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WITHIN-SESSION CHANGES IN RESPONDING DURING CONCURRENT VARIABLE-INTERVAL SCHEDULES

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Five rats and 4 pigeons responded for food delivered by several concurrent variable-interval schedules. The sum of the rates of reinforcement programmed for the two components varied from 15 to 480 reinforcers per hour in different conditions. Rates of responding usually changed within the experimental session in a similar manner for the two components of each concurrent schedule. The within-session changes were similar to previously reported changes during simple schedules that provided rates of reinforcement equal to the sum of all reinforcers obtained from the concurrent schedules. The number of changeovers also changed within sessions in a manner similar to the changes in instrumental responding. These results suggest that changeovers are governed by the same variables that govern instrumental responding. They also suggest that the within-session change in responding during each component of a concurrent schedule is determined by approximately the sum of the reinforcers obtained from both components when both components provide the same type of reinforcer.

Key words: within-session patterns, concurrent schedule, changeovers, key peck, lever press, rats, pigeons

Rate of responding often changes systematically within experimental sessions when subjects respond on operant conditioning procedures (e.g., McSweeney, 1992). These within-session changes deserve study because they are often large and orderly, and they occur for many species of subjects responding on many procedures (e.g., McSweeney & Roll, 1993). The implications of within-session changes in responding for other areas of operant research and theory particularly deserve study. The present experiments investigated the implications of within-session changes for quantitative theories of operant behavior.

Within-session changes in response rates have relatively clear implications for theories that predict the rate at which subjects will respond when responding is averaged over the session (e.g., Herrnstein, 1970). For example, finding within-session changes implies that changes in session length may confound the measurement of average response rate. The peak rate of responding is reached at an absolute amount of time after the beginning of the session, regardless of session length (McSweeney, 1992; McSweeney, Roll, & Cannon, 1994). As a result, sessions of different lengths may sample different parts of the within-session patterns of responding, yielding different average response rates.

Within-session changes in response rates have less clear implications for theories that predict the ratio of the rates of responding during the two components of concurrent schedules (e.g., the matching law; Baum, 1974; Herrnstein, 1970). The implications will depend on whether within-session changes are similar or different for the two component schedules.

Within-session changes may create problems for ratio theories if these changes follow different patterns for the two components. For example, suppose that response rates increase to a peak and then decrease during each component of a concurrent schedule, as response rates often do during simple and multiple schedules (e.g., McSweeney, 1992). Suppose also that the peak rate of responding occurs earlier in the session and that the within-session changes are larger for components that provide higher (richer) rates of reinforcement than for those that provide lower (leaner) rates (McSweeney, 1992; McSweeney, Roll, & Cannon, 1994; McSweeney, Roll, & Weatherly, 1994). In that case, the ratio of the rates of responding will not be constant across the session. Instead, the ratio of the richer to the leaner response rate will increase to a peak and then decrease with time in the session. If the peak rate of responding

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is reached at a constant time after the beginning of the session regardless of session length (McSweeney, 1992; McSweeney, Roll, & Cannon, 1994), then the ratio of response rates will also differ for sessions of different lengths when this ratio is calculated across the entire session.

This instability of the ratio of response rates will not necessarily occur if responding changes similarly within the session for both components. Suppose, for example, that within-session changes in responding are produced by changes in a multiplier that modulates the absolute rates at which subjects respond (e.g., Killeen, 1994). If that multiplier changes in the same way within sessions for the two components, then its effect will cancel when the ratio of the rates of responding is calculated.

McSweeney, Weatherly, and Roll (1995) examined whether responding changed similarly within sessions for the components of concurrent schedules when those components employed different operanda and provided different rates of reinforcement. Rats responded on several concurrent schedules in which pressing a lever produced reinforcers during one component and pressing a key produced reinforcers in the other component. Pigeons responded on several comparable concurrent key-peck treadle-press schedules. The within-session patterns of responding were usually similar for the two components, even when the components provided different rates of reinforcement. As a result, McSweeney et al. (1995) suggested that the form of the within-session pattern of responding was determined by a combination of the reinforcers received from the two components. Such a combination would be the same for the two components, yielding similar within-session patterns of responding.

The present experiments addressed the question of whether responding changes similarly within the session for the two components of concurrent schedules when similar instrumental responses produce reinforcers in those components. Concurrent schedules that employ similar instrumental responses are more frequently studied than those that use different responses. Therefore, the generality of McSweeney et al.'s (1995) conclusion should be extended to the more common concurrent-schedule procedure.

