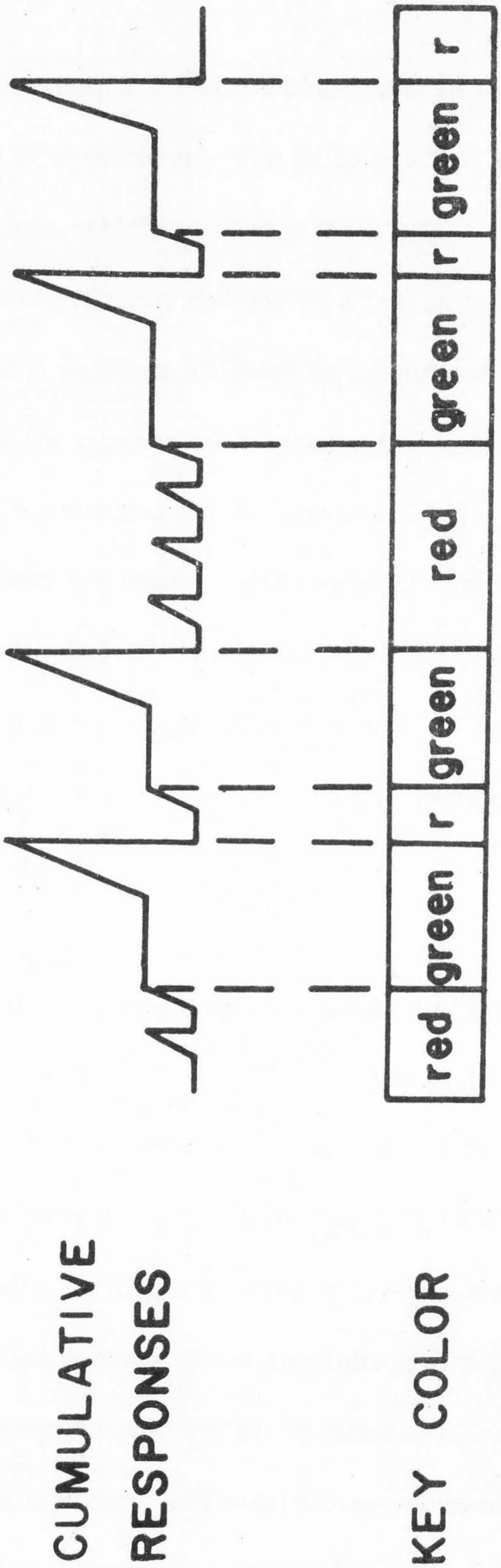

CUMULATIVE
RESPONSES
KEY COLOR
red

Figure 2. A diagram of the mix FR 10 chain FR 10 FR 90 schedule. The top line is a stylized cumulative response record. Reinforcement is indicated by the resetting of the pen. The key color is red during FR 10 but changes to green during FR 90.


CUMULATIVE
RESPONSES
KEY COLOR
red
green
green
r
green
green
red
green
green
r
green
r

SLLSSL where L represents the FR 100 component of the chain FR 10 FR 90 and S represents the FR 10 component. The daily session length was fixed at 60 reinforcements or 2 hrs, whichever occurred first.

A prime was arbitrarily defined as a run of from 8-40 responses at the beginning of the large component followed by a pause of at least 5 sec. A frequency distribution of the number of responses in a priming run, as well as the number of primes, was obtained for each session. The first FR in each session was ignored in determining primes. Each schedule remained in effect for a minimum of 18 sessions and until the behavior stabilized (or a maximum of 40 sessions). The behavior was stable when the mode of the frequency distributions of run lengths was identical for one block of three sessions and the following block of three sessions.

Results

The percent of large components containing primes for each session is shown in Figure 3. On the mixed FR 10 FR 100 (birds K-9 and K-12), primes were infrequent in the first eight to 14 sessions and then gradually increased to approximately 85-95%. On the mix FR 10 chain FR 10 FR 90 schedule (Birds K-11 and K-53), priming rapidly increased to approximately 100% for both birds.

A more detailed account of the acquisition of priming is provided in Figure 4. The frequency distribution of the number of responses in a prime is shown for every fourth session. In the initial sessions on the mix FR 10 FR 100 schedule (K-9 and K-12), the number of responses preceding an IRT of at least 5 sec varied unsystematically and no tendency for a priming run to consist of

Figure 3. Percent of FR 100s (or _chain_ FR 10 FR 90s) containing primes for each session. Birds K-9 and K-12 were on a _mix_ FR 10 FR 100 schedule and Birds K-11 and K-53 were on a _mix_ FR 10 _chain_ FR 10 FR 90 schedule.

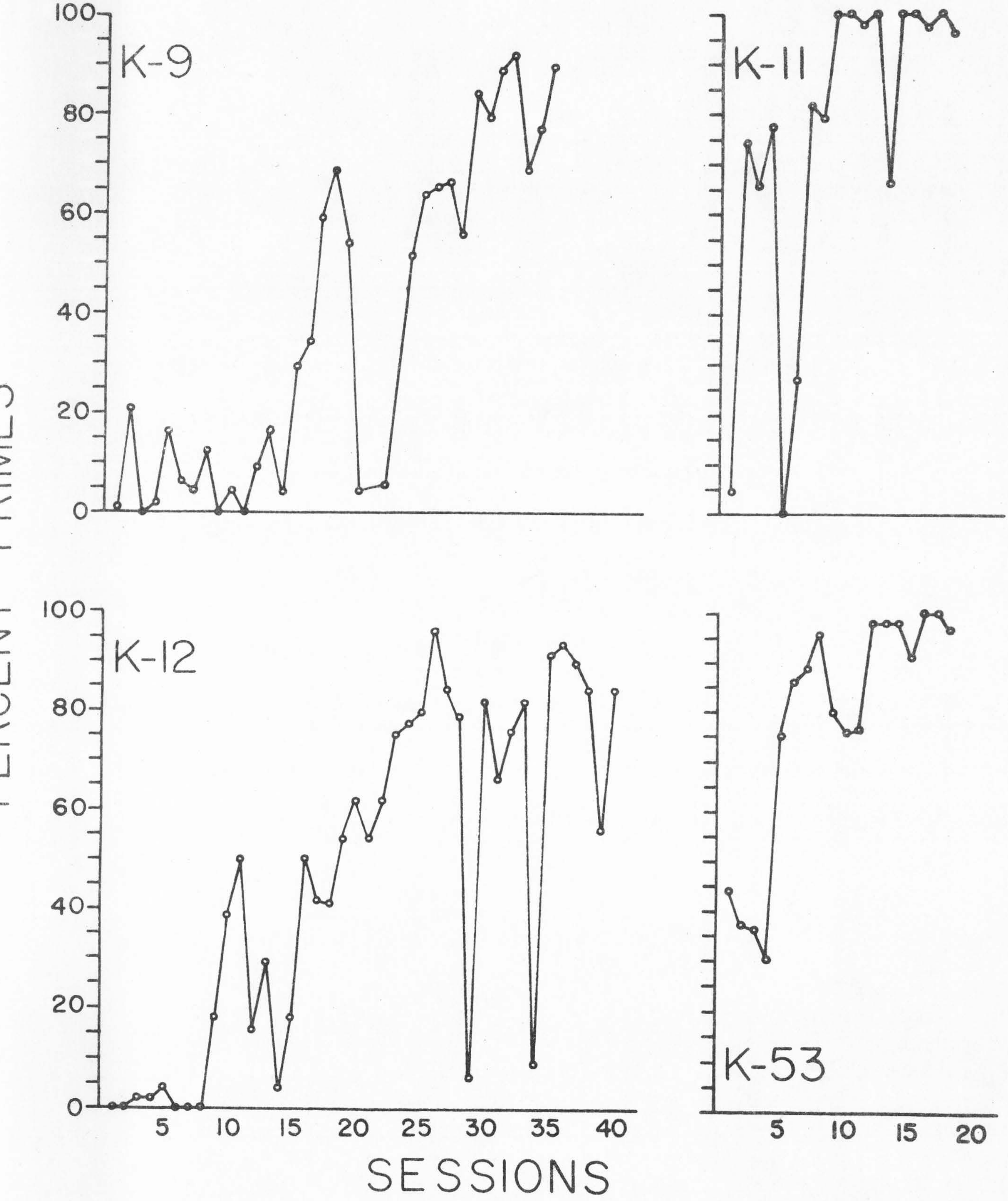
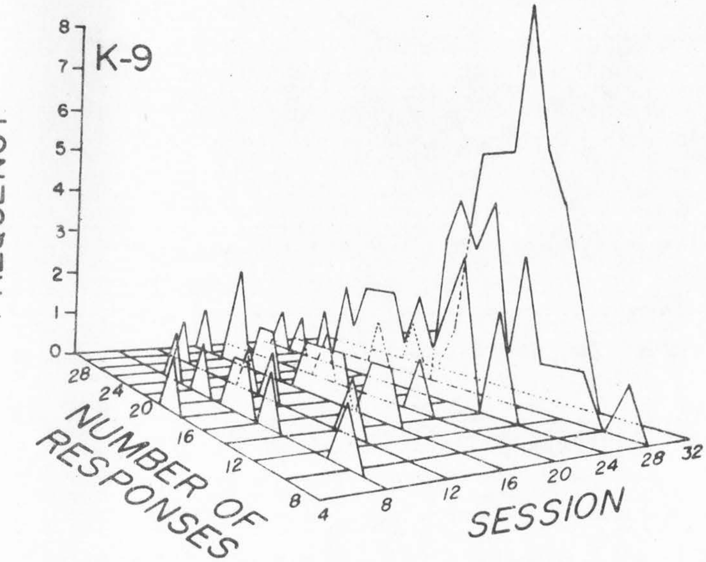
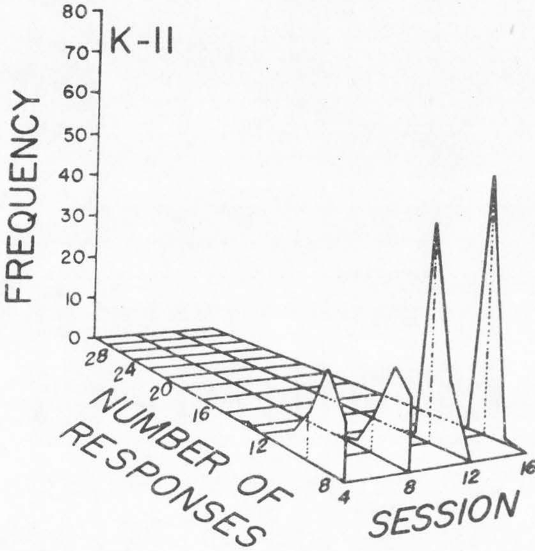
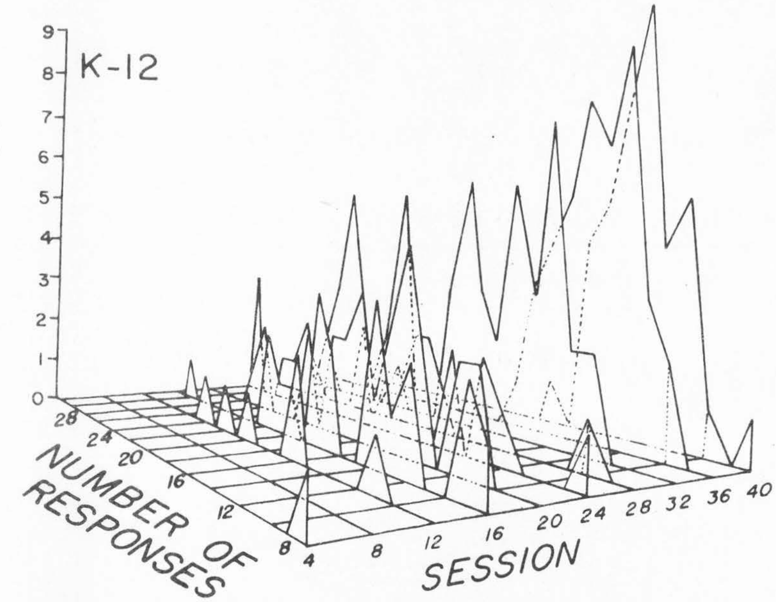
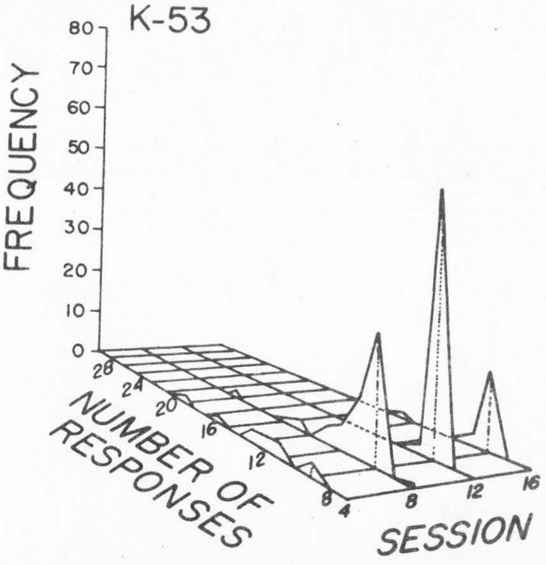

K-9
K-11
K-12
K-53
100
80
60
40
20
0
5
10
15
20
25
30
35
40
SESSIONS

Figure 4. The frequency distribution of the number of responses in a priming run for every fourth session. Birds K-9 and K-12 were on a _mix_ FR 10 FR 100 schedule and Birds K-11 and K-53 were on a _mix_ FR 10 _chain_ FR 10 FR 90 schedule. Dashed lines indicate priming runs consisting of 10 responses. Note the difference in the frequency ordinate for the _mix_ FR 10 FR 100 schedule (Birds K-9 and K-12) and the _mix_ FR 10 _chain_ FR 10 FR 90 schedule (Birds K-11 and K-53).


K-9
0
1
2
3
4
5
6
7
8
28
24
20
16
12
8
NUMBER OF RESPONSES
4
8
12
16
20
24
28
32
SESSION


K-11
FREQUENCY
0
10
20
30
40
50
60
70
80
28
24
20
16
12
8
NUMBER OF RESPONSES
4
8
12
SESSION

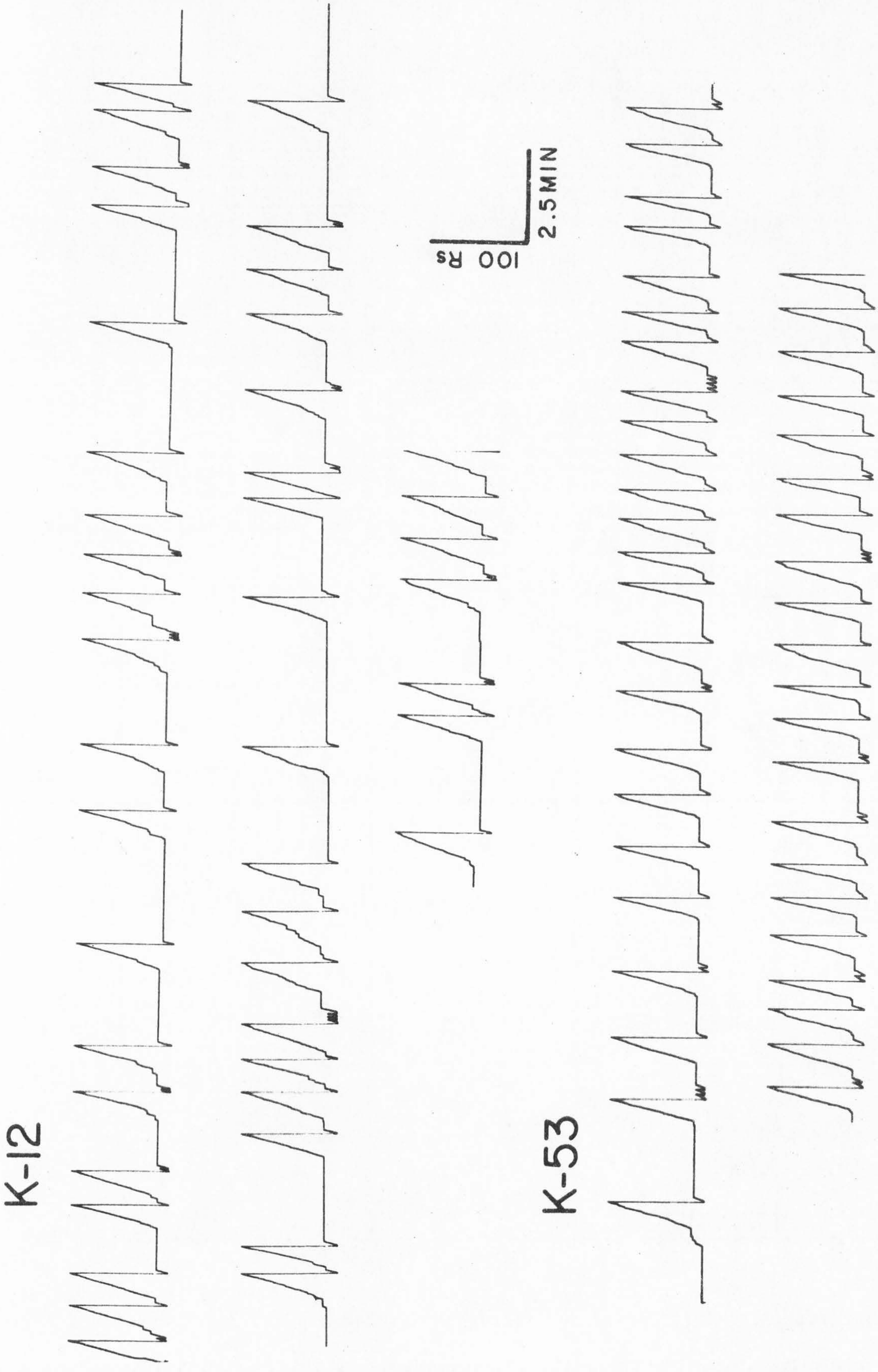

K-12
0
1
2
3
4
5
6
7
8
9
28
24
20
16
12
8
NUMBER OF RESPONSES
4
8
12
16
20
24
28
32
36
40
SESSION


K-53
FREQUENCY
0
10
20
30
40
50
60
70
80
28
24
20
16
12
8
NUMBER OF RESPONSES
4
8
12
16
SESSION

any particular number of responses was evident. As acquisition progressed, a definite mode developed which more closely approximated 10 responses, the value of the smaller FR. The modal frequency for K-9 and K-12 in the last six sessions occurred at 14-16 responses developed in the first session and was consistently maintained. In the final sessions, primes which did not consist of 10 responses were infrequent.

