

THE CONTRIBUTION OF AN ADDED COUNTER TO A FIXED-RATIO SCHEDULE

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Although previous research showed that a visual counter increased the rate of responding on a large fixed-ratio schedule, a theoretical analysis of the factors responsible for fixed-ratio performance suggests that the primary control by number of responses since reinforcement is to weaken the performance. The present experiment employed a multiple schedule in which the same fixed-ratio value alternated with and without an added counter. It tested the hypothesis that the differential reinforcement of high-rate responding masked the attenuation of the fixed-ratio performance from the unoptimal discriminative control produced by the fixed relation between number of responses and reinforcement. In the present experiment the postreinforcement pause was consistently longer in the components with the added counter, while running rates remained comparable between the components of the multiple schedule. Both components of the multiple schedule involved differential reinforcement of high-rate responding while only the components with the added counter amplified the discriminative control by number of pecks since reinforcement.

Key words: added counter, fixed-ratio schedule, key peck, pigeons

Fixed-ratio (FR) schedules of reinforcement generate high rates of responding which give way, at large response requirements, to a post-reinforcement pause followed by an abrupt shift to a high running rate. The main effect of increased FR requirements has been to lengthen the pause following reinforcement (Felton & Lyon, 1966; Ferster & Skinner, 1957; Powell, 1968). Two important effects of increasing an FR schedule's response requirement are: (1) to lengthen the postreinforcement pause; and (2) produce increases in the running rates. Among the factors likely to account for these findings are: (1) the number of pecks since reinforcement as a discriminative stimulus (Alferink & Crossman, 1977; Crossman, Heaps, Nunes, & Alferink, 1974; Mechner, 1958; Mintz, Mourer, & Gofseyeff, 1967; Pliskoff & Goldiamond, 1966; Rilling, 1967; Rilling & McDiarmid, 1965); (2) number of pecks as a conditioned reinforcer (Ferster & Skinner, 1957, p. 40); (3) the differential reinforcement of high rates at the moment of reinforcement (Ferster & Skinner, 1957, p. 459; Powers, 1968); (4) the increase in the rate of reinforcement that occurs collateral to increase in rate of responding (Neuringer &

Schneider, 1968); (5) the completion of food delivery and ingestion as stimuli negatively correlated with the next available reinforcer (Ferster, 1953; Rilling, 1968).

This experiment concerns what we consider to be the most plausible of these accounts of performances generated by FR schedules—control by number of pecks since reinforcement. In particular, we believe the fixed relation between responses and reinforcement is the major factor contributing to the long pauses that develop on large values of FR schedules. Their importance is suggested by experiments which equate responses per reinforcement on different types of schedules. For example, the transition from a large variable-ratio (VR) schedule to an FR of the same value results in rates of responding which are considerably lower than those occurring on the VR schedule (Ferster & Skinner, 1957, pp. 407-410). The results reported for conjunctive fixed-interval, fixed-ratio (FI FR) schedules bear out the same conclusion (Barrett, 1975; Herrnstein & Morse, 1958). When a large conjunctive FR requirement is added to an FI schedule, long pausing beyond the FI interval develops even though the conjunctive FR requirement is less than the average number of responses that would have occurred.

These studies suggest that number of responses since reinforcement is a discriminable

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stimulus controlling, in turn, the frequency of pecking (Ferster & Skinner, 1957; Mechner, 1958; Pliskoff & Goldiamond, 1966; Rilling, 1968; Rilling & McDiarmid, 1965). The "zero count" just after reinforcement, coupled with eating, is negatively correlated with the stimuli present when the final peck of the FR schedule operates the food magazine. According to this formulation one would expect that control by number of pecks would weaken the maintenance of the performance by increasing the length of the postreinforcement pause.

In terms of the argument advanced above, adding a visual stimulus on the key, which changes with number of pecks in the FR segment, would presumably accentuate control by number of responses since reinforcement. The heightened discriminative control by the added counter would weaken the FR performance particularly just after reinforcement when it is at the least optimal size. Yet, the experiments by Ferster and Skinner (1957, pp. 89-109) showed, with minor exceptions, that the added counter *increased* the overall rates of responding on large FR's (Ferster & Skinner, 1957, pp. 105-107). In fact, running rates were higher and postreinforcement pauses were shorter than would normally be expected with those magnitudes of FR values. Thus, there is a discrepancy between the results of those added-counter experiments and what might be expected from the aforementioned theoretical account of how control by number of responses since reinforcement should weaken an FR performance.

To resolve this discrepancy, the present experiment utilizes a multiple schedule, one component of which is an FR schedule supplemented by an added counter and the other the same value of FR without it. The performance in both components would be affected by the reinforcement of high-rate responding inherent in FR reinforcement schedules, while only the one component would be subject to the closer discriminative control by the visual added counter than normally occurs with the bird's own behavior as the controlling stimulus. The experiment tests the hypothesis that number of responses is a discriminative stimulus that weakens the performance on fixed-ratio schedules and that its influence may be masked by the concomitant differential reinforcement of high-rate responding that also occurs.

METHOD

Subjects

Two adult male Silver King pigeons, maintained at approximately 80% of their free-feeding weights, served. Subject P2 had an extensive history on a multiple FI FR schedule, and Subject P1 had an extensive history on chained FR schedules. Subjects were housed in a continuously lighted area with free access to water and health grit. The total daily ration of food was delivered during experimental sessions.