The present experiments also examined two questions that were not addressed by McSweeney et al. (1995). First, the experiments investigated whether the number of changeovers changed systematically within the session. Second, the experiments addressed the question of whether a simple summation rule described the combined effects of the reinforcers obtained from the two components. As argued earlier, finding similar within-session changes for the two components suggested that those changes are controlled by some combination of the reinforcers obtained from both components. The present experiments determined whether subjects responded according to the sum of the reinforcers. If they did, then the within-session patterns of responding during concurrent schedules should be similar to the within-session patterns during simple schedules that provided a rate of reinforcement equal to the sum of the rates provided by the components of the concurrent schedules.

Experiment 1 examined responding when rats pressed levers for sweetened condensed milk. Experiment 2 examined responding when pigeons pecked keys for mixed grain. The total programmed rate of reinforcement provided by the concurrent schedules was varied (15 to 480 reinforcers per hour) while the ratio of the programmed rates was held constant. A wide range of rates of reinforcement was used and two species of subjects were studied to determine the generality of the conclusions. If within-session changes occur only under limited conditions, then they may reflect processes that are peculiar to those conditions. If they occur more generally, they will have more fundamental theoretical and methodological implications.

EXPERIMENT 1

Method

Subjects. The subjects were 5 experimentally naive male rats, bred from Sprague-Dawley stock. They were housed individually and were approximately 120 days old at the beginning of the study. They had free access to water in their home cages, but were maintained at approximately 85% of their free-feeding body weights by postsession feedings

Table 1

The schedules on which subjects responded in order of presentation and the total programmed rate of reinforcement (reinforcers per hour) that they provided.

Schedule	Rate of reinforcement
Concurrent VI 45 s VI 90 s	120
Concurrent VI 180 s VI 360 s	30
Concurrent VI 360 s VI 720 s	15
Concurrent VI 22.5 s VI 45 s	240
Concurrent VI 90 s VI 180 s	60
Concurrent VI 11.25 s VI 22.5 s	480

delivered when all subjects had completed their session for the day. Subjects were exposed to a 12:12 hr light/dark cycle.

Apparatus. The apparatus measured 23.5 cm by 19 cm by 30 cm. Two levers (5.5 cm by 1.5 cm) were located 7 cm above the floor and 5 cm from each side of the apparatus. The levers were connected to microswitches that required approximately 0.3 N to operate. A light (2.5 cm diameter) was located 0.5 cm from each side of the apparatus and 8.5 cm above the floor. To the experimenters, the left light was red and the right was green. A third white light was located 4 cm from the ceiling and was evenly spaced between the sides. It served as a houselight and was illuminated during the session. Noyes pellets were dropped into a trough (4 cm by 4.5 cm by 2 cm) located 1 cm above the floor and 12.5 cm from the right side of the apparatus. A hole (5 cm diameter), located 2 cm from the right side of the apparatus and 1 cm above the floor, allowed access to a 0.25-ml dipper. The experimental enclosure was housed in a sound-attenuating chamber. A ventilating fan masked noises from outside the chamber. Experimental events were programmed and data were recorded by MED Associates® software on an IBM®-compatible computer.

Procedure. Subjects were trained to press the left and right levers by the method of shaping by successive approximations. The rate of reinforcement obtained by responding on each lever was gradually reduced. When the experiment began, subjects responded on the schedules presented in Table 1. Each schedule was presented for 30 sessions, conducted daily, five or six times per week. The schedule listed first was correlated with the left lever; the schedule listed second was correlated with the right lever. The left lever always provided the higher rate of reinforcement. This lever was farther from the dipper from which subjects obtained reinforcers, and subjects failed to press it unless it provided the higher rate of reinforcement. All sessions were 60 min long. The lights above both levers and the houselight were illuminated during the entire session except that the lever lights were extinguished during reinforcement. Reinforcement was 5-s access to 0.25 ml sweetened condensed milk mixed one to one with water, scheduled according to a 25-interval Fleshler and Hoffman (1962) series. The schedules for the two components were independent of each other. Neither the session timer nor the timers that governed the delivery of reinforcement advanced during reinforcement. A 3-s changeover delay, during which subjects could not obtain a scheduled reinforcer, followed all changes from one lever to the other.

These particular concurrent schedules were chosen for study because they provided a wide range of programmed rates of reinforcement that were identical to the programmed rates provided by the simple variable-interval (VI) schedules in McSweeney, Weatherly, and Swindell (1996). Although the obtained rate of reinforcement is under the control of the subject, presenting similar total programmed rates for concurrent and VI schedules allowed for the possibility that the sum of reinforcers obtained from some of the present concurrent schedules would be similar to the rates of reinforcement obtained from the simple VI schedules. This would allow a test of the summation rule, as described earlier. The ratio of the programmed rates of reinforcement was held constant so that only the sum of the rates would vary across conditions.