Selected cumulative records for K-12 and K-53 are shown in Figure 5. These records illustrate priming and the differences in priming which occurred in the *mix* FR 10 FR 100 (K-12) and the *mix* FR 10 *chain* FR 10 FR 90 (K-53) schedules. While priming occurred on both schedules, primes were more consistent on the *mix* FR 10 *chain* FR 10 FR 90 schedule. Priming runs were variable in length on the *mix* FR 10 FR 100 with generally more than 10 responses in a prime. However, primes consisted of 10 responses on the *mix* FR 10 *chain* FR 10 FR 90 schedule. Both records also illustrate the absence of post-reinforcement pausing, a characteristic typical of mixed schedule performance when one component is a small FR.

Figure 5. Cumulative records for K-12 and K-53 selected from the last six sessions. Bird K-12 was on the mix FR 10 FR 100 schedule while Bird K-53 was on the mix FR 10 chain FR 10 FR 90 schedule. The pen reset with each reinforcement.


K-12
K-53
100 Rs
2.5 MIN

Experiment II

Experiment I demonstrated that a stimulus change inserted in the large ratio controlled the number of responses in a priming run and produced more rapid acquisition of priming than a mixed schedule without the stimulus change. The purpose of Experiment II was to examine the effect on priming of varying the relationship between the stimulus change and the small ratio. This relationship was examined by varying the presence or absence of both the small FR and the stimulus change as well as varying the location of the stimulus change in the large FR.

Method

Subjects. Pigeons K-9 and K-12 served.

Apparatus. The apparatus was the same as in Experiment I.

Procedure. To determine if primes in the mix FR 10 chain FR 10 FR 90 were a function of the stimulus change alone in the chained component, both K-9 and K-12 were placed on a chain FR 10 FR 90 schedule. The key was red during FR 10 and green during FR 90. This chained schedule was used to determine if the stimulus change per se would control priming. After behavior stabilized, the schedule was changed to mix FR 10 FR 100 (see Experiment I). Next, the schedule was changed to a mix FR 10 chain FR 20 FR 80. The key was red druing FR 10 and FR 20 and green during FR 80. This schedule was included to assess if the stimulus change in the context of the mixed schedule would control priming independent of the location of that stimulus change within the chain. After several sessions, the chained component of this schedule was changed to *chain* FR 30 FR 70 (see below). The next condition was a *mix* FR 10 *chain* FR 10 FR 90. The key was red during FR 10 and green during FR 90. Following stabilization, the *mix* FR 10 FR 100 was reinstated.

A summary of the experimental conditions and the number of sessions each remained in effect is shown in Table 1. Conditions were changed when the behavior stabilized or a maximum of 40 sessions occurred. The stability criterion and all other conditions remained the same as in Experiment I.

Table 1

A Summary of the Experimental Conditions for Experiment II, the Number of Sessions Each Remained in Effect and the Proportion of the FR 100s (or Chains) Containing Primes

	Number of Sessions		Primes/FR 100s	
Condition	K-9	K-12		
Chain FR 10 FR 90	20	15	0/354	14/224
Mix FR 10 FR 100	36	40	227/274	215/254
Mix 10 *Chain* FR 30 FR 70	12	7	210/261	210/280
Mix FR 10 *Chain* FR 10 FR 90	9	6	173/210	321/245
Mix FR 10 FR 100	12	11	198/265	197/230

Results

Figure 6 shows the percent of FR 100s (or chained components) containing primes in the last six sessions for each condition. Few primes occurred in the *chain* FR 10 FR 90 schedule (condition 1) for either bird. When the schedule was changed to *mix* FR 10 FR 100 (condition 2), priming gradually developed. In the last six sessions, over 80% of the FR 100s contained primes.

On the *mix* FR 10 *chain* FR 30 FR 70 schedule (condition 3), the percent of *chain* FR 30 FR 70s containing primes decreased slightly from the percent priming obtained in the *mix* FR 10 FR 100. On the *mix* FR 10 *chain* FR 10 FR 90 schedule (condition 4), the percent primes showed a slight increase for both birds. When the *mix* FR 10 FR 100 schedule was reinstated (condition 5), percent priming decreased to a value similar to that previously obtained in this schedule.

In Figure 7, frequency distributions of the number of responses in a prime are shown for each condition. Of the few primes which occurred for Bird K-12 in the last six sessions on the *chain* FR 10 FR 90, none consisted of a run of 10 responses. In fact, priming runs of nine responses were more frequent for K-12 than any other priming runs. Thus, primes preceded rather than followed the stimulus change. On the *mix* FR 10 FR 100 schedule, primes of 16 responses for K-9 and 14 and 15 responses for K-12 occurred more frequently than other primes.

On the *mix* FR 10 *chain* FR 20 FR 80 schedule (not shown in Figure 7), primes tended to occur most frequently after runs of 20 responses. The

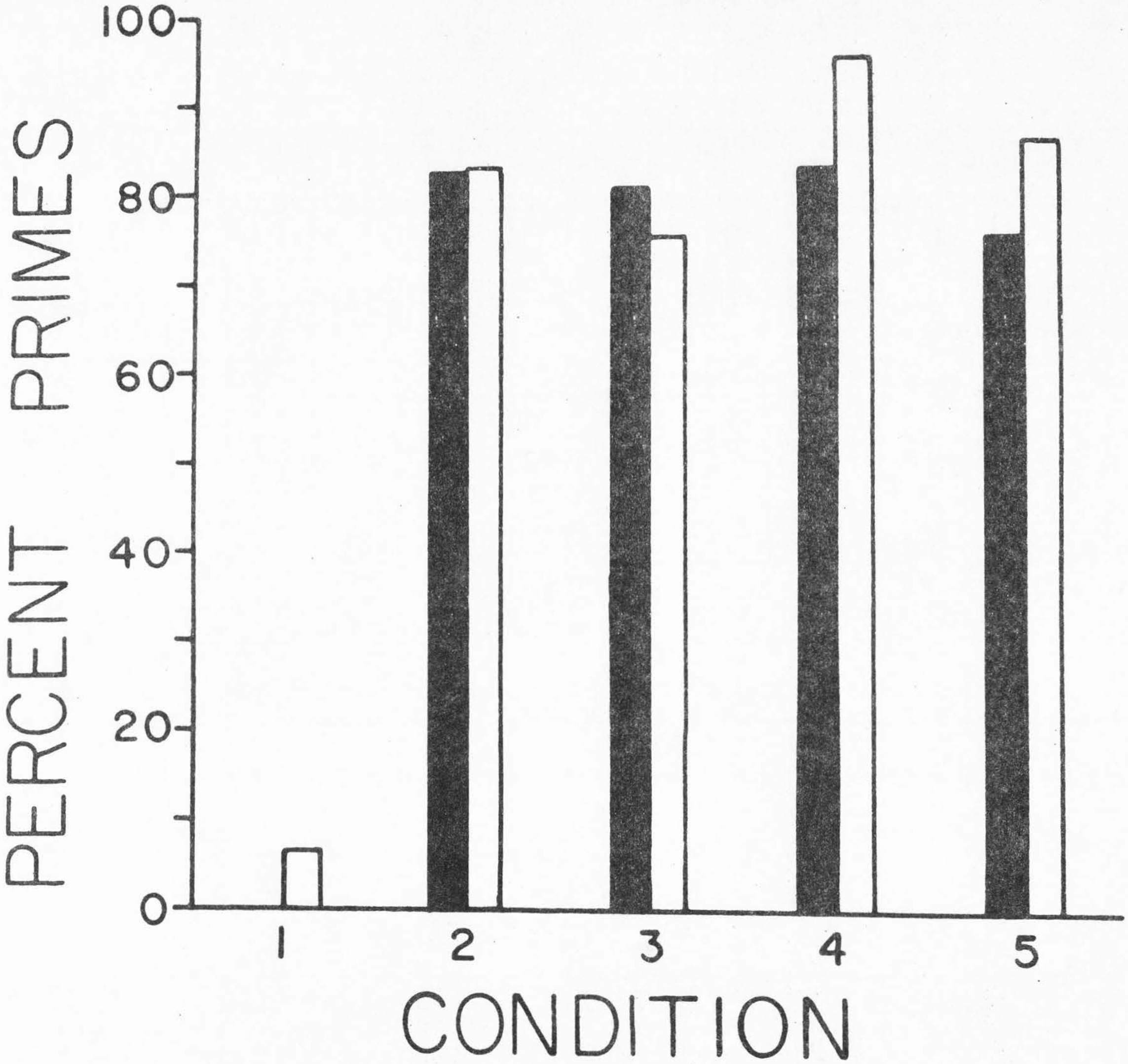

PERCENT PRIMES
100
80
60
40
20
0
1
2
3
4
5
CONDITION

Figure 6. Percent priming from the last six sessions for each condition. Condition 1 was the _chain_ FR 10 FR 90, condition 2 the _mix_ FR 10 FR 100, condition 3 the _mix_ FR 10 _chain_ FR 30 FR 70, condition 4 the _mix_ FR 10 _chain_ FR 10 FR 90 and condition 5 was a _mix_ FR 10 FR 100. The closed bars represent subject K-9 and the open bars represent subject K-12.

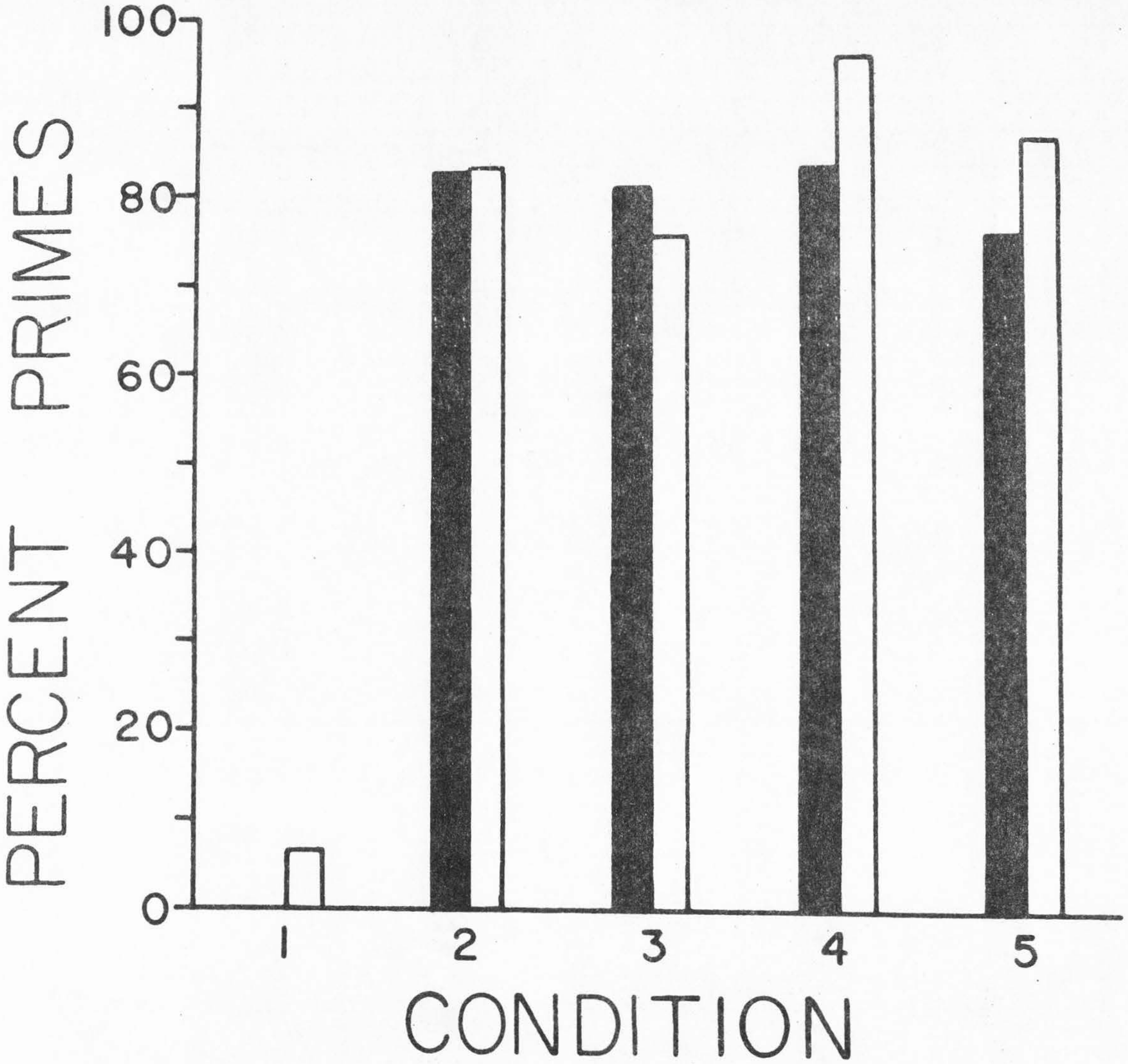
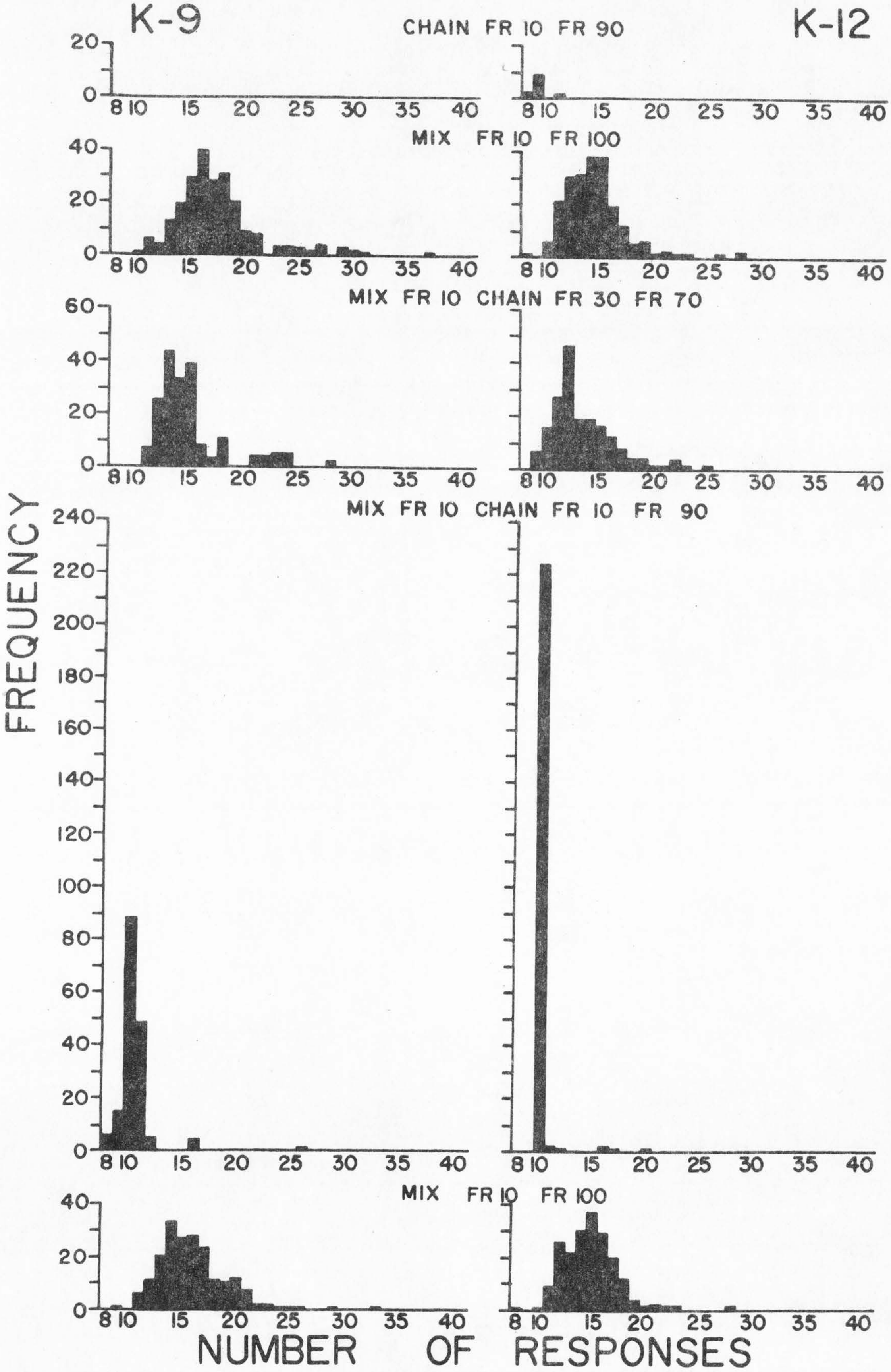

PERCENT PRIMES
100
80
60
40
20
0
1
2
3
4
5
CONDITION

Figure 7. Frequency distributions of the number of responses in a priming run from the last six sessions for each condition.