Apparatus

The experiments were carried out in a standard pigeon chamber, as described by Ferster (1953), equipped with an exhaust fan and continuous water supply. The added counter was a slit, $\frac{1}{8}$ inch wide and $1\frac{1}{8}$ inch high, behind a standard pigeon key that allowed a fixed amount of light to be projected on the key from a white light bulb mounted behind. The size of the slit grew from its smallest width, which was $\frac{1}{8}$ inch at the start of the ratio, to its maximum length of $1\frac{1}{8}$ inches after the FR requirement had been met.

The added counter consisted of incremental steps in the size of a keylight slit, produced by a rotating disc located between the key and the light source and driven by a stepping motor (cyclonome) which occluded the slit. The stepping motor was capable of over 30 operations per sec. A relay mounted in the chamber provided a brief click each time the bird pecked the lighted key. In order to change the size of the FR requirement, there were several sized gears linking the stepping motor to the rotating disc.

The rate of growth of the slit with pecks was determined by altering the radius of the disc as a function of the angle of rotation. Thus, as the stepping motor operated, the disc occluded progressively less of the slit.

Reinforcement during components of the multiple schedule without the added counter was programmed by a Sodeco predetermined counter. Reset of the added counter to its initial size occurred during the magazine cycle, taking less than .25 sec. The delivery of food was linked mechanically to a switch on the added counter to insure that the slit was al-

Table 1
Summary of Experimental Procedures

No. of sessions	Schedule	Stationary slit position
PIGEON P1		
3	multiple	small
2	multiple	large
3	multiple	small
4	multiple	large
10	multiple	small
2	added counter only	
2	multiple	small
2	multiple	large
2	multiple	small
2	multiple	large
1	added counter only	
1	multiple	large
6	added counter only	
1	multiple	large
1	multiple	small
PIGEON P2		
4	multiple	small
7	multiple	large
7	multiple	small
1	added counter only	
1	multiple	small
2	added counter only	
1	multiple	small
1	added counter only	
1	multiple	large
2	added counter only	
1	multiple	small
2	multiple	large

ways at its largest aperture when reinforcement occurred. Data were recorded on a Gerbrands cumulative recorder and a Sodeco counter which printed out interreinforcement times in seconds.

Procedure

The experimental procedure consisted of a multiple schedule in which the same FR schedule alternated with and without the added counter. The light behind the key was steady when the added counter was operating and flashing at one cycle per sec when the added stimulus was not operating. When the added stimulus was not operating, the slit was fixed at either its smallest or largest size. Experimental sessions were terminated after 60 reinforcements or, when extreme pausing prevailed, 7 to 8 hours for P1 (run during the day) and 13 hours for P2 (run at night). To determine the interaction of the added counter with the alternating component of the multiple schedule, blocks of sessions were

programmed in which the component without the added counter was omitted. Table 1 describes the order of the experimental procedures and the number of sessions that each were maintained.

Because of the previous history of FR reinforcement, it was possible to put both birds on the experimental procedure without transitional schedules. Approximately 30 sessions were required to develop the baseline performances. These data are not reported.

RESULTS

Figure 1 shows the main result for P1 on the multiple schedule with the slit remaining large in the component without the added counter. The performance in the component without the added counter is shown in Record A, and the alternating components when the counter grew from small to large are shown in Record B. Although running rates of pecking tend to be higher for brief periods with one schedule or the other, these differences are not as pronounced as the amount of pausing at the beginning of the ratio and, consequently, the amount of time taken to finish the ratio.

The magnitude of the difference between components with and without the added counter is large, with the former requiring much more time to complete. Of the 28 pairs of components with and without the counter, there were no cases where the time to complete the FR requirement was longer without the added counter than with it ($p < .0001$, sign test).

The performance for P2 shown in Figure 2 shows even more extreme separation between the components with and without added counter than that occurring with P1. Without the added counter there is virtually no pausing after reinforcement. In 20 instances of this component, there were no cases where its accompanying component with the added counter required more time to complete ($p < .0001$, sign test).

When the slit remained small in the component of the multiple schedule without the added counter, the performances of the two subjects diverged. The overall rate for P1 was considerably higher than that for P2, and there was little or no difference in the amount of pausing in the two components of the multiple schedule. However, P2 continued to show