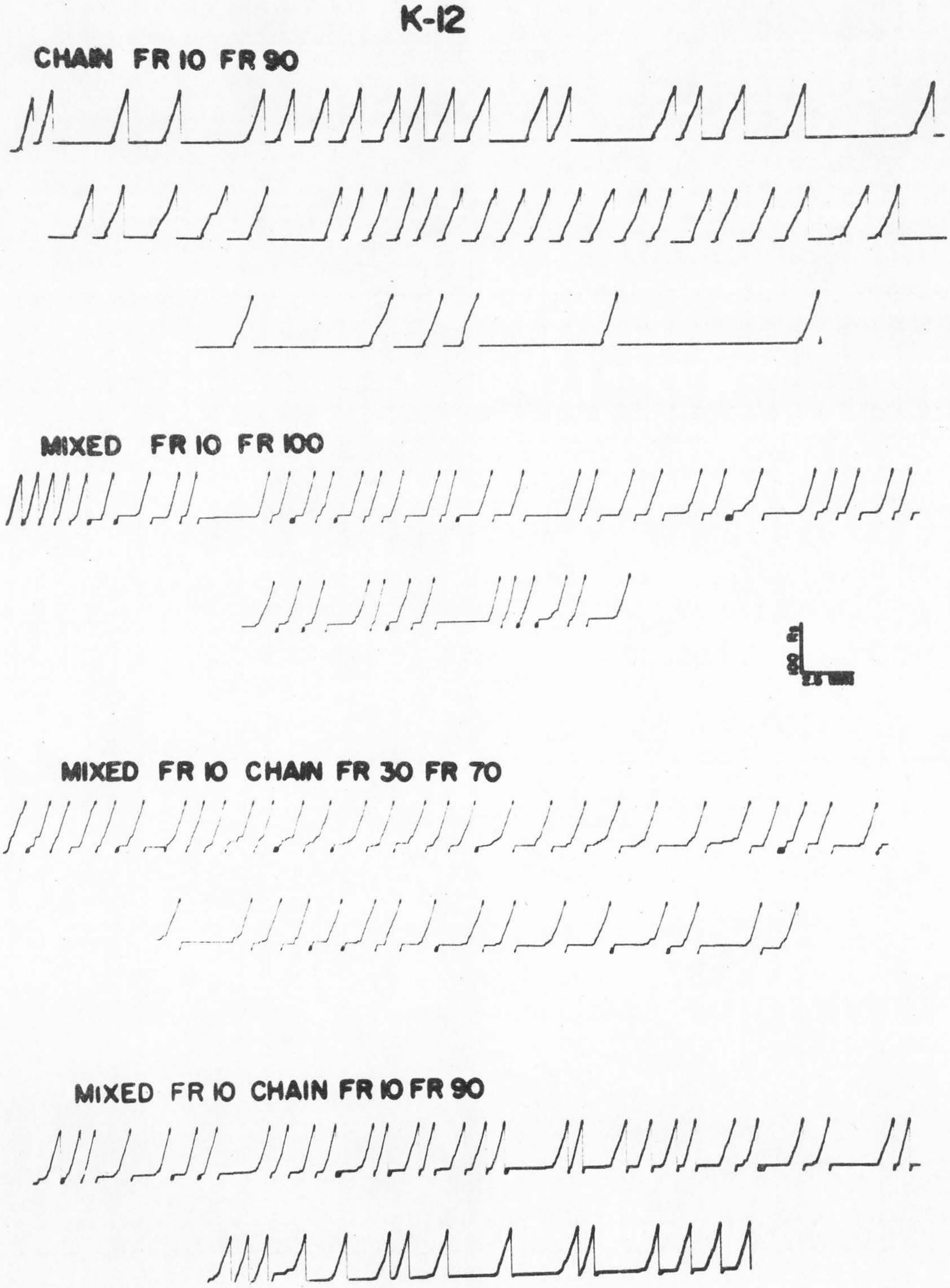

K-9
K-12
CHAIN FR 10 FR 90
MIX FR 10 FR 100
MIX FR 10 CHAIN FR 30 FR 70
MIX FR 10 CHAIN FR 10 FR 90
MIX FR 10 FR 100
FREQUENCY
NUMBER OF RESPONSES
0
20
40
60
80
100
120
140
160
180
200
220
240
8
10
15
20
25
30
35
40

occurrence of these primes may have resulted from a failure to discriminate between runs of 10 responses and runs of 20 responses. Therefore, the difference between the FR 10 and the location of the stimulus change was increased and 30 responses were required before the stimulus change. Following this change, primes generally preceded the occurrence of the stimulus change. Figure 7 shows that primes of 13 responses for K-9 and12 responses for K-12 occurred most frequently.

On the mix FR 10 chain FR 10 FR 90 schedule, primes generally consisted of 10 responses (see Figure 7). In addition, considerably less variability in the number of responses in a prime was evident for this schedule as opposed to the other mixed schedules. Each of the last six-session modes for K-12 and five out of the last six-session modes for K-9 occurred for primes consisting of 10 responses. On the other mixed schedules (excluding the mix FR 10 chain FR 20 FR 80 schedule), individual session modes did not necessarily correspond with the overall mode for the block of six-sessions.

In Figure 8, selected cumulative records are shown for K-12. These records illustrate the pattern of responding for each condition. In particular, they illustrate the general lack of pausing within the chain FR 10 FR 90. In addition, they show the precise control exercised by the mix FR 10 chain FR 90 schedule. Also, these records suggest that the pre-chain pause lengths on the chain FR 10 FR 90 schedule were longer than the pre-ratio pause lengths in the mixed schedules.

Figure 8. Cumulative records for K-12 selected from the last six sessions from each condition. The pen reset with each reinforcement.


K-12
CHAIN FR 10 FR 90
MIXED FR 10 FR 100
100 R
2.5 MIN
MIXED FR 10 CHAIN FR 30 FR 70
MIXED FR 10 CHAIN FR 10 FR 90

These differences are quantified in Table 2. Runtime, the time from the first to the last response in the FR 100 (or the *chain*) component, was shorter in the *chain* FR 10 FR 90 schedule than in any of the mixed schedules. In addition, the pause preceding the FR 100 (or *chain*) component was longer on the *chain* FR 10 FR 90 schedule than on any of the mixed schedules and the pre-FR 100 (or pre-*chain*) pause on the mixed schedule was approximately equal to the pre-FR 10 pause for each condition. Thus, for the *chain* FR 10 FR 90 schedule which did not produce primes, the pre-*chain* pauses were longer than in the mixed schedules.

Table 2

Mean of the Six-Session Medians for the Pre-FR 10 Pause, the Pre-FR 100 (or the Pre-Chain) Pause and the FR 100 (or Chain) Runtime

Condition	Pre-FR 10 (sec)		Pre-FR 100 (sec)		Runtime (sec)	
	K-9	K-12	K-9	K-12	K-9	K-12
Chain FR 10 FR 90	-	-	21.1	79.0	35.2	53.7
Mix FR 10 FR 10	1.9	1.6	1.9	1.6	50.4	73.6
Mix FR 10 Chain FR 30 FR 70	1.4	1.6	1.4	1.6	53.0	98.4
Mix FR 10 Chain FR 10 FR 90	1.4	1.7	1.5	1.6	51.1	120.4
Mix FR 10 FR 10	1.6	1.5	1.6	1.4	46.0	74.4

Experiment III

Experiments I and II demonstrated that a mixed chained schedule results in priming runs that are constant in length. When the response requirement of the first link of the chain is equal to the response requirement of the small ratio, the stimulus change is followed by a pause. This precise control over priming facilitates an examination of the variables controlling this pause. Experiment III was designed to investigate the length of the post-prime pause.

Research with the post-reinforcement pause suggests that pause length is controlled by the number of responses which are required after that pause (Findley, 1962; Griffiths and Thompson, 1973; Inman and Cheney, 1974). Therefore, Experiment III determined the relationship between FR y, the response requirement of the second link on the chain, and the length of the post-prime pause.

Method

Subjects. Four White King pigeons were used as experimental subjects. Three subjects (K-8, K-11 and K-53) had previous histories with automaintainence while the remaining subject (K-20) had an undetermined history. The age and sex of the subjects were undetermined.

Apparatus. A standard three-key pigeon chamber was used. Reinforcement consisted of 3 sec access to an illuminated hopper containing Purina Pigeon Chow. The left response key, located 9.8 cm above this food hopper, was transilluminated by a colored light during each session, except during reinforcement. The remaining two keys were not used and remained dark. Pause lengths were recorded by an on-line, PDP-8 digital computer (Digital Equipment Corporation). All other aspects of the apparatus were identical with that used in Experiment I.

Procedure. The subjects were trained to peck a key on continuous reinforcement. The response requirement was then gradually raised until an FR 120 was established.

After this training, a mix FR x chain FR x FR y schedule was introduced. The component sequences and proportions were the same as in Experiment I. The value of x was fixed at x = 10 and the value of y was varied from 10 to 120. Completion of the first link of the chain was followed by a 0.25 sec interval in which responses had no effect except to produce the relay click. This time interval was included to prevent extra responses from interfering with the recording of the post-prime pause. The sequence of schedule conditions and the number of sessions each condition remained in effect are shown in Table 3.

The median pre-FR x, pre-chain and the post-prime pauses were obtained. A change in the schedule conditions occurred when the post-prime pause stabilized. This pause was considered stable if the mean of a block of the first three-session medians and the mean of the next three-session medians did not differ by more than 10% from the mean of all six session medians. The mean of these medians was used to ensure a rigorous stability criterion. In addition, stability required that no consistent trend in these six session medians occurred as determined by the Runs Test for Randomness with alpha = .10 (Mendenhall, 1971). Thus, the behavior was not stable if the medians of the first three sessions were all larger (or smaller) than any of next three medians.

Table 3

The Sequence of Experimental Conditions and the Number of Sessions each Condition Remained in Effect in Experiment III

Condition	Number of Sessions			
x x y	K-8	K-11	K-20	K-53
mix FR 10 *chain* FR 10 FR 120	12	9	--	--
mix FR 10 *chain* FR 10 FR 90	--	--	6	9
mix FR 10 *chain* FR 10 FR 10	6	7	8	9
mix FR 10 *chain* FR 10 FR 40	14	11	--	--
mix FR 10 *chain* FR 10 FR 90	--	--	10	9
mix FR 10 *chain* FR 10 FR 120	11	9	6	6

Results

Mean post-prime pauses are shown in Figure 9 for each subject as a function of the size of FR y. As FR y size decreased to 10, the length of the post-prime pause decreased to less than 1 sec for all subjects. As the size of FR y was subsequently increased, the post-prime pause increased.

Figure 9. Means of the last six-day median post-prime pauses for each subject as a function of the size of FR y. Only the points for the ascending series are connected. FR x was fixed at 10 responses. Note the log scale of the ordinate.

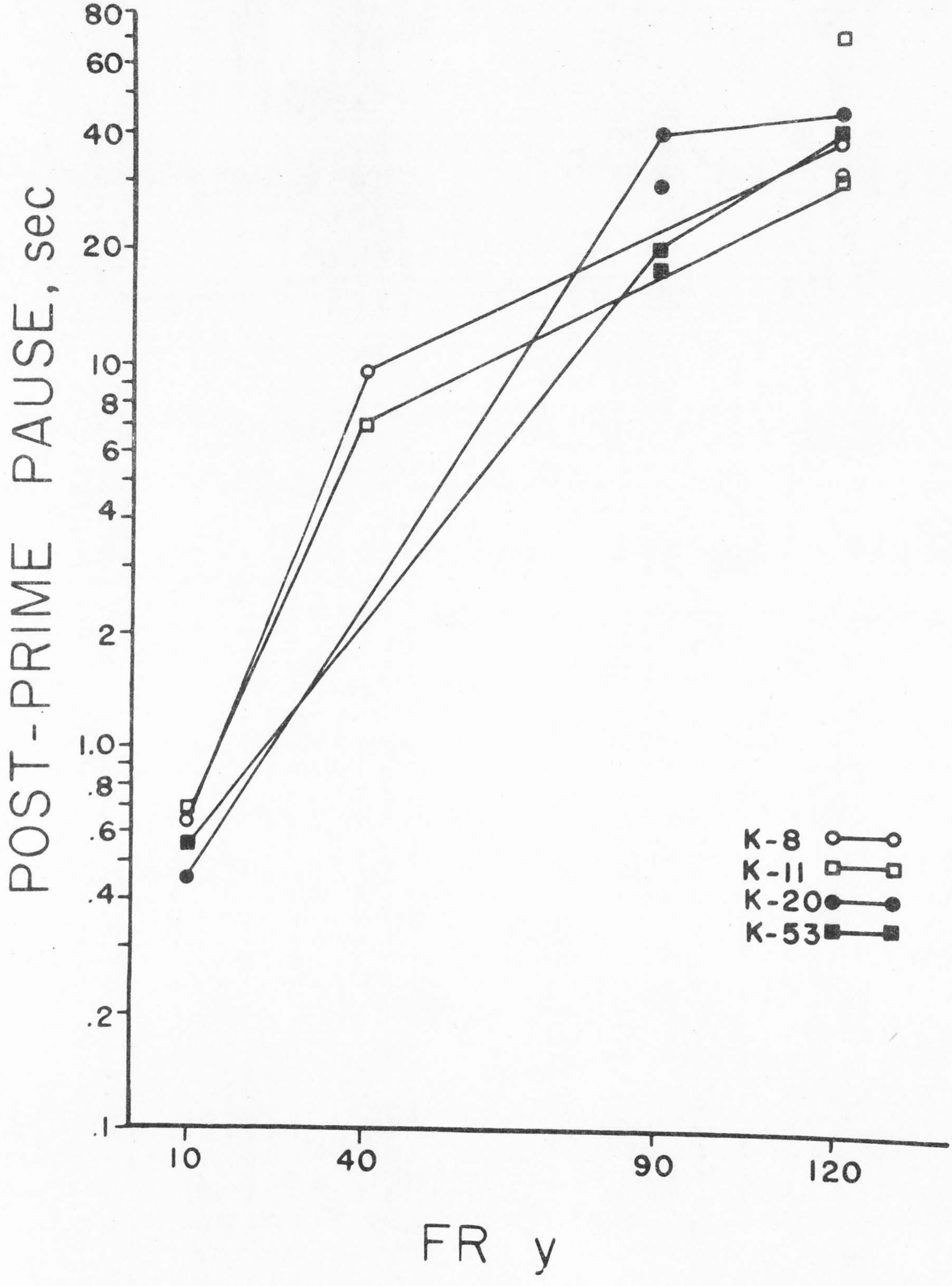
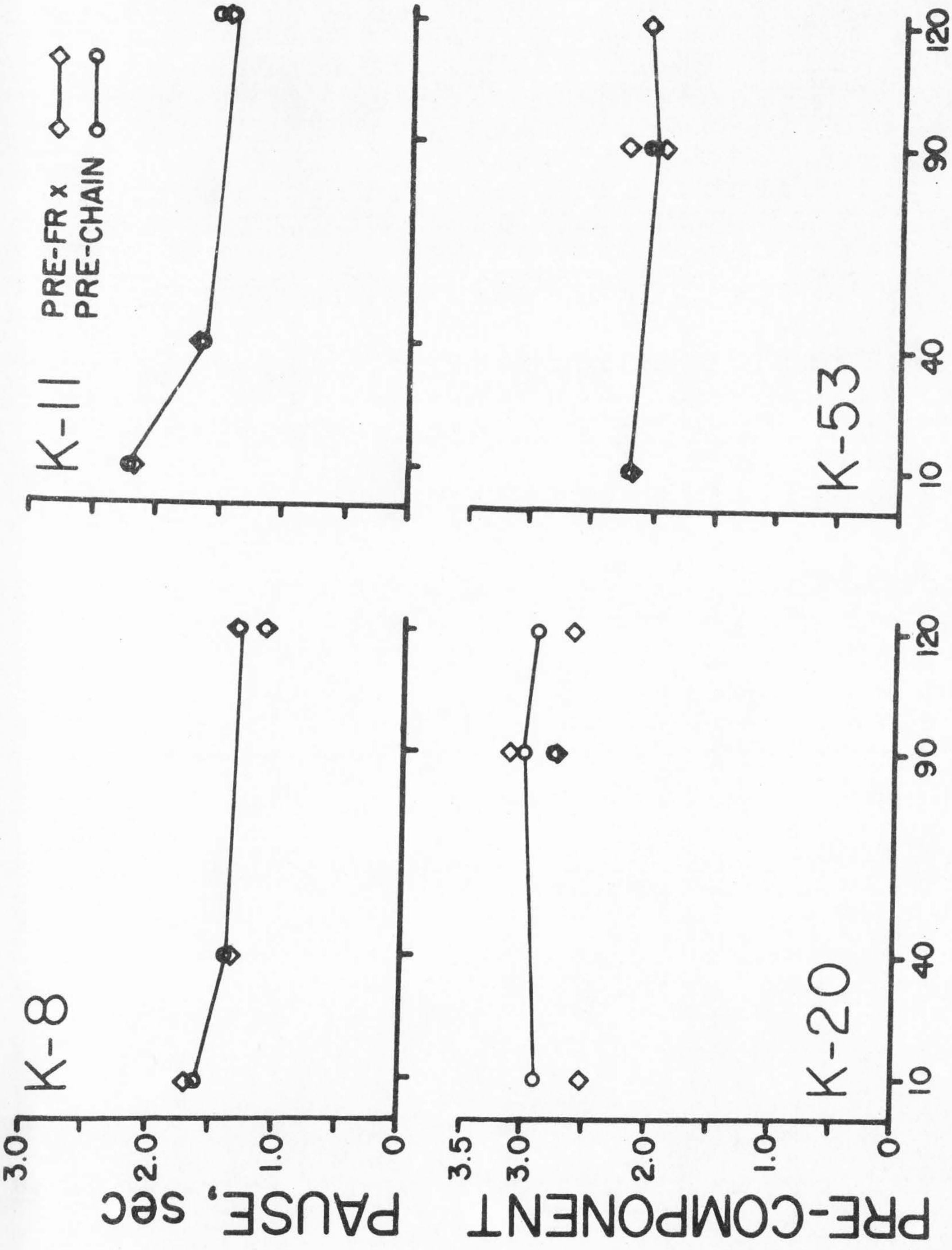

POST-PRIME PAUSE, sec
80
60
40
20
10
8
6
4
2
1.0
.8
.6
.4
.2
.1
10
40
90
120
FR y
K-8
K-11
K-20
K-53

Figure 10 shows the pre-FR x and the pre-chain FR x FR y pauses as a function of the size of FR y. As the size of FR x was varied, little change was observed in either of these pauses. At all values of FR y, the pre-FR x and the pre-chain FR x FR y pause lengths were approximately equal.

Figure 10. Means of the last six-day median pre-FR x and pre-chained FR x FR y pauses for each subject as a function of the size of FR y. Only the points for the ascending series are connected. FR x was fixed at 10 responses.


K-8
K-11
K-20
K-53
PRE-FR x
PRE-CHAIN
PAUSE, sec
PRE-COMPONENT
3.0
2.0
1.0
0
3.5
3.0
2.0
1.0
0
10
40
90
120
10
40
90
120
FR y

Experiment IV

In Experiment III, the relationship between FR y, the post-prime pause length and each pre-component pause length was examined with FR x held constant at 10 responses. The post-prime pause increased with FR y but neither pre-component pause varied with FR y. In Experiment IV, FR y was held constant and FR x was varied. The lengths of the post-prime pause and the pre-component pauses were obtained as a function of FR x.

Method

Subjects. The subjects were the same as in Experiment III.

Apparatus. The apparatus was the same as in Experiment III.

Procedure. As in Experiment III, a mix FR x chain FR x FR y was used. FR y was fixed at 120 (90 for K-20) responses while FR x was varied from 10 to 120 responses. Thus, the size of the second link of the chained component was held constant while the size of the first link and of the small FR was varied. The sequence of schedule conditions and the number of sessions each remained in effect are shown in Table 4. The mix FR 10 chain FR 10 FR 120 schedule was also the last point used in Experiment III. All other conditions were the same as in Experiment III.

Results

The mean post-prime pause is shown in Figure 11 for each subject as a function of the size of FR x. The post-prime pause decreased as FR x was increased from 10 to 90 for subjects K-8 and K-53. A slight increase then

Table 4

Summary of Experiment IV

Condition			Number of Sessions			
x	x	y	K-8	K-11	K-20	K-53
Mix FR 10	*Chain* FR 10	FR 90	--	--	12	--
Mix FR 10	*Chain* FR 10	FR 120	11	9	--	6
Mix FR 40	*Chain* FR 40	FR 90	--	--	22	--
Mix FR 40	*Chain* FR 40	FR 120	--	19	--	--
Mix FR 90	*Chain* FR 90	FR 90	--	--	12	--
Mix FR 90	*Chain* FR 90	FR 120	12	--	--	17
Mix FR 120	*Chain* FR 120	FR 120	7	8	--	7

occurred as FR x was increased to 120. For subject K-20, the post-prime pause increased as FR x was raised from 10 to 40 to 120. For K-11, a large increase occurred as FR x was raised from 10 to 40. A large decrease followed the increase to 120.

Thus, the changes in the post-prime pause were largely a function of the subject and FR x rather than simply FR x alone. Furthermore, the changes which did occur, with the possible exception at FR x = 40 for K-11 and FR x = 90 for K-20, were relatively small when contrasted with the changes obtained in the post-prime pause when FR y was varied in Experiment III.

Figure 11. Means of the last six-day median post-prime pauses for each subject as a function of the size of FR x. FR y was fixed at 120 responses for K-8, K-11 and K-53 and at 90 responses for K-20.

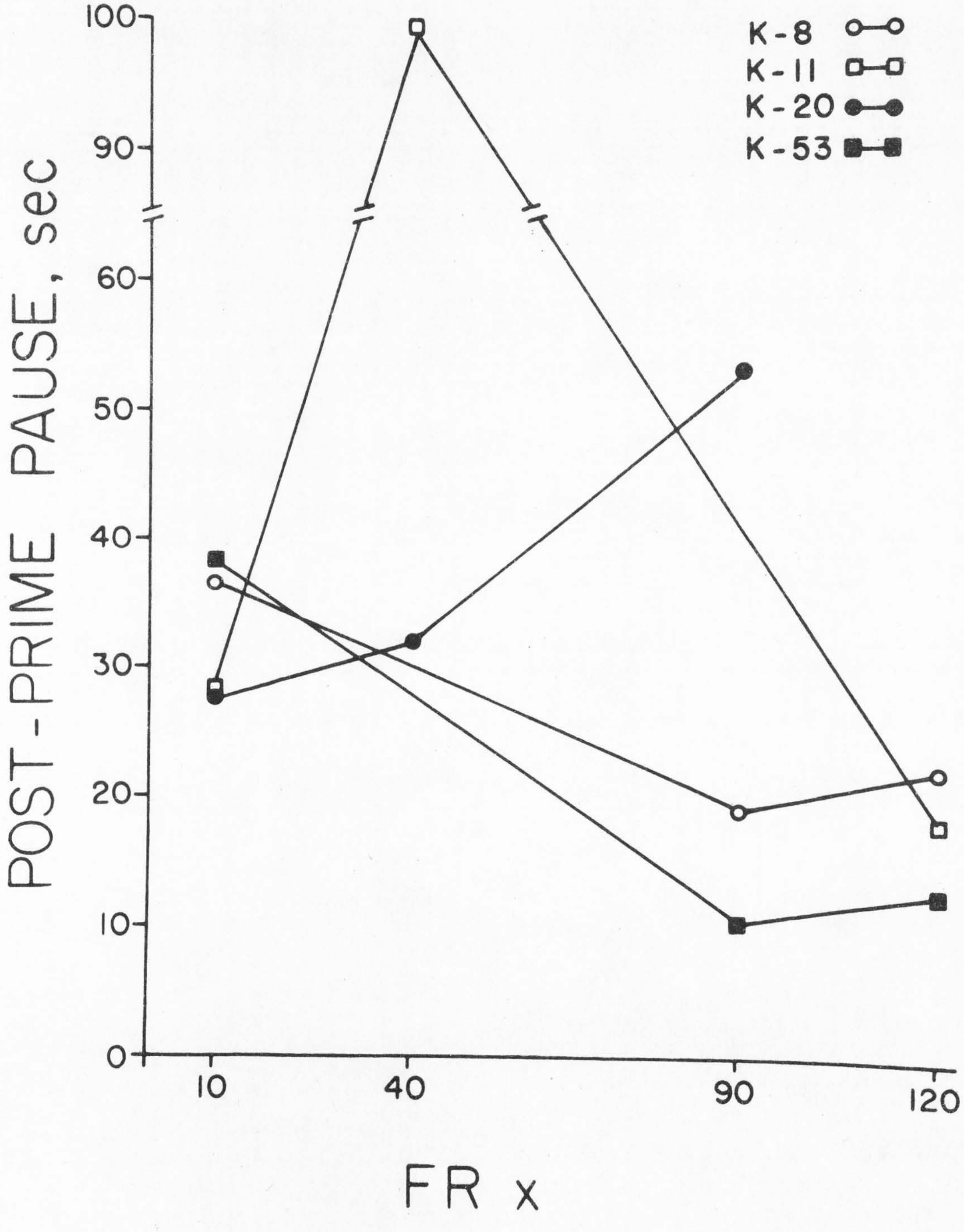

POST-PRIME PAUSE, sec
100
90
60
50
40
30
20
10
0
10
40
90
120
FR x
K-8
K-11
K-20
K-53

Figure 12 shows the pause which preceded the small component (FR x) of the mixed schedule. The pre-FR x pause increased with FR x. Here, the changes were relatively large and consistent across subjects although some separation occurred at higher values of x. As shown in Figure 13, similar increases were obtained in the pre-*chain* pause as a function of FR x. Again, the changes were large and consistent.

Figure 12. Means of the last six-day median pauses which preceded the FR x component. Note the use of log scale in plotting pause length. FR y was fixed at 120 responses for K-8, K-11 and K-53 and at 90 responses for K-20.

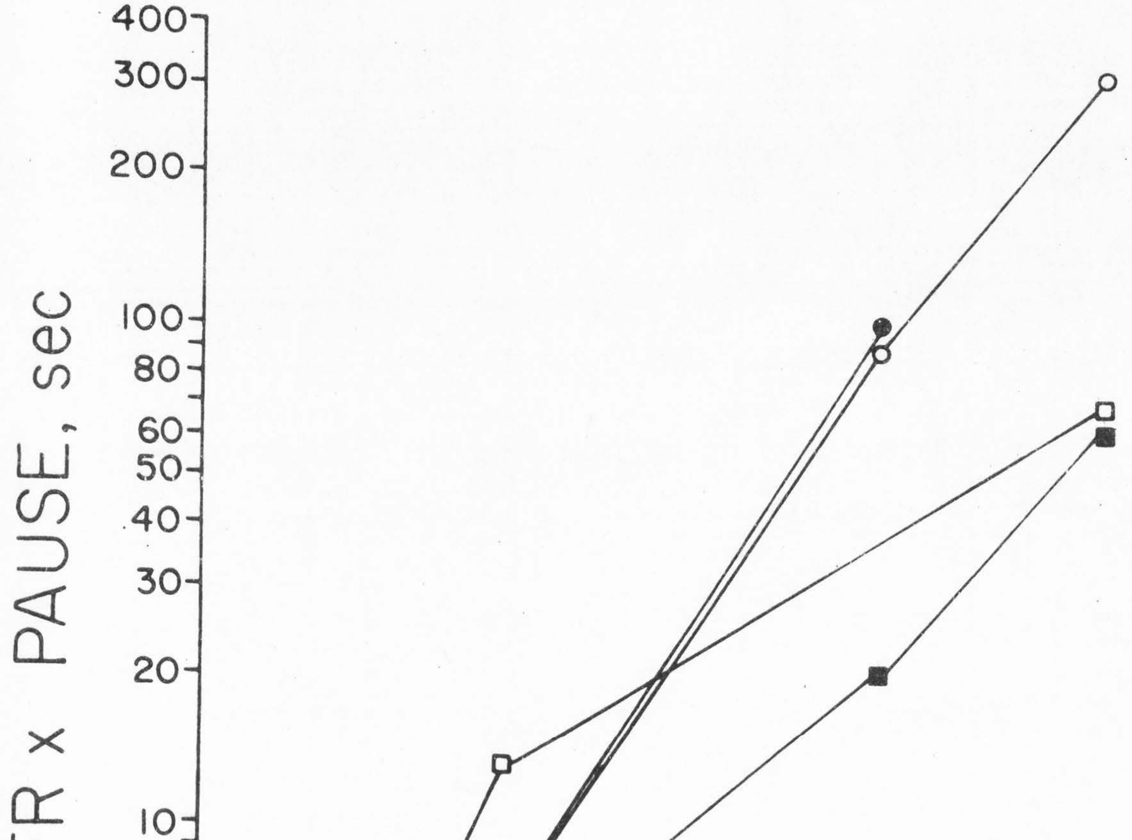
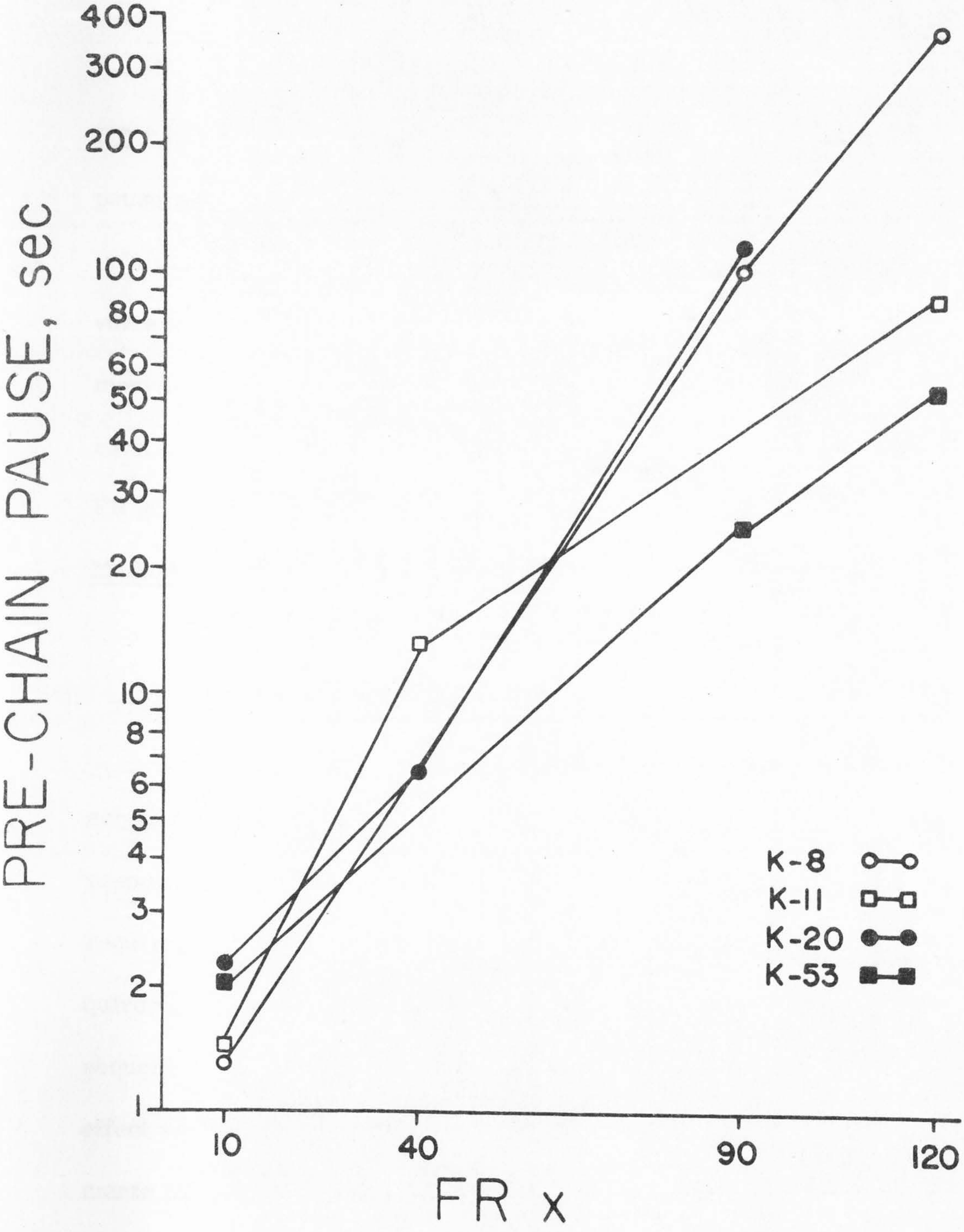

PRE-FR x PAUSE, sec
400
300
200
100
80
60
50
40
30
20
10
8
6
5
4
3
2
1
FR x
10
40
90
120
K-8 ○—○
K-11 □—□
K-20 ●—●
K-53 ■—■

Figure 13. Means of the last six-day median pauses which preceded the chained FR x FR y component. Note the use of a log scale in plotting pause length. FR y was fixed at 120 responses for K-8, K-11 and K-53 and at 90 responses for K-20.


PRE-CHAIN PAUSE, sec
400
300
200
100
80
60
50
40
30
20
10
8
6
5
4
3
2
1
10
40
90
120
FR x
K-8 ○—○
K-11 □—□
K-20 ●—●
K-53 ■—■

Experiment V

In Experiment III, the value of FR y was varied from 10 to 120 with FR x held constant at 10. Large increases were obtained in the post-prime pause as FR y increased but little or no change was observed in either post-reinforcement pause. In Experiment V, FR x was held constant at a higher value to investigate the possibility that the changes which occurred in Experiment III were partially due to the value of FR x used in that Experiment. With FR x held constant at this higher value, the effect on pause length of varying FR y was investigated.

Method

Subjects. The subjects were the same as in Experiments III and IV.

Apparatus. The apparatus was the same as in Experiments III and IV.

Procedure. As in Experiments III and IV, a mix FR x chain FR x FR y schedule was used. The response requirement of FR x was fixed at 120 responses (90 responses for K-20) while FR y was varied. Thus, the response requirement of the second link of the chain was varied while the response requirement of the first link and of the small component was held constant. The sequence of schedule conditions and the number of sessions each remained in effect is shown in Table 5. All other conditions were the same as in Experiments III and IV.

Table 5

Summary of Experiment V

Condition	Number of Sessions			
x x y	K-8	K-11	K-20	K-53
Mix FR 120 *Chain* FR 120 FR 120	7	14	--	8
Mix FR 120 *Chain* FR 120 FR 90	13	--	--	6
Mix FR 120 *Chain* FR 120 FR 40	--	7	--	--
Mix FR 120 *Chain* FR 120 FR 10	6	7	--	7
Mix FR 90 *Chain* FR 90 FR 90	--	--	9	--
Mix FR 90 *Chain* FR 90 FR 40	--	--	8	--
Mix FR 90 *Chain* FR 90 FR 10	--	--	6	--

Results

The length of the post-prime pause is shown in Figure 14 for each subject as a function of the size of FR y. As FR y decreased to 10, the length of the post-prime pause decreased to less than 1 sec for all subjects.

Figure 15 shows the length of the pauses which preceded FR x, the small component. Small decreases occurred in the pre-FR x pause length as FR y was decreased. The only exception to this was the slight increase which occurred for subject K-53 as FR y was decreased.

Similar results were obtained for the pre-chain FR x FR y pause as is shown in Figure 16. Again the pause length decreased as FR y was decreased.

Figure 14. Means of the last six-day median post-prime pauses for each subject as a function of FR y. FR x was fixed at 120 responses for K-8, K-11 and K-53 and at 90 responses for K-20. Note the use of a log ordinate in plotting pause length.

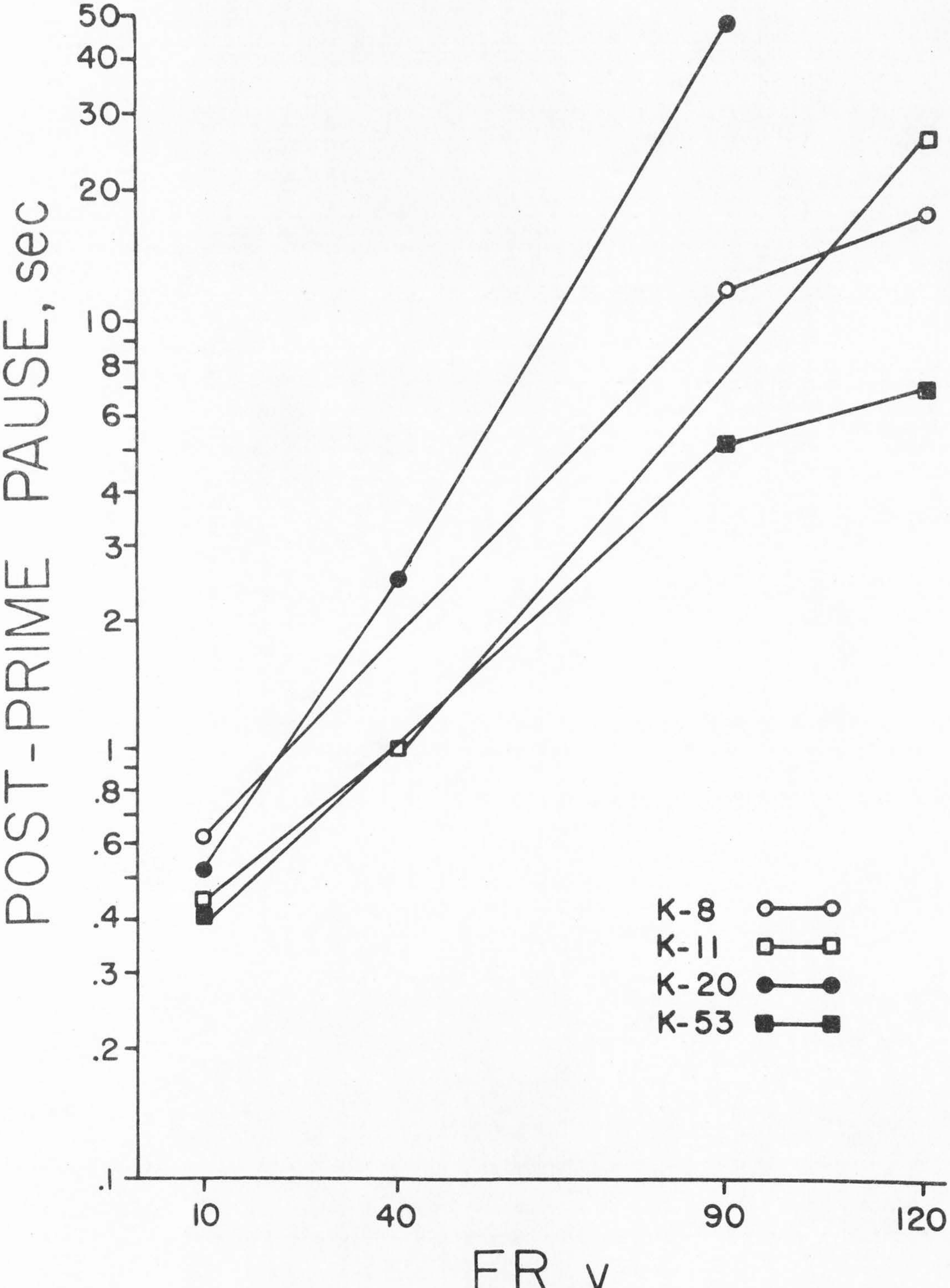

POST-PRIME PAUSE, sec
50
40
30
20
10
8
6
4
3
2
1
.8
.6
.4
.3
.2
.1
10
40
90
120
FR y
K-8
K-11
K-20
K-53

Figure 15. Means of the six-day median pre-FR x pause lengths for each subject as a function of FR y. FR x was fixed at 120 responses for K-8, K-11 and K-53 and at 90 responses for K-20. Note the use of a log scale in plotting pause length.