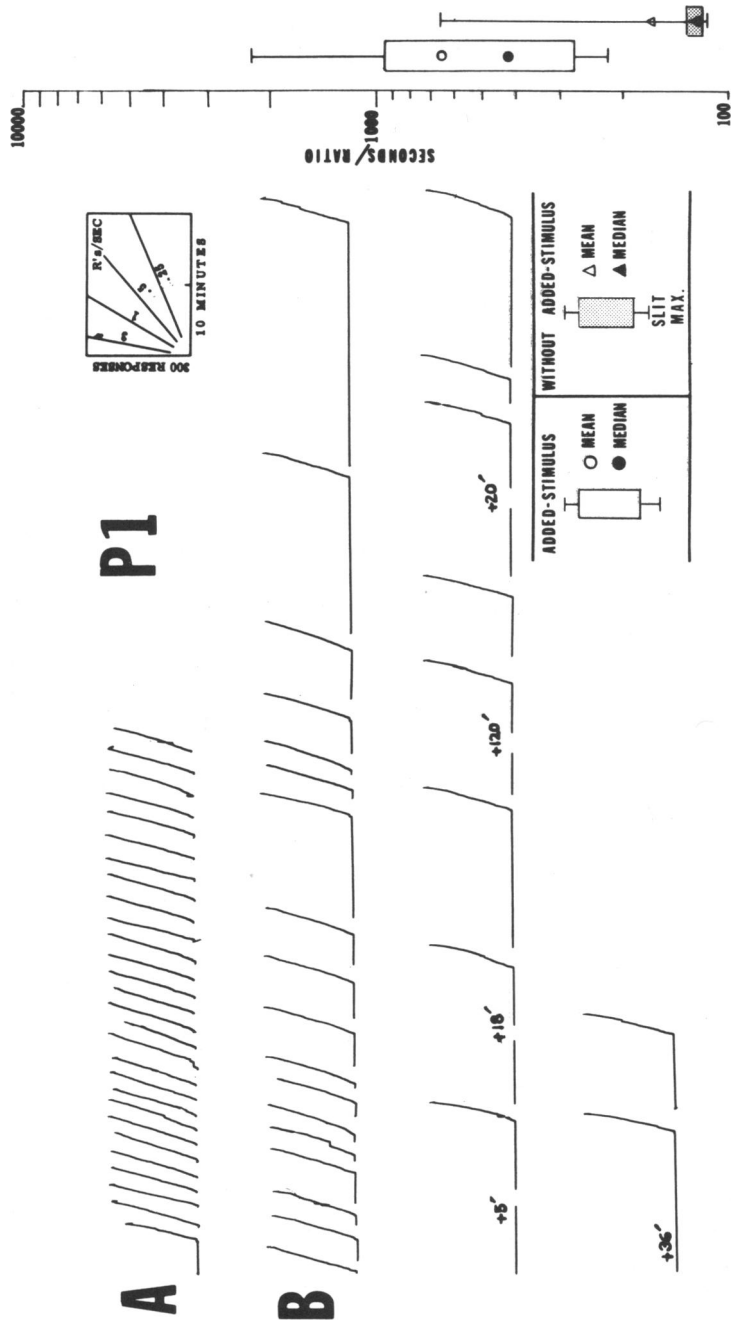


Fig. 1. Cumulative records for P1 of an entire session of the multiple schedule in which the FR 220 performances alternated with and without added counter. Record A contains the segments recorded without added counter with the slit fixed at large; Record B, with the added counter operating. Although the segments are aggregated in the figure, they occurred alternately during the experimental sessions. The graph at the right of the figure, presenting mean, median, interquartile ranges, and range of interreinforcement times, summarizes the session. The segments with long pauses are collapsed by cutting out a portion of the pause after reinforcement. The time omitted is indicated by the numeral over the break.

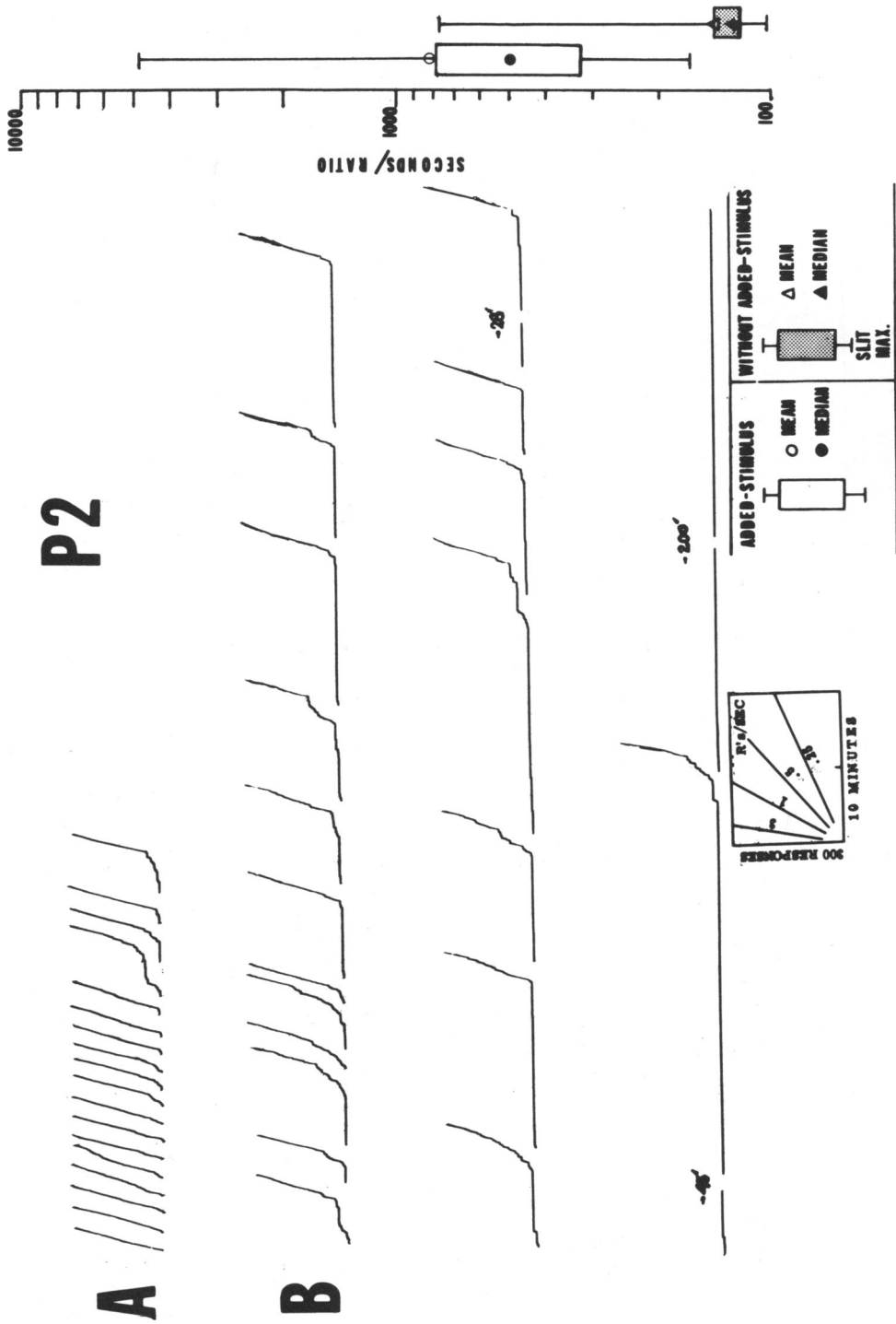


Fig. 2. Cumulative records for P2 of an entire session of the multiple schedule in which the FR 220 performance alternated with and without the added counter. Record A contains the segments recorded without added counter with the slit fixed at large; Record B, with the added counter operating. Although the segments are aggregated in the figure, they occurred alternately during the experimental sessions. The graph at the right of the figure, presenting mean, median, interquartile range, and range of interreinforcement times, summarizes the session. The segments with long pauses are collapsed by cutting out a portion of the pause after reinforcement. The time omitted is indicated by the numeral over the break.

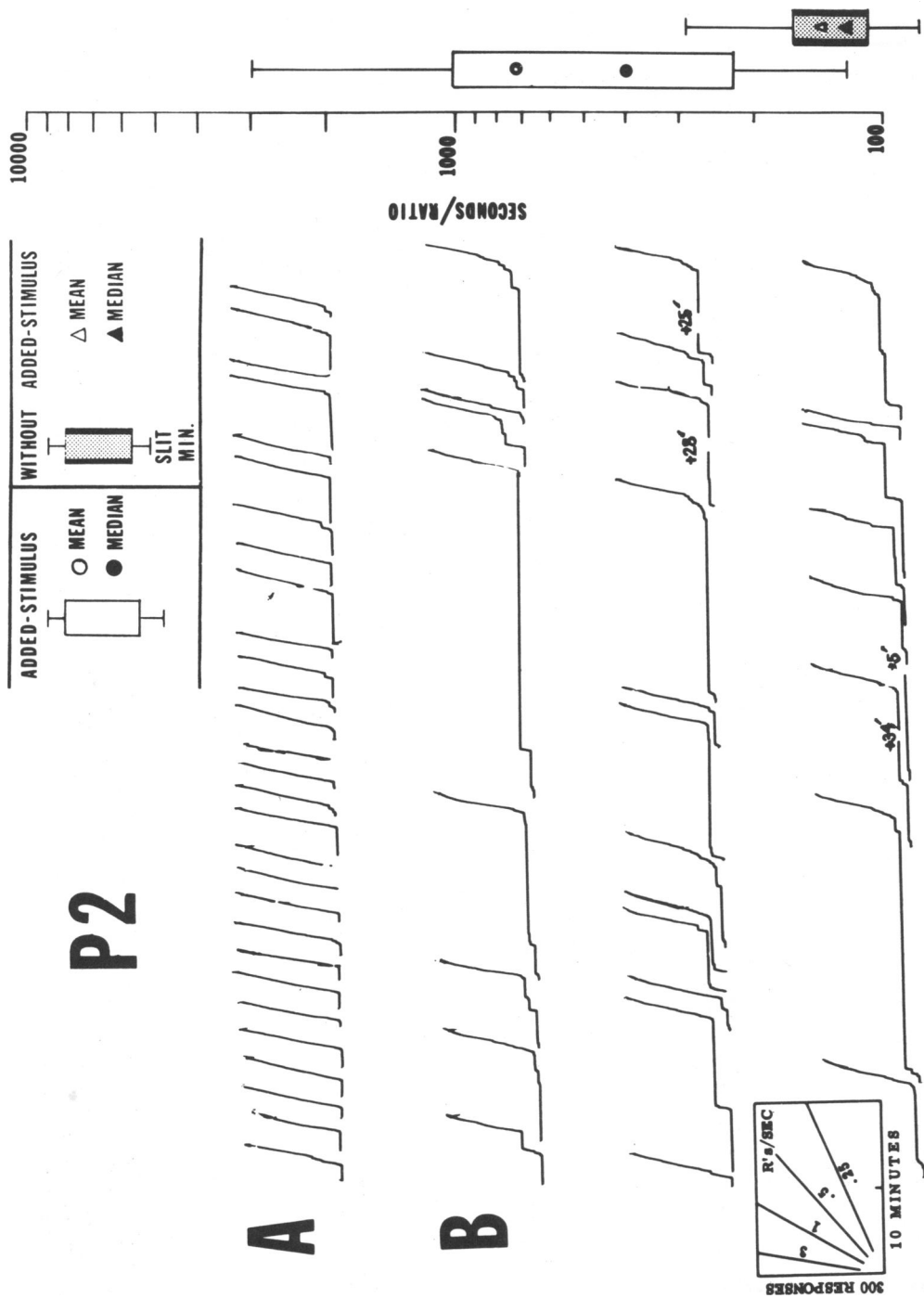


Fig. 3. Cumulative records for P2 of an entire session of the multiple schedule in which the FR 220 performance alternated with and without the added counter. Record A contains the segments recorded without added counter with the slit fixed at small; Record B, with the added counter operating. Although the segments are aggregated in the figure, they occurred alternately during the experimental sessions. The graph at the right of the figure, presenting mean, median, interquartile range, and range of interreinforcement times, summarizes the session. The segments with long pauses are collapsed by cutting out a portion of the pause after reinforcement. The time omitted is indicated by the numeral over the break.