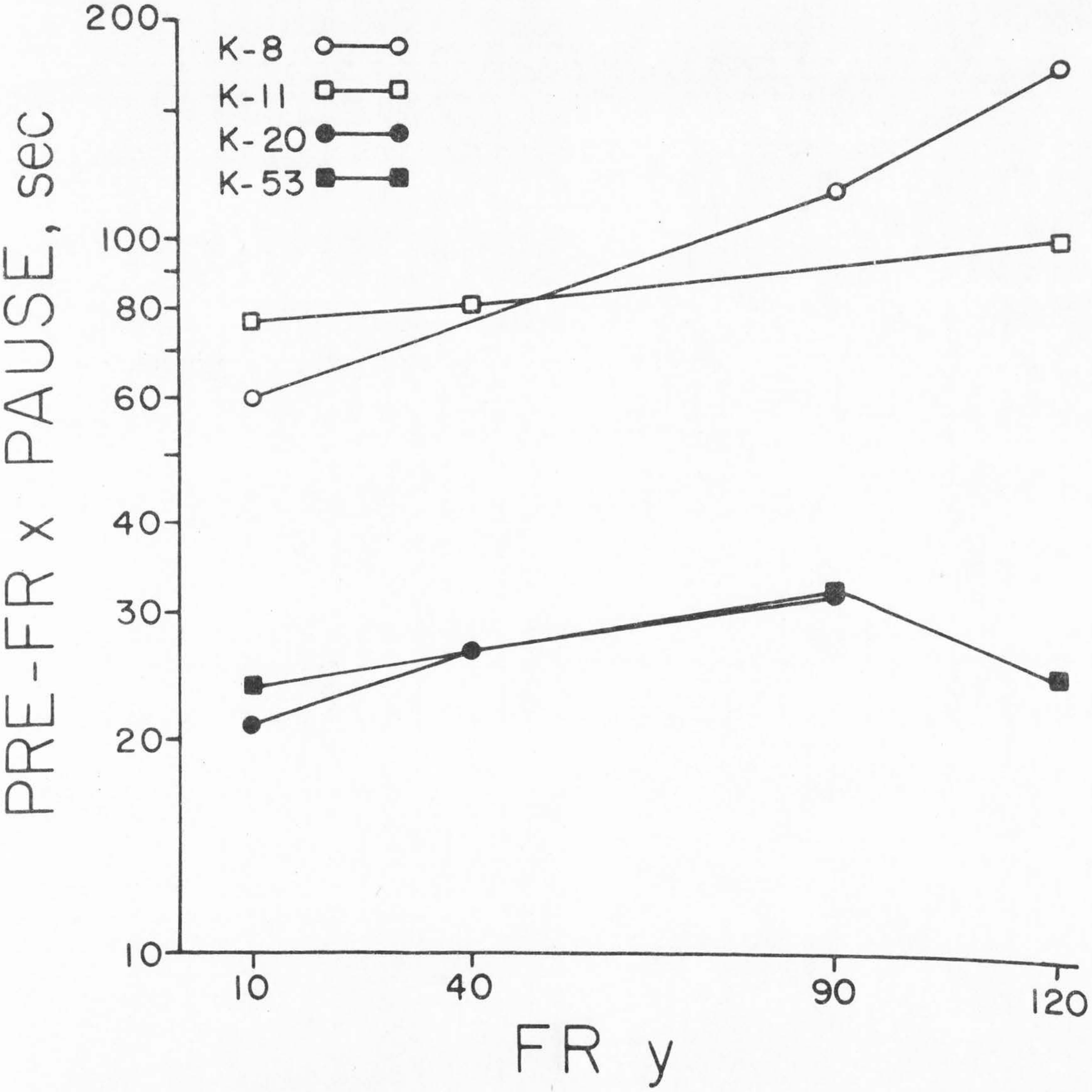
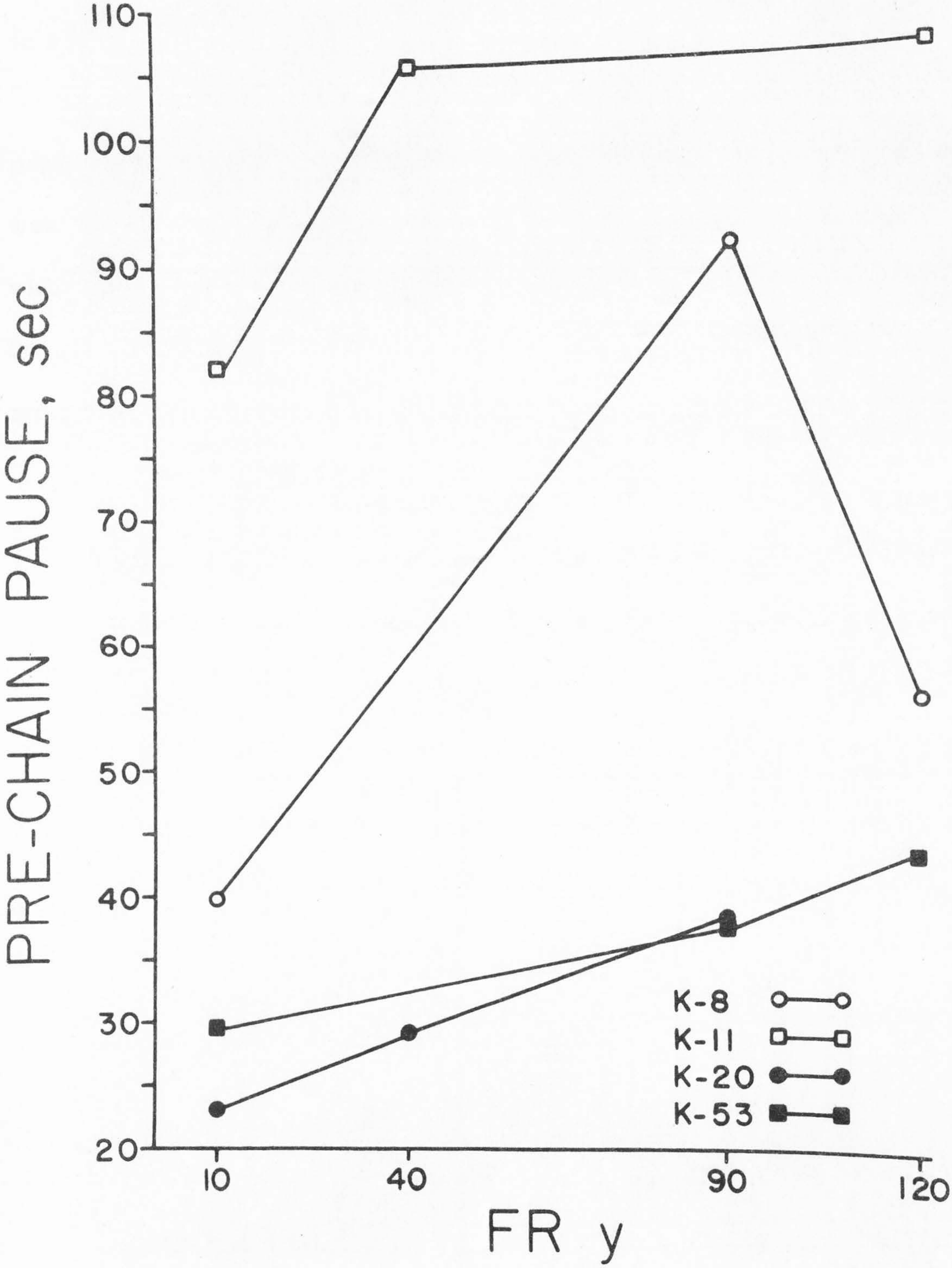

K-8
K-11
K-20
K-53
200
100
80
60
40
30
20
10
PRE-FR x PAUSE, sec
10
40
90
120
FR y

Figure 16. Means of the last six-day median pause lengths preceding the *chain* FR x FR y component of the mixed schedule. The FR x requirement was fixed at 120 responses for K-8, K-11 and K-53 and at 90 responses for K-20.


PRE-CHAIN PAUSE, sec
110
100
90
80
70
60
50
40
30
20
10
40
90
120
FR y
K-8
K-11
K-20
K-53

The only exception to this occurred when an increase accompanied a decrease in FR y from 120 to 90 for subject K-8.

While the variation in both the pre-FR x and pre-*chain* FR x FR y pauses within subjects was relatively small, the variability between subjects was quite large. For the pre-FR x pause, two subjects were grouped together with longer pauses and two with shorter pauses. A similar effect occurred for the pre-*chain* FR x FR y pause, although in this case, K-8 and K-11 were not grouped as closely together.

Experiment VI

In Experiment IV, the value of x was varied with y held constant at either 90 or 120. To test for the possibility that the results obtained in Experiment IV were due to the value of FR x, the effect of varying x was again assessed in Experiment VI with the value of y held constant at 10.

Method

Subjects. The subjects were the same as in Experiments III, IV and V.

Apparatus. The apparatus was the same as in Experiments III, IV and V.

Procedure. As in Experiments III, IV and V, a mix FR x chain FR x FR y schedule was used. The response requirement of FR x was varied with the response requirement of FR y held constant at 10 responses. Thus, the response requirement of the second link of the chain was held constant while the requirement of the first link of the chain and of the small component were varied. The sequence of schedule conditions and the number of sessions each remained in effect are shown in Table 6. All other conditions were the same as in Experiments III, IV and V.

Results

The length of the post-prime pause is shown in Figure 17 for each subject as a function of the size of FR x. In general, there was little effect of FR x on the post-prime pause. For K-8, little change was observed as FR x

Table 6

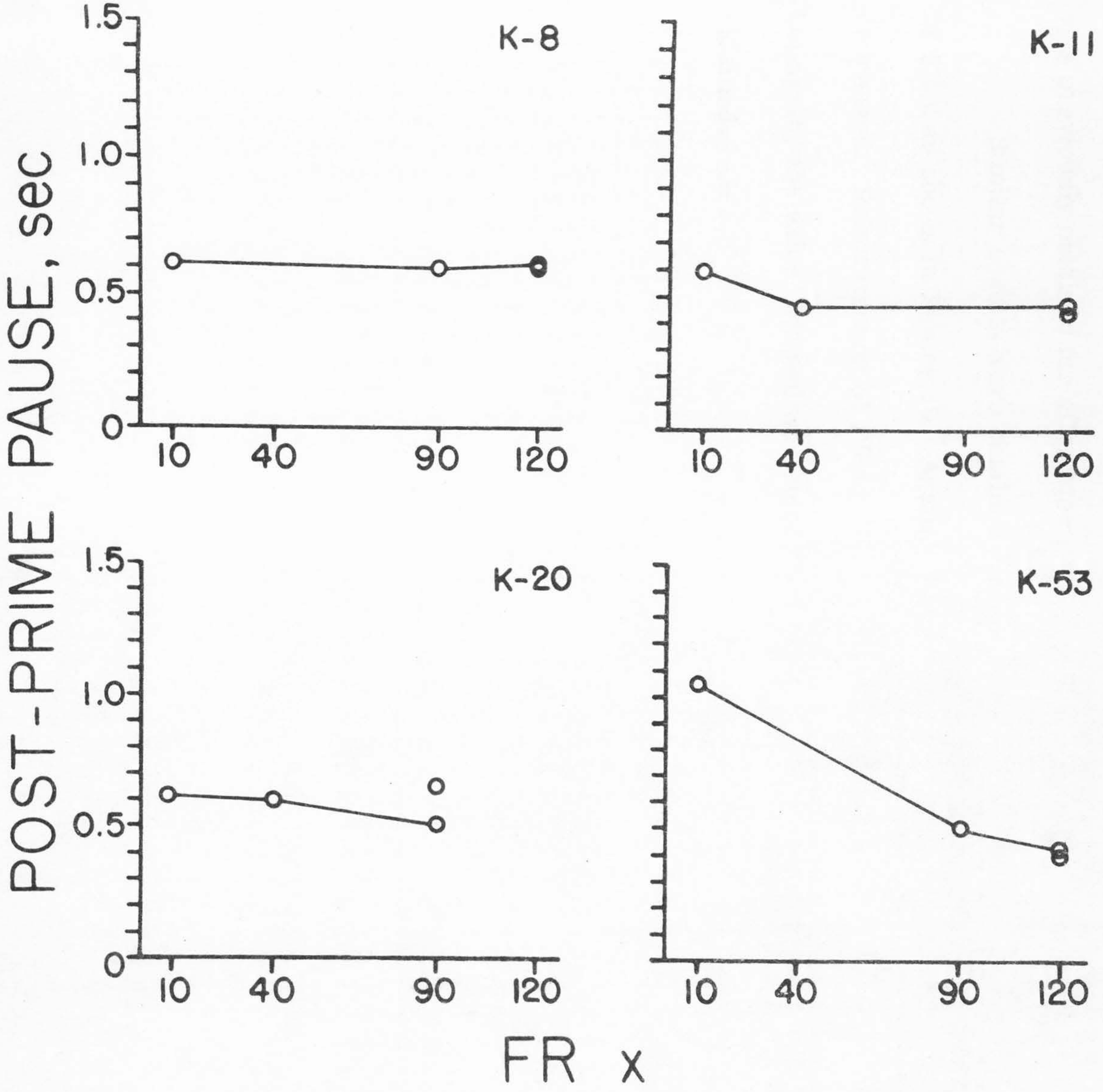
Summary of Experiment VI

Condition	Number of Sessions			
	K-8	K-11	K-20	K-53
Mix FR 120 _Chain_ FR 120 FR 10	6	7	--	7
Mix FR 90 _Chain_ FR 90 FR 10	6	--	6	6
Mix FR 40 _Chain_ FR 40 FR 10	--	6	6	--
Mix FR 10 _Chain_ FR 10 FR 10	6	7	6	9
Mix FR 90 _Chain_ FR 90 FR 10	--	--	7	--
Mix FR 120 _Chain_ FR 120 FR 10	6	6	--	6

varied. For K-11, little change occurred except that the post-prime pause increased slightly as FR x was decreased from 40 to 10. A slight decrease subsequently occurred as FR x was raised from 10 to 120. For K-20 a slight increase occurred as FR x was decreased from 90 to 40 to 10. This slight increase continued as FR x = 90 was reinstated. For K-53, the post-prime pause increased slightly as FR x was decreased from 120 to 90. A larger increase occurred upon the subsequent decrease from 90 to 10. A large decrease occurred as FR x = 120 was reinstated. Except for K-53, the functions relating the size of FR x to the post-prime pause are relatively flat.

Considerably different results were obtained for both the pre-_chain_ and the pre-FR x pauses. The pre-_chain_ pause is shown as a function of FR x

Figure 17. Means of the last six-session median post-prime pause lengths as a function of the size of FR x. Only the points in the descending series are connected. FR y was fixed at 10 responses.


K-8
K-11
K-20
K-53
POST-PRIME PAUSE, sec
1.5
1.0
0.5
0
10
40
90
120
FR X

in Figure 18. In each case, the pre-chain pause decreased as FR x decreased from 90 or 120 to 10. An increase occurred when FR x = 90 or FR x = 120 was reinstated. However, this reinstatement produced a shorter pause than was previously obtained for all subjects.

Similar results were obtained for the pre-FR x pause as a function of FR x as shown in Figure 19. Again, pause length decreased as FR x was decreased. Reinstatement of FR x = 90 or FR x = 120 produced an increase but again, the value obtained was consistently lower than was previously obtained.

Figure 18. Means of the last six-session median pre-FR x pause lengths as a function of the size of FR x. Only the points in the descending series are connected. Note the use of a log scale in plotting pause length.