P1

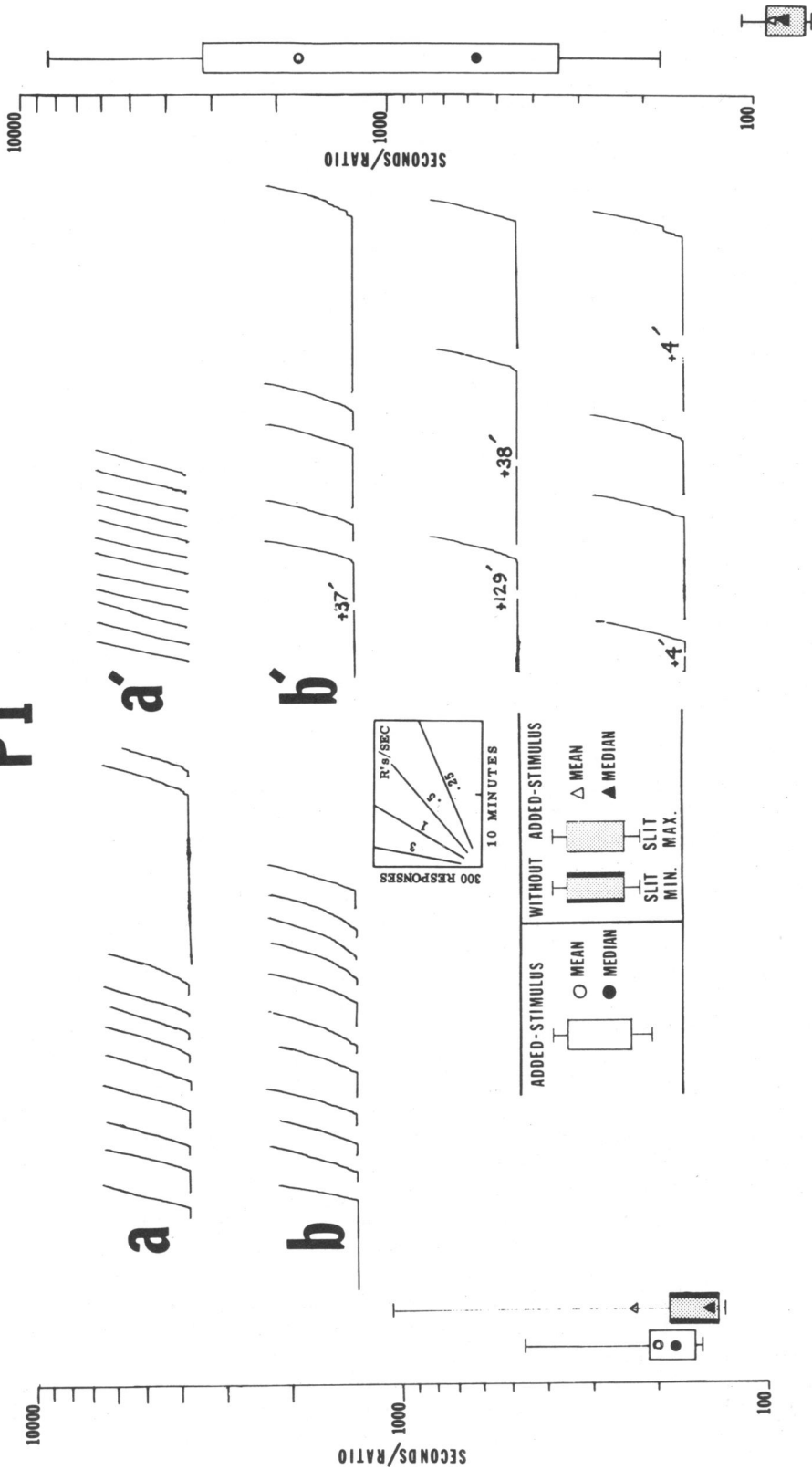


Fig. 4. Cumulative record of an entire experimental session for P1 showing a transition from the small size of the added counter during the component of the multiple schedule without added counter (left portion, Records a and b) to the large size (right portion, Records a' and b'). The graphs at the left side of the figure present the mean, median, interquartile range, and range of the interresponse times for the first part of the session and the graph at the right side those for the second half of the session.

a large separation of interreinforcement times between the components with and without the added counter. Figure 3 shows cumulative records for P2 for an entire session, during which there was virtually no pausing in the component of the multiple schedule without the added counter (Record A). With the added counter (Record B), however, pausing reached very long durations. In 35 pairs of components with and without the added counter, no cases occurred where the time to complete the FR was longer in components without the added counter than with it ($p < .0001$, sign test).

A performance for P1, more typical than the ones in the preceding figure, is shown in the left portion of Figure 4. There is considerable overlap between the two components of the multiple schedule. Of the 11 pairs of components with and without the added counter, there were only four cases where the time to complete the ratio requirement was longer in components without the added counter than with it (N.S., sign test). The right portion of the same figure shows the transition, during the same session, to the procedure with the slit large during components of the multiple schedule without added counter. The larger differences between the two components of the multiple schedule were reinstated immediately, with no overlaps between the time required to complete the respective components. Of the 12 pairs of components with and without added counter, no cases occurred wherein the time to complete the FR was longer in components without the added counter.

Unlike P2, P1 responded consistently regardless of whether the slit was fixed small or fixed large. The cumulative record for P1 of an entire daily session is shown in Figure 5. There is a slight increase in pausing at the start of segments without added counter, but not nearly so much as occurred when the added counter was operating. Of the 28 pairs of performance with and without the added counter, there was only one case where the time to complete the number requirement was longer without the added counter than with it ($p < .001$, sign test).

Figure 6 compares the three main conditions of the experiment in summary form: (a) the multiple schedule with the slit small during the stationary component; (b) the multiple

schedule with the slit large during the stationary component; and (c) the added counter without the interaction from the alternating stationary component. The first panel, summarizing 21 sessions for P1 when the slit was small without the added counter, shows large overlap between the components of the multiple schedule. Of the 621 pairs of components with and without added counter, there were 294 cases where the time to complete the FR was longer without the added counter than with it ($p < .10$, sign test). The comparable result for P2, the overall distribution of 14 sessions, shows considerable separation between the two components of the multiple schedule. Overall, there is less overlap between the two distributions. Of the 411 pairs of components with and without the added counter, only 107 cases occurred where the time to complete the FR was longer in components without the added counter than with it ($p < .001$, sign test).

The second bar of Figure 6 summarizes 10 sessions for P1 and 12 sessions for P2 when the slit was large during the stationary component of the multiple schedule. The time to complete the FR requirement was consistently longer with the added counter than without it for both birds. Of the 441 pairs of components with and without added counter for P1, there were only 31 cases where the time to complete the FR was longer without the added counter than with it ($p < .0001$, sign test). For the 175 pairs of components with and without added counter for P2, only 24 cases occurred where the time to complete the FR was longer without the added counter than with it.

The third bar of Figure 6, summarizing nine sessions for P1 and six sessions for P2, shows the results when the added counter was programmed without the alternating stationary component. The length of the pause is intermediate to that occurring when the stationary component was also arranged: shorter than when the slit size was small during the stationary component and longer than when the slit size was large.

Although the differences between the components of the multiple schedule with and without added counter over all of the conditions were not large, they were significantly different, $p < .01$ for P1; ($p < .001$ for P2, Kruskal-Wallis test).