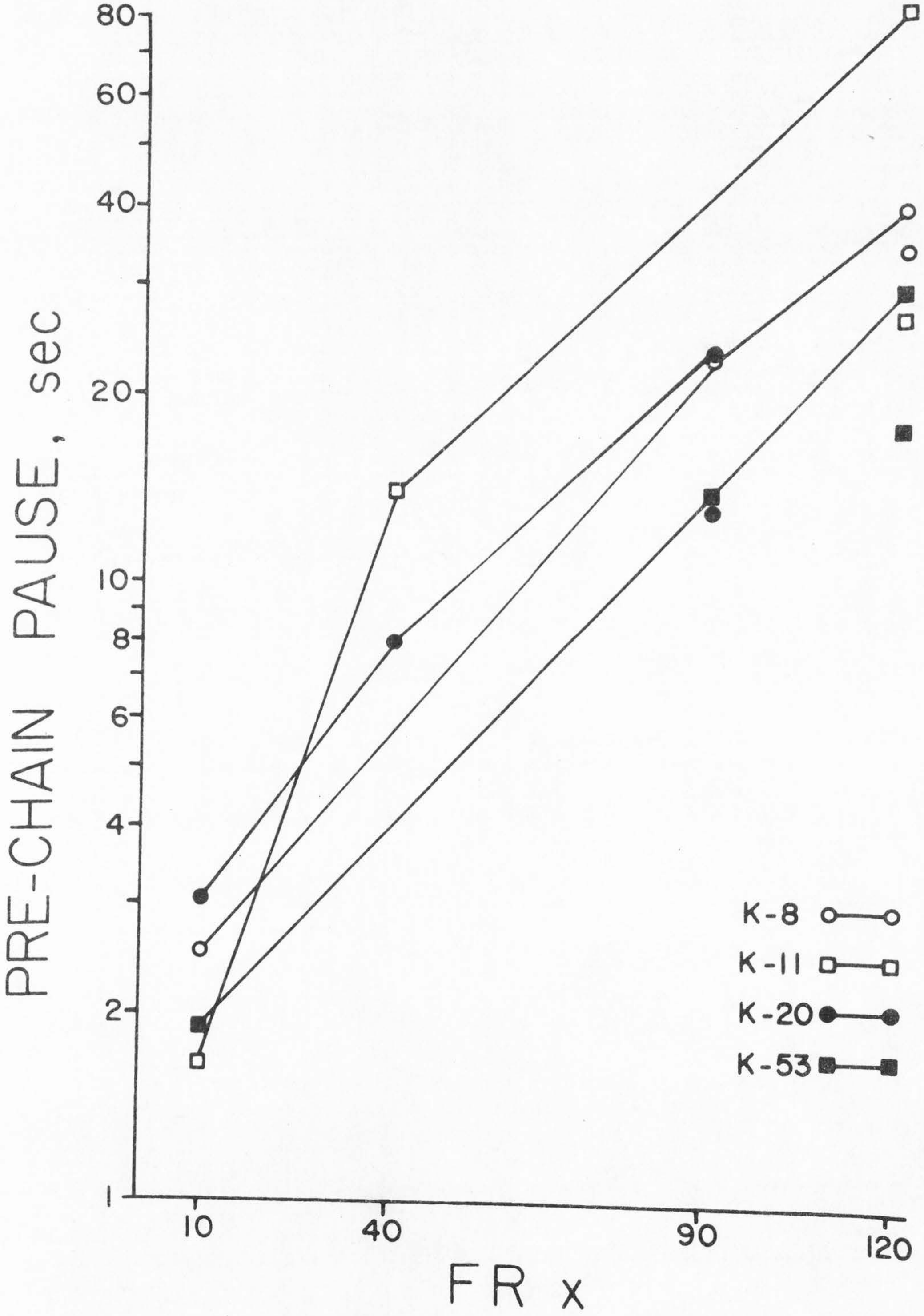
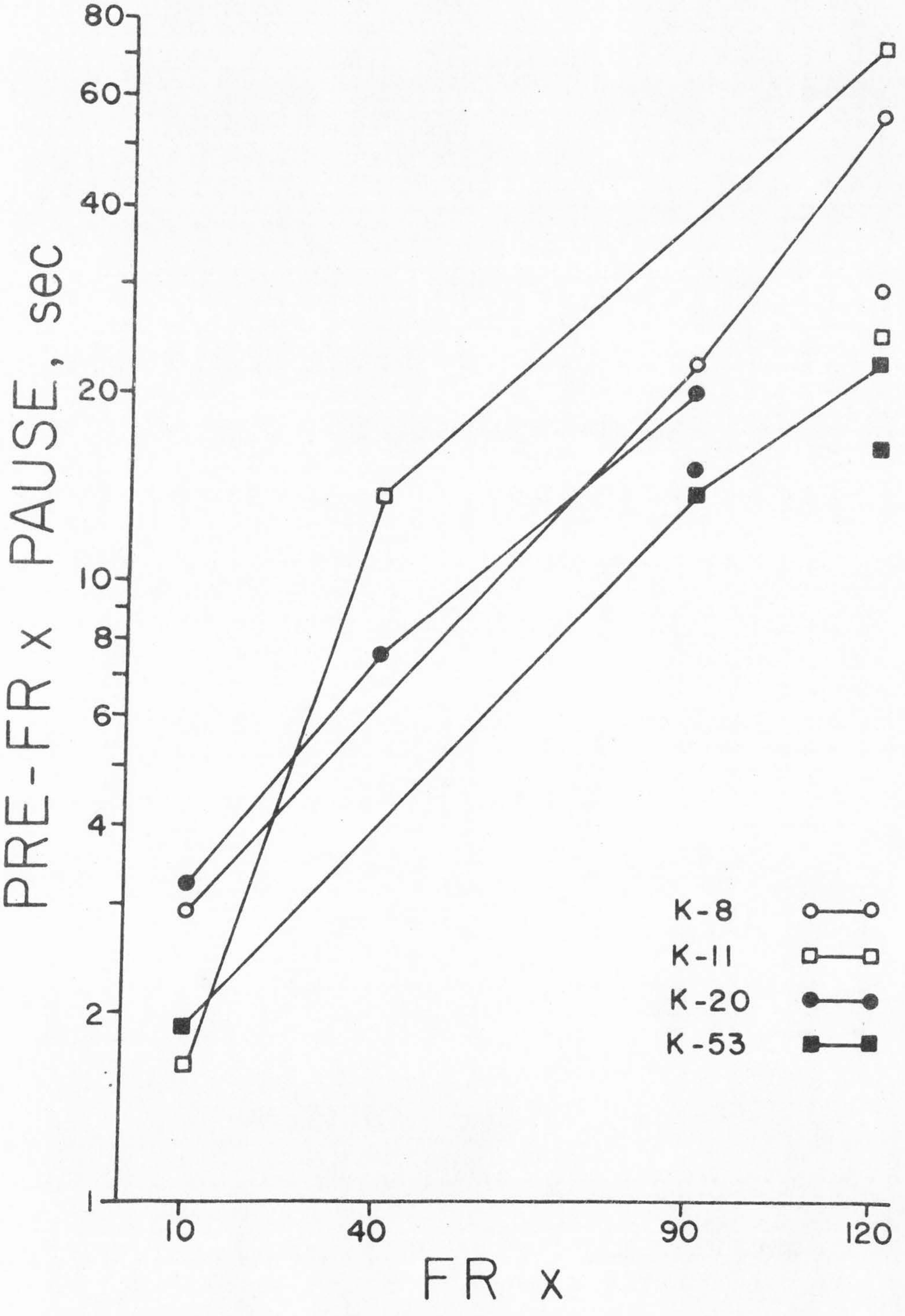

PRE-CHAIN PAUSE, sec
80
60
40
20
10
8
6
4
2
1
10
40
90
120
FR x
K-8 ○—○
K-11 □—□
K-20 ●—●
K-53 ■—■

Figure 19. Means of the last six-session median pre-<u>chain</u> FR x FR 10 pause lengths as a function of the size of FR x. Only the points in the descending series are connected. Note the use of a log scale in plotting pause length.


80
60
40
20
10
8
6
4
2
1
PRE-FR x PAUSE, sec
10
40
90
120
FR x
K-8
K-11
K-20
K-53

Summary of Experiments III-VI

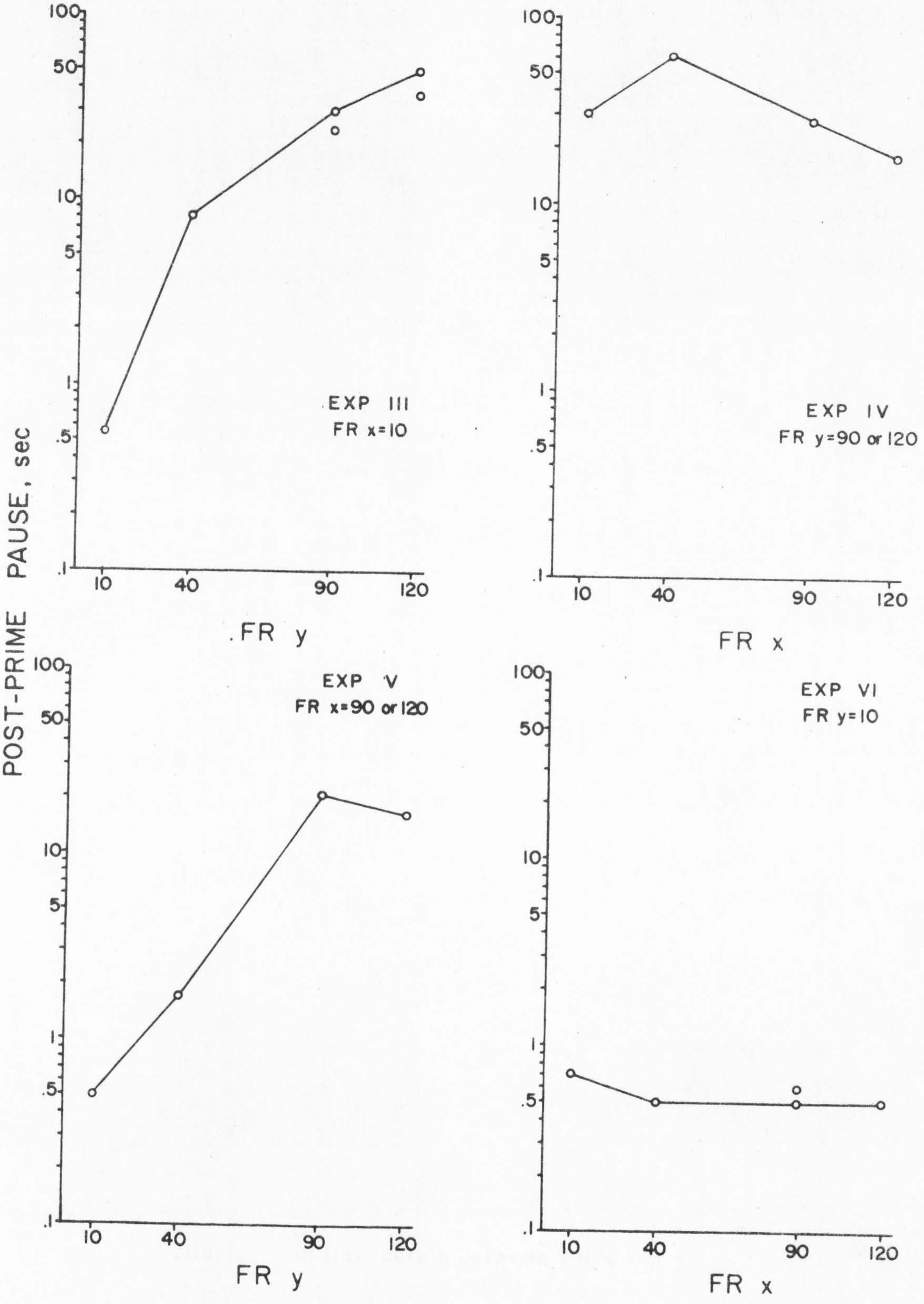
The Post-Prime Pause

A summary of the effects of either FR x or FR y on the post-prime pause is presented for the last four experiments in Figure 20. The data in Figure 20 are the means for all four subjects. In Experiments III and V, as FR y increased from 10 to 120, large increases in the length of the post-prime pause occurred. These large increases occurred independent of whether FR x was held constant at 10 responses or at 90 or 120 responses. However, the rate of this increase was greater in Experiment III with FR x = 10 than in Experiment V with FR x = 90 or 120.

As FR x increased, little systematic change in the length of the post-prime pause occurred with FR y = 10. A slight and inconsistent decrease did occur as FR x was varied with FR y = 90 or 120. Also, the absolute length of the post-prime pause was longer in Experiment IV with FR y = 90 or 120 than in Experiment VI with FR y = 10.

The slope obtained in Experiment III was greater than that obtained in Experiment V and the slight decrease in the post-prime pause as a function of FR x was obtained only when FR y = 90 or 120. These results represent an interaction between FR x and FR y. The effect of FR y on the length of the post-prime pause was determined by the size of FR x.

Figure 20. The mean post-prime pause length in Experiments III-VI as a function of either FR x or FR y. The size at which FR x or FR y was held constant is noted below the number of the experiment.


POST-PRIME PAUSE, sec
100
50
10
5
1
.5
.1
10
40
90
120
FR y
EXP III
FR x=10
EXP IV
FR y=90 or 120
FR x
EXP V
FR x=90 or 120
FR y
EXP VI
FR y=10
FR x

The Post-Reinforcement Pause

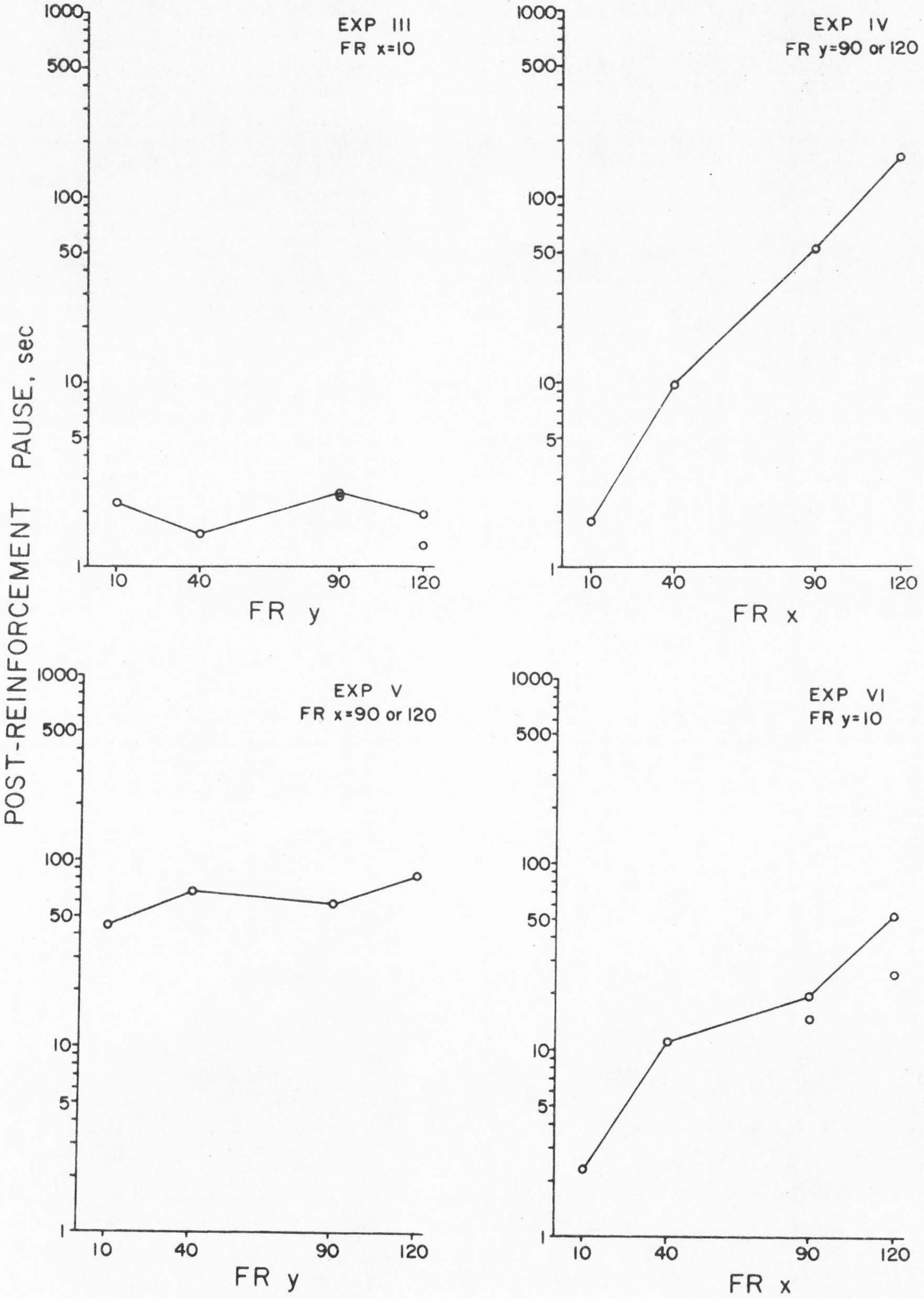
In each experiment, the lengths of the pre-FR x and the pre-chain FR x FR y pauses were presented separately. A similar relationship was observed between either FR x or FR y and both of these pauses. In addition, the absolute lengths of these pauses under the same conditions were extremely comparable. Therefore, to simplify the discussion of these results, the data for the two pauses have been combined and will be treated as a single pause. The mean length of this post-reinforcement pause is presented in Figure 21 as a function of either FR x or FR y.

As FR x increased from 10 to 120, large increases in the length of the post-reinforcement pauses occurred. These large increases were independent of whether FR y was held constant at 10 responses or at 90 or 120 responses. However, the rate of this increase was greater in Experiment IV when FR y was held constant at 90 or 120 responses than in Experiment VI when FR y = 10.

As FR y varied, the length of the post-reinforcement pause did not change with FR x = 10. However, a small but inconsistent increase in the post-reinforcement pause did occur as FR y was varied with FR x = 90 or 120. In addition, the absolute length of the post-reinforcement pause was longer with FR x held constant at 90 or 120 responses in Experiment V than in Experiment III where FR x = 10.

As was true for the post-prime pause, the post-reinforcement pause also reflects the effects of an interaction between FR x and FR y. The slope was greater when FR x was varied with FR y = 90 or 120 than with FR y = 10

Figure 21. The mean post-reinforcement pause-length in Experiments III-VI as a function of either FR x or FR y. The size at which FR x or FR y was held constant is noted below the number of the experiment.


POST-REINFORCEMENT PAUSE, sec
EXP III
FR x=10
FR y
EXP IV
FR y=90 or 120
FR x
EXP V
FR x=90 or 120
FR y
EXP VI
FR y=10
FR x
1000
500
100
50
10
5
1
10
40
90
120

and an increase in the post-reinforcement pause occurred as FR y was increased with FR x = 90 or 120. This increase did not occur when FR x was held constant at 10 responses. Thus, the effects of the size of FR x on the post-reinforcement pause depended on the size of FR y.

Discussion

The present series of experiments showed that a stimulus change in the large ratio of a mixed schedule controlled priming. With this control of priming, the definition of primes is simplified and priming becomes more amenable to further study. Using this procedure, the variables controlling the post-prime and the post-reinforcement pauses in mixed PR schedules were investigated.

Control of Primes

Acquisition of primes. The increase in control afforded by the mixed chained schedule was predicted to have two effects. First, acquisition of priming was expected to occur more rapidly than in a standard mixed FR FR schedule. Secondly, priming run length was expected to equal the response requirement of the small ratio with little or no variability present.

The results of Experiment I confirmed both predictions. Acquisition of primes was compared for both birds on a mix FR 10 FR 100 schedule and two birds on a mix FR 10 chain FR 10 FR 90 schedule. Acquisition was more rapid for both birds on the mixed chained schedule than for either bird on the standard mixed procedure. In addition, a higher percentage of primes occurred during acquisition on the mixed chained procedure.

Run length. In the initial sessions on the standard mixed procedure, no tendency for runs to consist of any particular length was evident. As acquisition progressed, a definite mode gradually developed. However, this mode occurred at 15 instead of 10 responses and considerable variability was evident. On the mixed chained schedule, priming runs of 10 responses rapidly developed.