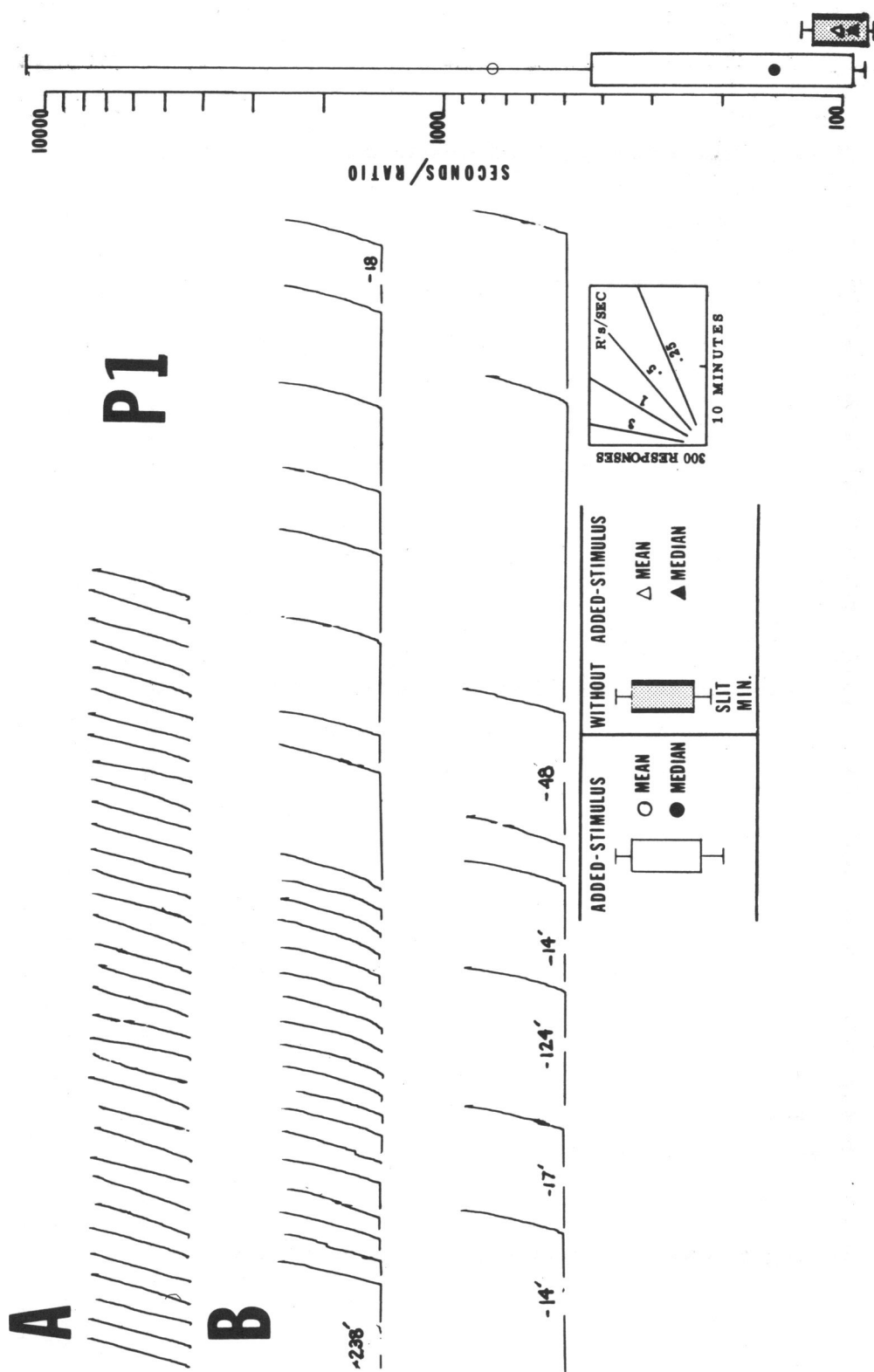


Fig. 5. Cumulative records for P1 of an entire session of the multiple schedule in which the FR 220 performances alternated with and without added counter. Record A contains the segments recorded without added counter with the slit fixed at small; Record B with the added counter operating. Although the segments are aggregated in the figure, they occurred alternated during the session. The graph at the right of the figure, presenting mean, median, interquartile range, and range of interreinforcement times, summarizes the session.

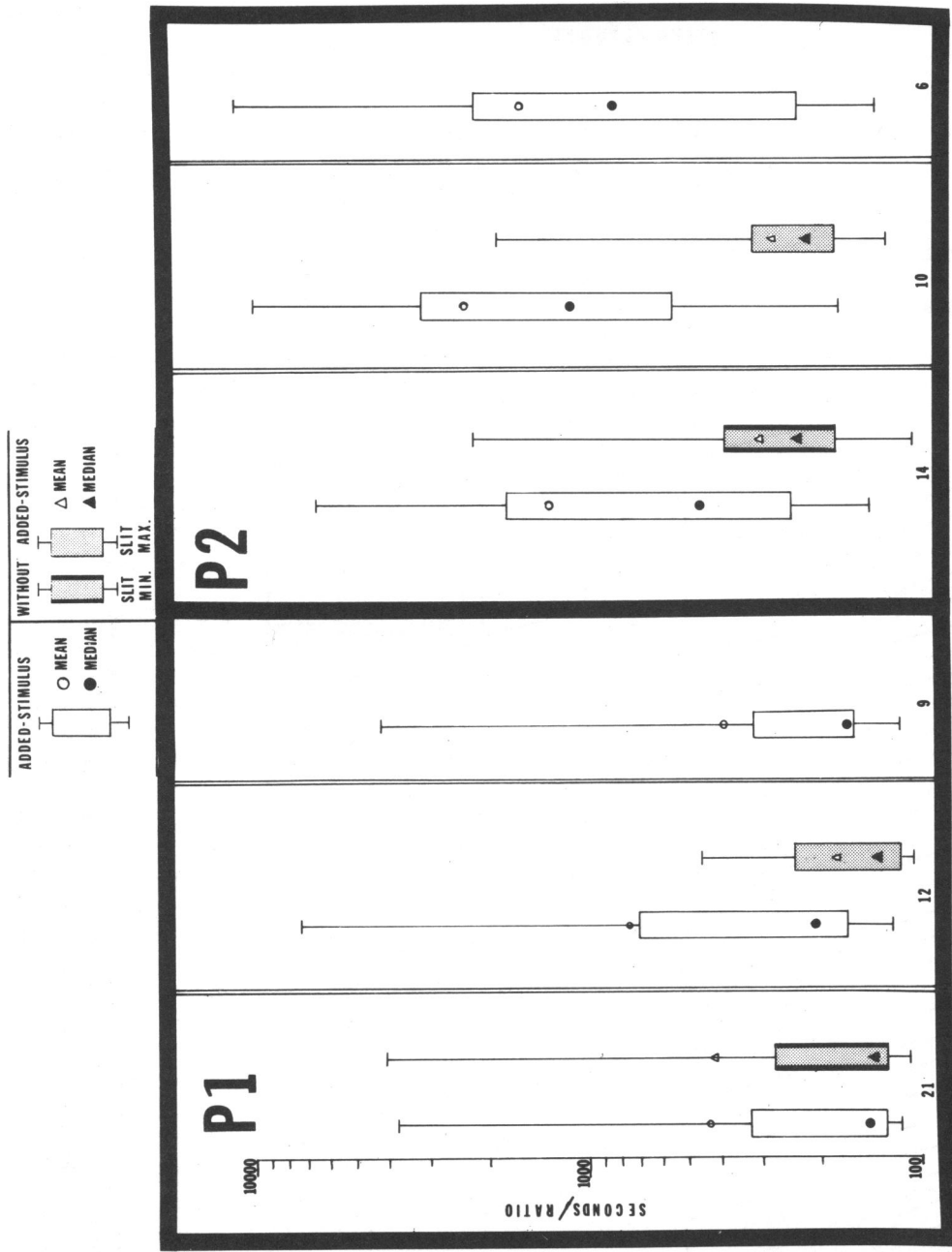


Fig. 6. A comparison of the main conditions of the experiment. The first panel summarizes all of the sessions where the slit was small in the fixed component. The second panel summarizes the sessions where the slit was large in the fixed component. The third panel summarizes those sessions where the added counter was programmed without the alternating schedule with the slit stationary. The total number of sessions is given by the numeral at the bottom of each panel. The mean and median are indicated by the unfilled and filled triangles when the slit was stationary and by the filled and unfilled circles when the added counter was operating. The bar indicates the interquartile range and the extended lines the range.