These differences in run length obtained across birds in Experiment I were confirmed in Experiment II which permitted a within-subject comparison. Again, run length varied around a mode of approximately 15 responses in both the first and second exposure to the mix FR 10 FR 100 schedule for both subjects. A mode of 10 responses developed for both subjects on the mix FR 10 chain FR 10 FR 90 schedule. While priming was slightly more variable for bird K-9 on the mixed chained schedule, this variability might have disappeared had a minimum number of sessions been required in this experiment. Thus, the results do not differ substantially from those obtained across subjects in Experiment I. These results demonstrated the control exercised by the stimulus change in the mixed chained schedule. Thus, they supplement previous findings that added stimuli may control run length in other procedures (Hurwitz, 1963) or may increase efficiency (Ferster and Skinner, 1957).

The role of the stimulus change. It is clear from these results that the stimulus change in the mixed chained schedule controlled the length of the priming run. However, the priming run could be an artifact of the stimulus change rather than a function of the mixed schedule. Therefore, Experiment II also included control procedures to show that the behavior generated by the mixed chained schedule was priming.

The pause that terminated the priming run could have resulted from the stimulus change per se. Thus, the "prime" would have been independent of the

FR 10 Component. To examine this possibility, the chained FR 10 FR 90 component of the mixed chained schedule was programmed to occur in isolation, that is in the absence of the FR 10 component. Pauses sometimes follow the completion of each link in chained FR schedules (Ferster and Skinner, 1957; Findley, 1962; Thomas, 1964). However, the chained FR 10 FR 90 schedule did not produce many primes. Those few primes which did occur tended to precede rather than follow the stimulus change. This result confirms previous work which showed that the stimulus change in chained FR schedules was not necessarily followed by a pause (Crossman, 1969; Sheldon, 1971). Thus, primes in the *mix* FR 10 *chain* FR 10 FR 90 schedule were not a function of the stimulus change per se. The prime was not independent of the FR 10 component.

This result confirms the importance of the FR 10 in generating primes. But, it also suggests the possibility that the stimulus change independent of its location in the large ratio, may interact with the FR 10 to control primes. Thus, as a further check on the role played by the stimulus change in the *mix* FR 10 *chain* FR 10 FR 90 schedule, the location of the stimulus change was changed to 30 responses while the size of the small component was held constant at 10 responses. The schedule was a *mix* FR 10 *chain* FR 30 FR 70 schedule. Nevertheless, primes occurred around 13 responses where the stimulus change occurred, further substantiating the observation that the stimulus change and the prime coincided only when the stimulus change occurred after 10 responses, the response requirement of the smaller component. In fact, scheduling the stimulus change after 30 responses in the chained component produced the somewhat puzzling effect of a slight shift in the distribution of primes toward shorter runs rather than the longer runs which would be expected if the stimulus change had controlled priming. Only speculation is possible at this point, but this shift could simply represent an improvement in priming due to increased exposure to the mixed schedules. Although reinstatement of the *mix* FR 10 FR 100 schedule produced distributions similar to those previously obtained with this schedule, the locus of control in the intervening *mix* FR 10 *chain* FR 10 FR 90 schedule was the stimulus change rather than the pigeon's behavior. This intervening condition could have interfered with the control of priming by the behavior of the animal, resulting in a shift to longer priming runs.

The results of Experiment II thus indicate that primes were not controlled by the stimulus change per se nor by the stimulus change in the context of the mixed schedule independent of its location. Rather, the results suggest that primes in the mixed chained schedule, as in standard mixed schedules, were maintained by the intermittent occurrence of the FR 10. The stimulus change simply provided an additional cue which reduced variability.

The informative properties of the stimulus change. The role of the stimulus change in controlling primes can be analyzed in terms of the informative properties of the stimulus change. Egger and Miller (1962) have distinguished between stimuli which are not informative because the information provided by the stimulus is already available to the organism and those stimuli which are uninformative because of an unreliable relationship with environmental events.

In one experiment, Egger and Miller presented one stimulus, S_1 followed 0.5 sec later by another stimulus, S_2. Both of these stimuli were terminated simultaneously with the delivery of food. In later tests, only S_1 exhibited strong conditioned reinforcing properties; S_2 was a redundant stimulus and therefore did not have informative properties.

In a second experiment, Egger and Miller presented S_1 and S_2 periodically with S_1 presented twice as frequently as S_2. The combination of S_1 and S_2 always terminated with food while S_1 alone was never followed by food. Thus, S_2 was followed by food 100 % of the time while S_1 was followed by food only 50% of the time. In later tests, only S_2 had reinforcing properties. S_1 was an unreliable predictor of food deliveries.

While informative stimuli have traditionally been discussed in terms of the conditioned reinforcement resulting from a reduction in uncertainty (Egger and Miller, 1962; Hendry, 1969), no conditioned reinforcing function is currently intended. The information provided by the stimulus change in the present study did exert stimulus control over priming due to the informative properties of the stimulus change. The stimulus change was always a reliable predictor of the schedule in effect. The schedule after the stimulus change was always the large ratio. If the stimulus change had sometimes occurred in both the large and small components, then it would have been an unreliable predictor of the response requirement and probably would have exercised no control over priming.

In the <u>chain</u> FR 10 FR 90 schedule, the stimulus change was reliable but redundant. Since the small component never occurred, the information about the schedule in effect was already available and no primes occurred. In the *mix* FR 10 *chain* FR 30 FR 70 schedule, the information provided by the stimulus change was also redundant, although for different reasons. While both a large and a small component were present, the information about the schedule in effect was already available to the subject based on stimuli arising from its behavior since primes generally occurred at 15 responses if no stimulus change occurred. Since the information was already available after 15 responses, a stimulus change after 30 responses was redundant. However, the stimulus did exert some control over primes when it occurred after 20 responses. This could have resulted from the information provided by the stimulus being more reliable than that provided by the behavior of the organism.

Only in the *mix* FR 10 *chain* FR 10 FR 90 schedule was the information provided by the stimulus change both reliable and non-redundant. This schedule was also the only condition that resulted in the precise control of the priming run.

Pause Length

The post-reinforcement pause. Comparison of pause lengths which occurred in Experiment II indicates that the pauses which followed reinforcement in the *chain* FR 10 FR 90 schedule were considerably longer than the pauses after reinforcement on the mixed schedules. Such a difference was predicted by the "mean ratio hypothesis" advanced by Ferster and Skinner (1957). This hypothesis suggests that the post-reinforcement pause in mixed schedules will be a function of the mean of the component ratios rather than the actual sizes of the separate ratios. The mean of the ratios is obtained by weighing the size of the components by their frequency.

The actual function relating pause length to the mean ratio was left unspecified by Ferster and Skinner. Therefore, it is not clear whether the mean ratio hypothesis would predict that a mean ratio of 100 would produce pauses comparable to those which preceded an FR 100 schedule or whether pause length and the mean ratio should simply covary. The pauses on all of the mixed schedules in Experiment II were extremely short. A mean ratio of 82 (obtained by averaging an FR 10 with an FR 100 which was three times more frequent) was in effect in Experiment II. This mean ratio would be expected to produce considerably longer pauses if the mean ratio has an effect comparable to a fixed ratio of the same size. However, some kind of covarying relationship can not be ruled out based on the data in Experiment II. Therefore, the possibility of such a relationship was more systematically investigated in the remaining experiments.

There are two ways in which the mean ratio can be varied in mixed schedules. First, the component proportions can be varied. As the proportion of small components decreases, the mean ratio will increase. This approach was selected by Crossman and Silverman (1973) who varied the proportion of the FR 10s in a mixed FR 10 FR 100 schedule.

The approach followed in the present study consisted of varying the response requirement of either component. In one set of manipulations, the size of the second link of the chain (FR y) was varied while the small component and the first link of the chain were held constant. Thus, the size of the large component, which changes with FR y, varied while the size of the small component was held constant. In a second set of manipulations, FR x was varied while FR y was held constant. Thus, the size of the small component was varied. Because of the nature of the *mix* FR x *chain* FR x FR y schedule, the size of the large component also varied with FR x, since FR x specified the response requirement of the first link of the chain.

As FR x increased, so did the mean of the component ratios. Accompanying these increases were large increases in the post-reinforcement pause-length. The post-reinforcement pause increased with FR x, independent of whether FR y was held constant at high or low response requirements. This result is consistent with the mean ratio hypothesis.

As FR y increased, the mean of the component ratios again increased. However, in spite of these large increases in the mean ratio, the post-reinforcement pause did not consistently increase. Instead, little change in either post-reinforcement pause was evident with increases in FR y with FR x = 10. This effect was sufficiently small to require further research for confirmation. In contrast, there was a tendency for the post-reinforcement pause to increase slightly with increases in FR y with FR x = 90 or 120. However, the main effect of large values of FR x was to increase the variability.

In either case, these results are not consistent with the mean ratio hypothesis which would have predicted a consistent and large increase in pause length. Instead, post-reinforcement pause length primarily varied with the response requirement of the small component. As FR x increased, so did the post-reinforcement pause. When FR x was held constant and FR y was varied, the post- reinforcement pauses did not change consistently. Thus, the post-reinforcement pause in mixed FR schedules is primarily a function of the small ratio size rather than the size of the large ratio or of the mean of the ratios.

This explanation also fits nicely with the data obtained by Crossman and Silverman (1973). They varied the proportion of FR 100s to FR 10s in a mixed schedule from 99:1 to 1:1. They found that the post-reinforcement pauses could be separated into three distinct groups. The first group, long post-reinforcement pauses, extended from 99:1 to 19:1 and corresponded roughly to those proportions in which primes were infrequent. Intermediate post-reinforcement pause-lengths occurred from 15:1 to 9:1 during which primes were developing. At proportions of 7:1 to 1:1, primes were well established and the post-reinforcement pauses were short. Although the mean ratio hypothesis would predict a decrease in post-reinforcement pause-lengths, it is not clear why this decrease should occur in three stages or why it should correspond with changes in priming frequency.

The FR x hypothesis would predict no changes in the post-reinforcement pause as a function of component proportions provided that primes were well established. If the size of the small FR was held constant, pause length should not vary, in fact, that is what occurred in Crossman and Silverman's study when primes were well established. However, the post-reinforcement pause did vary indirectly with component proportions since the post-reinforcement pause was directly related to priming. Priming was related to component proportions. Similar results were obtained by Alferink and Crossman (in press).

The post-prime pause. The post-prime pause has generally been ignored in previous studies of priming. While the length of the pause has been used to define the termination of the priming run (Alferink and Crossman, in press; Crossman and Silverman, 1973), no studies have attempted to manipulate systematically the variables controlling its length. There are several reasons why the post-prime pause has not been studied.

The first difficulty in studying the post-prime pause is specifying where it begins and where it ends. All previous studies have relied on *post hoc* measurements obtained from cumulative response records. A possible solution to this would be to use a minimum IRT procedure such as was used in Experiments I and II. Thus, as soon as five sec has elapsed since the previous response, an IRT becomes the post-prime pause. However, this approach is not totally satisfactory because it places a restriction on the minimum length of the pause. Because of this, those variables which produce pauses shorter than this minimum length could not be studied. Even more serious, the number of responses required after the prime depends on the number of responses in the priming run. Thus, the precise variables which are candidates for study are not under the control of the experimenter but vary as a function of the behavior of the animal.

These problems are avoided with the mixed chained procedure. As was shown in Experiments I and II, the mixed chained schedule precisely controlled the length of the priming run giving the control of these response requirements to the experimenter. Thus, the definitional properties of the pause can be ignored. A prime can be defined as a run of x responses at the beginning of the larger component which leaves the pause after these responses free to vary.

Perhaps a terminological note is also appropriate here. Removal of the pause as a condition defining a prime makes the term "post-prime pause" applicable. When the pause was part of the prime, it was a contradiction in terms to speak of it as the "pause after the prime." However, when the prime is simply defined as x responses, this contradiction is avoided. Thus, the terms "prime" and "priming run" become synonymous in the mixed chained procedure.

This leaves the problem of what term to use for this pause in standard mixed schedules. One suggestion would be to call it the "pause after the priming run" or the "post-priming-run pause." Since this is somewhat unwieldy, it is suggested that the term "post-prime pause" be used as a shorthand version. Such shorthand conventions have previously proved useful in the development of scientific language. For example, while one actually reinforces the responses which terminate an IRT, it has become established practice to refer to this operation as "reinforcing an IRT" (Anger, 1956). With this convention understood, the term post-prime pause is accurate in a descriptive sense (but not necessarily in a functional sense) in that no ambiguity exists as to what event the term describes.

increased slightly for another and generated an inverted U-shaped function for the fourth. A slight increase did occur when these data were averaged for all four subjects. The major effect of changes in FR x on the post-prime pause was to increase the variability and the occurrence of ratio strain.

The post-prime pause varied as a function of FR y but little systematic relationship was obtained as FR x was varied with FR y held constant. This represents an interesting extension of the principle that pause length is a function of the response requirement after the pause (Findley, 1962). This relationship has never previously been investigated when a run of unreinforced responses preceded the pause.

Interactions of FR x and FR y. Although the post-prime pause did not vary as a function of FR x and the post-reinforcement pause was not a function of FR y, this does not rule out the possibility of an interaction between FR x and FR y with either or both pauses. In fact, there were two interactions present between FR x and FR y in Experiments III-VI. The post-prime pause was longer as FR y was varied with FR x = 10 than with FR x = 90 or 120. The post-reinforcement pause was longer as FR x was varied with FR y = 90 or 120 than with FR y = 10. In addition, the post-reinforcement pause increased as FR y was increased only when FR x = 90 or 120. None of these interactions were large but seems instead to place limits on the effects of the other variable on pause length. FR x limits the effect of FR y on the post-prime pause while FR y limits the effect of FR x on the post-reinforcement pauses.

The dampening effect of FR y on the post-reinforcement pause suggests that the total response requirement may have an effect on the post-reinforcement pauses. When both FR x and FR y were large, the post-reinforcement pauses were longer than when other values of FR x or FR y were used. However, the post-prime pause was slightly shorter under these conditions than with FR x = 10. This suggests that the lengthening of the post-reinforcement pause was "taken from" the post-prime pause and that the total pause length in mixed schedules is a closed system. Such a closed system would suggest that the sum of the post-reinforcement and the post-prime pauses would be a constant when the sum of FR x and FR y was held constant. Thus the sum of the pause lengths should be the same if FR x = 10 and FR y = 120 as it is if FR x = 120 and FR y = 10, for example. The extent to which such a "closed system" exists requires further research.

Chaining vs Response Units

Platt and Johnson (1971) have pointed out two possible explanations of counting behavior in FCN schedules.. The response unit account maintains that reinforced run lengths behave as a unit and subsequent runs tend to be of the same length. The chaining account maintains that the runs of responses in FCN schedules behave as a response chain. In this chaining account, fewer than the required number of responses would be discriminative for additional responses on operandum A, while more than the required responses would be discriminative for a response on operandum B. In the case of primes, the pause after the priming run would be analogous to an operandum B response in the chaining hypothesis.

Both Crossman and Silverman (1973) and Alferink and Crossman (in press) argued that primes were units of behavior. Runs of 10 responses in a mixed FR 10 FR 100 schedule were intermittently followed by food deliveries in both of these studies. The development of primes corresponded with the development of the FR 10 as a unit of behavior. In the present study, a relationship was found between the number of responses in a priming run and the length of the pause preceding this run. A second relationship was found between the length of the post-prime pause and the number of responses required after this pause. These relationships suggest the existence of two response units in mixed FR FR schedules.

On the other hand, the present study found these two units as a result of a chaining analysis of mixed schedule performance. In the present study, the stimuli postulated by Platt and Johnson (1971) to control the response on operandum B were made explicit by the experimenter. Upon encountering the stimulus change, the subjects paused. Thus, the chaining analysis also seems to be supported. The first link of this chain is the priming run while the second link is the run of responses after the prime.

Part of the problem results from the fact that the two accounts are not necessarily mutually exclusive. The response-unit account emphasizes the cohesive properties of behavior obtained with certain schedules of reinforcement. The chaining account emphasizes the control of behavior by stimulus changes, some of which may be response-produced. Both schedules and stimulus control are equally ubiquitous and may both operate simultaneously.

So it is with primes. The response-unit account explains why the animal primes. The prime develops as a unit maintained by the intermittent reinforcement which occurs following food delivery after the FR 10. The chaining account emphasizes how the subject manages to emit approximately the same number of responses each time. Completion of the priming unit provides an informative stimulus which signals that the schedule is FR 100 and the animal pause. In the presence of this stimulus, the animal emits the second unit.

Yet, there is one instance in which only a chaining account would be appropriate. The chaining account would be supported if a differential stimulus were required after each response in the priming run. In this case, the unit would be one response and an explanation in terms of response units would be trivial and incomplete. It is not sufficient to show that such differential stimuli occur but it must also be shown that they are necessary for priming. The present study suggests that this is not the case.

In addition, the mixed schedule provides for the separation of both of these units. Normally in chained FR FR schedules, the subject completes both links of the chain as a single unit. A pause does not occur between each link except under special circumstances (Sheldon, 1971). In the mixed chained schedule, the links of the chain are separated into two functional units. This separation may prove useful in the analysis of the behavior occurring within response chains.

Directions for Future Research

In addition to further research on whether or not pause lengths in mixed schedules represent closed systems, further research is necessary on the transfer of the stimulus control of priming from internal response-produced stimuli to external stimuli. In the present experiments, a stimulus change after 30 responses in the mixed schedule resulted in priming run distributions which were similar to those obtained without the stimulus change. A stimulus change after 10 responses resulted in primes of 10 responses instead of the primes of variable length controlled by response-produced stimuli. Further research is necessary to determine the point at which stimulus control transfers from response-produced stimuli to the exteroceptive stimulus change.

While several techniques are feasible to examine this problem, a titration technique appears particularly promising because of the within-session control exerted on the point of transfer. This titration procedure would consist of: (1) increasing FR x in the next chained component if a prime corresponded with or occurred after the stimulus change, (2) decreasing FR x if a prime occurred before the stimulus change, and (3) leaving FR x unchanged if no prime occurred. The response requirement of the small ratio and the total response requirement of the large ratio would be held constant. Using this procedure, it should be possible to identify the point of transfer with any small ratio size.