DISCUSSION

The main finding of this experiment is the lengthening of the interreinforcement time by the visual added counter as compared with the same FR response requirement without it. The added counter appears to weaken FR performance because of its discriminative effects. The main difference between the control by the visual added counter and the bird's own behavior as a controlling stimulus is the imprecision of the latter compared with the former. The imprecise control by the bird's own behavior as a discriminative stimulus, compared with that of the visual added counter, is parallel to the change in performance that occurs during the transition from FR to VR and vice versa. The VR schedule represents the extreme case where the discriminative control by count cannot operate at all (Ferster & Skinner, 1957). Intermediate stages of the same process are evident in the control of behavior by a conjunctive FI FR schedule (Herrnstein & Morse, 1958). In that experiment the progressive increase in the size of the FR requirement led to increases in interreinforcement times. The addition of conjunctive FR requirement of 180 and 240 responses led to interreinforcement times far longer than the FI 15-min component even though the birds had been emitting more than enough pecks, on the average, to meet this requirement during the previous exposure to the FI schedule without the conjunctive FR requirement. Simply fixing the relation between number of pecks and reinforcement appears a sufficient basis for increasing interreinforcement times. An experiment similar to that of Herrnstein and Morse but with smaller FR requirements was carried out by Barrett (1975), who reported that a conjunctive FR requirement of 50 or 100 produced lower overall rates of responding than occurred on a simple FI schedule.

The interaction between the components of the multiple schedule (similar to the transitions reported by Ferster and Skinner, 1957, pp. 89-107) is also evidence of the discriminative control by the count.

The position of the slit during the component without added counter influenced the amount of pausing that occurred when the added counter was operating, increasing it when it was large and decreasing it when it

was small. Such interactions were consistent with the added counter's control by number as a discriminative stimulus. Thus, the weak maintenance of the behavior by the added counter at its smallest size would be opposed by the probability of reinforcement at the small slit size during the alternating components without added counter where reinforcement occurred at the small size. Conversely, the small size of the slit during the component without the added stimulus would lessen the likelihood of pecking at the start of the ratio in the other component of the multiple schedule when the added counter was operating. This is because of the small slit's unoptimal function in the component with the added counter where small slit size controlled a low frequency of pecking discriminatively. These two processes would operate to reduce the differences between the amount of pausing in the two components of the multiple schedule.

The foregoing analysis can account for the difference between P1 and P2 with the slit small during the component without added counter. There is evidence in the data for P1 of considerably more interaction between the two components despite the correlation of the unit schedules with the flashing and steady key lights. In general, the small slit size increased the amount of pausing that occurred without the added counter and decreased the amount of pausing with it. Perhaps one of the reasons for the differences between the birds was that P1 had a more extensive history on FR schedules than P2. Yet, both birds confirmed the general process, even with the slit small. P1 showed occasional sessions where there was a clear separation between the components with and without the added counter (see Figure 1), and P2 showed a large magnitude of separation even though it was slightly less than had occurred when the slit was fixed at large. Although the interactions between the two components provided useful information in the present experiment, there would be an advantage, in future experiments, of avoiding it by programming the multiple schedule on two keys. In that case the stimulus on the stationary key could have a totally different dimension such as a color.

The discrepancy between the effects of an added counter reported by Ferster and Skinner (1957), showing enhancement of the FR performance, and those of the present experi-

ment requires further comment. At first glance, the findings appear to be contradictory. The discrepancy can be resolved, however, by taking into account the several factors that determine rate of responding on FR schedules, particularly the differential reinforcement of high-rate responding and the unoptimal value of number just after reinforcement. In the earlier results the FR performance was influenced simultaneously by the differential reinforcement of high-rate topographies and the discriminative control by the added counter. Furthermore, the added counter contributed to the differential reinforcement of high rates because of the fine-grain relation between pecking and the growth of the slit on the key. High-rate responding, particularly in the form of bursts of responses, produced a discriminable increase in the size of the slit. These bursts were especially visible because the added counter had an exponential growth pattern: it grew more rapidly at the end of the ratio requirement than at the start. Ferster and Skinner's (1957, pp. 110-112) block-counter experiments provide evidence that the growth of the counter, independent of its relation to reinforcement, shapes high-rate topographies.

The present experiment, employing a multiple schedule, provided a way to separate the control by these two factors. Once high-rate responding was differentially reinforced, it would occur in both components of the multiple schedule. Only the component with the added counter, however, would be influenced by the unoptimal value of the slit size just after reinforcement. It seems reasonable to conclude, therefore, that the reinforcement of high rates in the earlier experiments masked the discriminative control by the added counter.

The issue addressed by this experiment appears general to the control by most schedules of reinforcement. It concerns why there is so much disparity in the amount of behavior that can be sustained at a given reinforcement frequency. In a similar manner, the ability of conditioned reinforcers to increase the rate of performances producing them is enhanced by a reduction in their clarity with respect to reinforcement (Kendall, 1975).

The large amounts of behavior maintained by second-order schedules compared with equivalent simple ones provides further evidence for this view (Findley & Brady, 1965; Kelleher, 1966a, 1966b; Shull, Guilkey, &

Witty, 1972; Thomas & Stubbs, 1967). Experiments introducing ambiguity in second-order schedules of reinforcement by manipulations of the conditioned reinforcers also show higher overall levels of responding than occurs on a simple second-order schedule (Byrd & Marr, 1969; Rose & Fantino, 1978; Squires, Norburg, & Fantino, 1975; Webbe & Malagodi, 1978; Zimmerman & Hanford, 1966). These experiments support the hypothesis suggested by the added-counter experiments that more responding will be maintained by a schedule if the stimuli present at the moment of reinforcement are similar to those present during the time between reinforcers.

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