Summary

The present study investigated the effect of a stimulus change on primes in the large ratio of a mixed FR FR schedule. When the stimulus change occurred in the large ratio after the animal had completed the response requirement of the small ratio, the stimulus change resulted in more rapid acquisition of priming and better control of priming run length than a comparable mixed schedule without the stimulus change. This control by the stimulus change was shown to depend on the location of the stimulus change in the large ratio rather than the stimulus change per se. When the stimulus change occurred after 10 responses, the size of the small FR, primes consisted of 10 responses. When the stimulus change occurred after 30 responses with the size of the small FR held constant at 10 responses, the distribution of the number of responses in a prime approximated the distribution obtained without the stimulus change. Thus, shifting the location of the stimulus change from 30 to 10 responses shifted control from a response-produced stimuli to the exteroceptive stimulus change.

The control exerted by the stimulus change was used to investigate the variables which controlled the length of the post-prime pause. Technically, the schedule was a mixed FR x chained FR x FR y schedule. In two studies, the size of FR y was varied with FR x held constant at both high and low values. In two other studies, the size of FR x was varied with FR y held constant at both high and low values.

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Appendix

Table 7

Proportion of FR 100s (or chained FR 10 FR 90s) Containing Primes for Each Session

Session	Mixed FR 10 FR 100		Mixed FR 10 chained FR 10 FR 90	
	K-9	K-12	K-11	K-53
1	3/230	0/21	2/45	11/53
2	9/43	0/43	32/43	19/51
3	0/44	1/44	29/44	16/44
4	1/44	1/44	34/44	10/33
5	7/44	2/43	0/51	27/36
6	3/44	0/41	12/44	38/44
7	2/43	0/46	18/22	14/16
8	7/57	0/44	30/38	42/44
9	0/44	8/44	44/44	20/25
10	2/44	17/44	44/44	33/44
11	0/44	22/44	41/42	33/43
12	4/44	7/44	44/44	43/44
13	7/44	5/17	29/44	43/44
14	2/43	2/44	44/44	43/44
15	13/44	8/44	44/44	39/43
16	15/43	22/44	43/44	16/16
17	26/44	13/31	44/44	12/12
18	30/44	18/44	42/44	30/31
19	24/44	24/44		
20	2/44	27/44		
21	No data	17/31		
22	26/46	27/44		
23	No data	33/44		
24	22/43	34/44		
25	28/44	35/44		
26	28/43	42/44		
27	29/44	37/44		
28	24/43	11/14		
29	27/44	2/9		
30	35/44	36/44		
31	39/44	29/44		
32	41/45	34/45		
33	30/44	36/44		
34	40/52	13/14		
35	41/46	40/44		

Table 7 (Continued)

Session	Mixed FR 10 FR 100	Mixed FR 10 chained FR 10 FR 90
36	41/44	
37	33/37	
38	37/44	
39	23/41	
40	37/44	

Table 8

Median Pause Lengths from the Last Six Sessions for Subject K-8 as a Function of the Values of x and y for Experiments III-VI

x	y	Post-Prime Pause	Pre-Chain Pause	Pre-FR x Pause
			Experiment III	
10	120	33.7 sec	1.1 sec	1.1 sec
		29.8	1.1	1.1
		30.4	1.1	1.1
		25.5	1.1	1.0
		29.1	1.2	1.2
		31.7	1.1	1.1
10	10	0.7	1.1	1.2
		0.7	1.4	1.5
		0.6	1.5	1.6
		0.5	1.8	2.2
		0.6	2.0	2.0
		0.7	1.9	1.8
10	40	9.2	1.3	1.3
		9.0	1.4	1.4
		9.4	1.4	1.4
		10.2	1.5	1.4
		10.4	1.4	1.2
		8.9	1.4	1.5
10	120*	25.5	1.4	1.5
		45.3	1.3	1.3
		39.4	1.3	1.2
		37.2	1.3	1.3
		25.5	1.4	1.3
		47.2	1.2	1.2
			Experiment IV	
90	120	17.7	55.2	21.1
		14.7	85.6	85.2
		19.8	78.9	40.3
		24.1	98.9	45.2
		23.2	132.2	95.9
		15.2	137.7	247.4

Table 8 (Continued)

x	y	Post-Prime Pause	Pre-Chain Pause	Pre-FR x Pause
		Experiment IV (Continued)		
120	120	35.0 sec	698.2 sec	598.4 sec
		17.8	320.1	125.3
		13.4	276.4	501.0
		22.9	300.6	275.6
		18.4	183.2	210.1
		24.7	270.1	209.9
		Experiment V		
120	120	21.4	16.0	18.8
		17.5	141.3	146.0
		9.2	81.4	284.6
		9.5	34.6	140.7
		26.1	2.5	3.8
		14.0	58.4	419.6
120	90	6.4	--	59.6
		12.4	27.7	29.4
		16.2	16.7	54.3
		12.2	121.9	46.3
		12.7	31.2	215.1
		9.1	293.7	289.0
120	10*	0.7	45.0	60.7
		0.6	37.6	137.3
		0.6	31.2	20.5
		0.6	67.4	89.0
		0.6	28.3	30.7
		0.6	29.1	22.4
		Experiment VI		
90	10	0.7	13.8	17.3
		0.6	22.1	25.6
		0.6	25.4	29.7
		0.5	25.9	22.2
		0.6	22.5	24.6
		0.6	27.2	21.3

Table 8 (Continued)

x	y	Post-Prime Pause	Pre-Chain Pause	Pre-FR x Pause
		<u>Experiment VI (Continued)</u>		
10	10	0.9 sec	2.3 sec	1.9 sec
		0.5	2.7	1.9
		0.6	2.1	2.1
		0.4	2.9	4.5
		0.9	3.2	4.8
		0.4	1.9	2.2
120	10	0.6	20.6	22.1
		0.6	43.1	36.4
		0.6	33.2	37.1
		0.6	44.0	41.7
		0.6	35.7	27.0
		0.6	27.8	24.0

*Indicates that these values also served as the first value for the next experiment.

Table 9

Median Pause Lengths from the Last Six Sessions for Subject K-11 as a Function of the Values of x and y for Experiments III-VI

x	y	Post-Prime Pause	Pre-Chain Pause	Pre-FR x Pause
			Experiment III	
10	120	50.7 sec	1.6 sec	1.6 sec
		67.2	1.5	1.4
		79.6	1.7	1.7
		61.0	1.4	1.3
		68.1	1.5	1.2
		78.0	1.4	1.4
10	10	0.6	1.9	2.1
		0.5	1.8	1.8
		0.5	1.8	1.8
		0.5	1.9	2.6
		0.6	2.3	2.6
		0.6	3.7	2.2
10	40	3.4	2.0	2.1
		6.7	1.7	1.5
		8.7	1.5	1.6
		8.0	1.5	1.6
		5.7	1.5	1.7
		9.2	1.6	1.5
10	120*	24.7	1.6	1.5
		31.9	1.4	1.3
		37.3	1.3	1.5
		21.7	1.5	1.5
		55.9	1.4	1.4
		3.5	1.3	1.4
			Experiment IV	
40	120	96.2	13.1	11.9
		92.5	9.8	10.8
		119.0	10.4	10.6
		115.5	14.3	13.9
		125.3	16.9	13.0
		46.1	13.5	18.6

Table 9 (Continued)

x	y	Post-Prime Pause	Pre-Chain Pause	Pre-FR x Pause
		Experiment IV (Continued)		
120	120	16.4 sec	107.2 sec	131.0 sec
		22.7	83.7	48.4
		17.6	132.4	128.6
		20.4	4.9	15.5
		18.5	--	--
		14.6	85.3	93.0
		Experiment V		
120	120	19.2 sec	111.2 sec	111.6 sec
		2.92	210.3	93.4
		31.0	123.7	68.1
		30.8	70.8	112.1
		19.8	68.0	143.3
		18.7	59.3	56.5
120	40	1.3	156.5	142.8
		0.7	88.3	69.4
		0.7	108.8	114.8
		1.3	118.2	89.1
		1.1	115.8	137.7
		0.8	80.4	84.8
120	10*	0.4	114.9	69.7
		0.4	77.9	91.9
		0.5	74.9	140.5
		0.5	72.9	44.0
		0.5	72.8	57.0
		0.5	73.7	63.8
		Experiment VI		
40	10	0.4	13.8	14.2
		0.5	13.1	14.3
		0.5	17.9	20.5
		0.5	10.9	12.1
		0.5	6.7	11.1
		0.4	20.9	15.0

Table 9 (Continued)

x	y	Post-Prime Pause	Pre-Chain Pause	Pre-FR x Pause
		<u>Experiment VI (Continued)</u>		
10	10	0.5 sec	1.5 sec	1.4 sec
		0.6	1.6	1.5
		0.6	1.5	1.5
		0.8	1.5	1.5
		0.6	1.9	1.9
		0.4	1.9	1.6
120	10	0.4	57.9	47.7
		0.5	16.1	29.8
		0.4	32.4	24.2
		0.4	24.5	28.4
		0.4	16.9	18.2
		0.4	10.0	11.6

*Indicates that these values also served as the first value for the next experiment.

Table 10

Median Pause Lengths from the Last Six Sessions for Subject K-20 as a Function of the Values of x and y for Experiments III-VI

x	y	Post-Prime Pause	Pre-Chain Pause	Pre-FR x Pause
		Experiment III		
10	90	21.3 sec	2.1 sec	2.0 sec
		28.2	2.7	3.1
		31.7	2.8	2.5
		30.6	2.9	2.7
		34.6	3.5	3.4
		24.7	2.6	2.5
10	10	0.5	2.3	2.3
		0.4	2.7	2.5
		0.4	2.4	2.0
		0.5	3.0	3.3
		0.4	3.7	2.6
		0.5	3.4	2.5
10	90	35.8	2.4	2.4
		41.2	2.9	3.0
		38.8	3.3	3.4
		35.6	2.9	2.9
		39.7	3.1	3.3
		40.4	3.4	3.7
10	120	35.8	3.0	2.9
		50.7	3.1	3.7
		47.6	3.3	2.5
		23.5	3.0	3.7
		52.3	2.7	2.8
		46.7	2.4	3.0
		Experiment IV		
10	90	24.1	2.2	2.3
		17.2	2.2	1.9
		13.2	2.3	2.5
		12.6	2.1	2.5
		19.3	2.2	3.0
		19.7	2.6	2.6

Table 10 (Continued)

x	y	Post-Prime Pause	Pre-Chain Pause	Pre-FR x Pause
		Experiment IV (Continued)		
40	90	30.4 sec	7.6 sec	8.9 sec
		16.6	6.8	5.9
		20.7	7.1	6.3
		40.9	4.1	5.6
		28.1	5.8	5.2
		7.3	6.8	6.6
90	90	66.0	445.6	138.5
		41.0	50.5	120.9
		41.9	37.5	31.1
		41.2	46.7	16.2
		51.1	60.6	61.7
		77.0	31.0	234.4
		Experiment V		
90	90	76.7	52.4	60.9
		42.1	53.7	--
		19.7	36.0	20.1
		48.9	41.4	27.6
		48.3	25.9	33.1
		45.5	19.8	19.1
90	40	2.3	23.5	31.5
		1.3	26.2	22.1
		3.9	31.6	38.6
		3.6	32.9	22.8
		2.8	32.1	20.9
		1.1	28.7	23.7
90	10*	0.5	17.6	16.4
		0.6	34.2	12.8
		0.4	16.8	21.4
		0.6	21.6	20.5
		0.4	21.8	21.8
		0.6	26.2	32.6

Table 10 (Continued)

x	y	Post-Prime Pause	Pre-Chain Pause	Pre-FR x Pause
			Experiment VI	
40	10	0.6 sec	7.1 sec	7.6 sec
		0.6	10.7	10.0
		0.6	7.4	6.1
		0.6	7.5	9.2
		0.6	6.3	5.1
		0.6	8.6	8.4
10	10	0.7	1.8	2.1
		0.4	2.3	2.5
		0.7	2.4	2.3
		0.7	4.0	3.8
		0.7	3.7	4.8
		0.6	4.1	3.9
90	10	0.6	24.7	21.2
		0.7	7.6	6.8
		0.7	10.3	12.2
		0.7	11.1	20.5
		0.6	14.4	22.1
		0.6	11.7	11.7

*Indicates that these values also served as the first value for the next experiment.

Table 11

Median Pause Lengths from the Last Six Sessions for Subject K-53 as a Function of the Values of x and y for Experiments III-VI

x	y	Post-Prime Pause	Pre-Chain Pause	Pre-FR x Pause
		Experiment III		
10	90	11.7 sec	2.0 sec	2.0 sec
		17.6	1.9	1.9
		25.8	2.0	2.5
		17.6	1.9	2.1
		17.8	2.1	2.2
		15.7	2.4	2.7
10	10	0.6	2.1	2.0
		0.6	2.2	2.5
		0.4	2.4	2.2
		0.4	2.1	2.2
		0.6	2.2	2.2
		0.8	2.2	2.2
10	90	14.6	2.0	1.8
		18.6	2.0	1.9
		26.4	2.0	1.9
		20.7	2.0	1.9
		23.7	1.9	2.1
		17.0	2.1	2.1
10	120*	44.1	2.3	2.3
		29.3	1.8	1.8
		34.1	1.9	1.8
		40.2	1.8	2.1
		65.0	2.1	2.0
		17.5	2.4	2.3
		Experiment IV		
90	120	7.1	11.5	9.5
		14.7	15.1	7.5
		9.2	18.7	16.2
		9.0	32.9	25.9
		10.3	34.0	29.4
		12.1	41.6	31.1

Table 11 (Continued)

x	y	Post-Prime Pause	Pre-Chain Pause	Pre-FR x Pause
Experiment IV (Continued)				
120	120	7.9 sec	73.7 sec	66.0 sec
		10.0	53.0	28.0
		18.5	41.8	54.3
		16.2	55.9	46.5
		10.2	57.6	92.2
		13.6	16.7	81.3
Experiment V				
120	120	6.7	11.1	38.3
		8.6	28.8	15.1
		6.8	50.4	43.1
		8.1	112.8	17.5
		5.2	34.3	4.9
		6.2	23.2	28.0
120	90	5.0	47.0	36.4
		4.5	30.0	22.2
		5.6	53.1	40.0
		4.4	42.1	41.4
		6.1	35.0	27.7
		5.6	17.9	15.4
120	10*	0.5	22.6	16.2
		0.4	26.4	24.2
		0.4	30.6	21.4
		0.4	37.6	24.7
		0.4	35.2	47.0
		0.4	25.2	8.8
Experiment VI				
90	10	0.5	13.7	17.0
		0.7	11.3	10.0
		0.4	10.8	13.2
		0.6	15.1	12.4
		0.4	14.9	17.3
		0.4	17.5	16.1

Table 11 (Continued)

x	y	Post-Prime Pause	Pre-Chain Pause	Pre-FR x Pause
			Experiment VI (Continued)	
10	10	1.0 sec	2.0 sec	2.0 sec
		1.0	1.7	1.6
		1.1	1.7	1.8
		1.1	1.9	1.9
		1.0	1.9	1.8
		1.1	2.1	2.1
120	10	0.4	9.2	9.6
		0.4	16.7	8.5
		0.4	30.9	37.1
		0.4	10.2	15.5
		0.4	17.7	13.6
		0.4	22.1	18.8

*Indicates that these values also served as the first value for the next experiment.

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Doctor of Philosophy

Dissertation: Priming and the Post-Prime Pause

Major Field: Psychology

Biographical Information:

Birth:	May 26, 1948; Holland, Michigan
Name of Spouse:	Laura Rae
Children:	Kristine Jennifer

Education:

Degree	Institution	Dates Attended
B.A., 1970	Western Michigan University Kalamazoo, Michigan	1966-1970
M.S., 1973	Utah State University Logan, Utah	1970-1973

Honors:

University Scholarship, Western Michigan University, 1966-67
Board of Trustees Scholarship, Western Michigan University, 1969-1970
University Research Fellowship, Utah State University, 1972-74
University Summer Research Fellowship, Utah State University, 1974

Affiliations:

American Association for the Advancement of Science
American Association of University Professors

Teaching Experience:

1970-72	Utah State University, Teaching assistant in the Department of Psychology
1974	Drake University, Instructor in the Department of Psychology

Research Experience:

1970	Fort Custer State Home and the Department of Psychology, Western Michigan University, Laboratory Technician
Summer, 1972 and 1973	Utah State University, Psychology Animal Behavior Laboratory Manager

Applied Experience:

1973-74	Behavior Management Company, Behavior Management Consultant to the Utah School for the Deaf.

Other Relevant Experience:

1973-74	Member of the Executive Board of the Utah State Chapter of the AAUP

Papers and Publications:

Alferink, L. A. Fixed-ratio schedules and the protestant ethic. Paper presented in the Graduate Research Finals, Society of the Sigma Xi, Logan, Utah, 1972.

________ and Crossman, E. K. An experimental analysis of responding in the presence of free food. Paper presented at the Rocky Mountain Psychological Association, Albuquerque, May, 1972.

________ and Crossman, E. K. The effect of fixed-interval macroscheduling on mixed and multiple fixed-ratio schedules. Paper presented at the Utah Academy of Letters, Arts and Sciences, Salt Lake City, 1972.

________ Memory transfer in the digital computer. *The Worm Runner's Digest*, 1972, *14*, 56.

________ The fixed-interval presentation of a small fixed ratio. Thesis submitted to the Department of Psychology, Utah State University, Logan, Utah, 1973.

________, Crossman, E. K. and Cheney, C. D. Control of responding by a conditioned reinforcer in the presence of free food. *Animal Learning and Behavior*, 1973, *1*, 38-40.

________ and Crossman, E. K. Fixed-interval scheduling with large behavioral units. Paper presented at the Rocky Mountain Psychological Association, Las Vegas, May, 1973.

________ and Powers, R. B. Post-reinforcement pauses on two interval schedules using different topographies. Paper presented at the Rocky Mountain Psychological Association, Las Vegas, May, 1974.

Crossman, E. K., Heaps, R. S., Nunes, D. L. and ________ The effects of number of responses on pause length with temporal variables controlled. *Journal of the Experimental Analysis of Behavior*, 1974, *22*, 115-120.

________ and Crossman, E. K. A stimulus change produces fixed-ratio patterning in extinction. Paper presented at the Rocky Mountain Psychological Association, Denver, May, 1974.

________ and Crossman, E. K. Acquisition of priming in two types of mixed schedules. Paper presented at the Rocky Mountain Psychological Association, Denver, May, 1974.

________ and Crossman, E. K. A technique for gaining stimulus control of priming. Paper presented at the American Psychological Association, New Orleans, September, 1974.

________ and Crossman, E. K. Mixed fixed-ratio schedules: Priming and the pre-ratio pause. *The Psychological Record*, in press.