Results and Discussion

Figures 1 and 2 present the rates of responding throughout the session for individual subjects. Rates were calculated by dividing the number of responses during a 5-min interval by 5 min. Because the interval timer stopped during reinforcement, the time for which the dipper was available was excluded from these measures and from all that follow in this paper. These results, and all that fol-

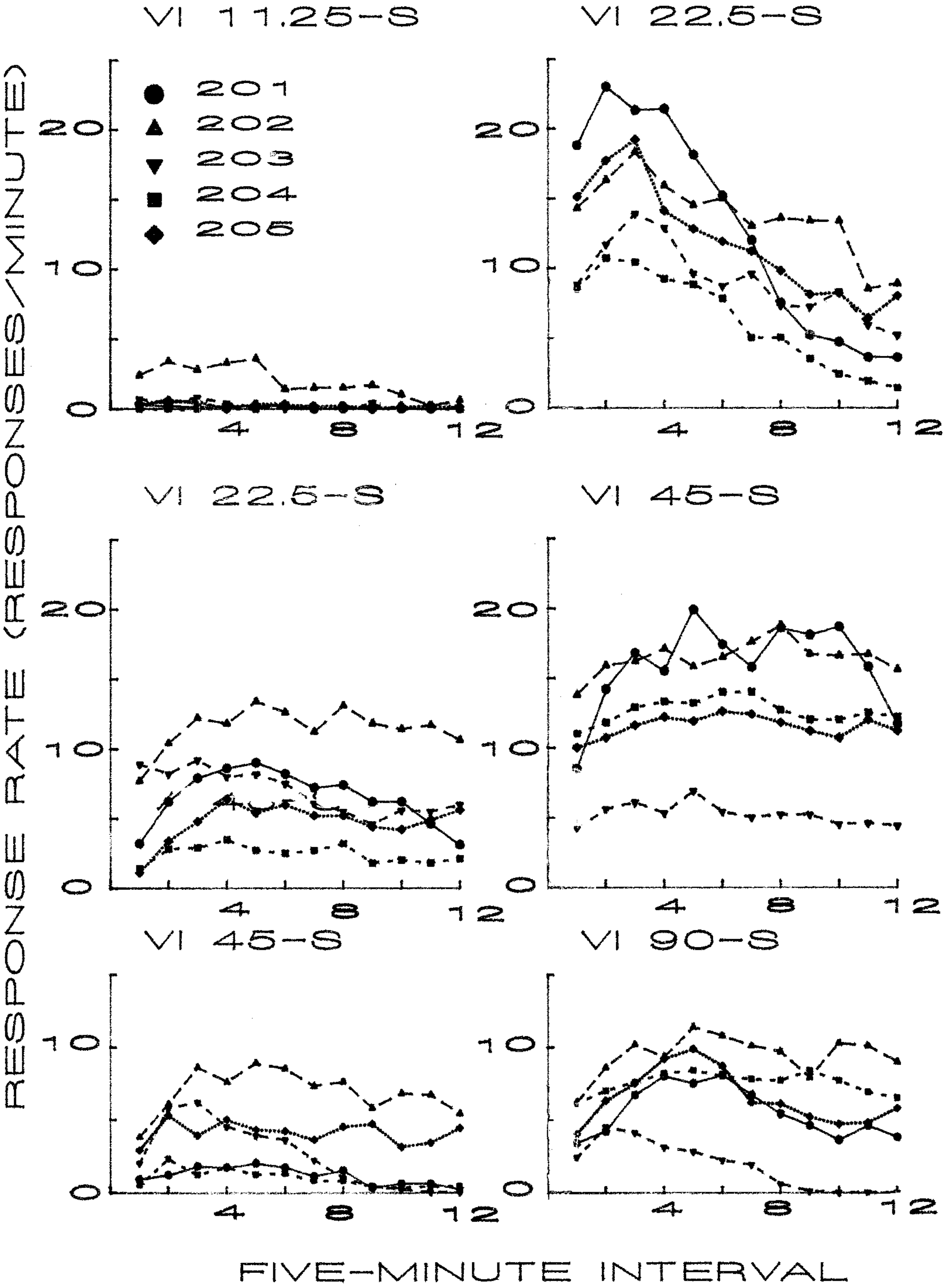

Fig. 1. Rates of lever pressing (responses per minute) during successive 5-min intervals in the session for each subject responding on each component of the concurrent VI 11.25-s VI 22.5-s, concurrent VI 22.5-s VI 45-s, and concurrent VI 45-s VI 90-s schedules in Experiment 1. Each panel presents the results for a component schedule; each curve presents the results for an individual subject. Results for the two components of a concurrent schedule are presented adjacently.

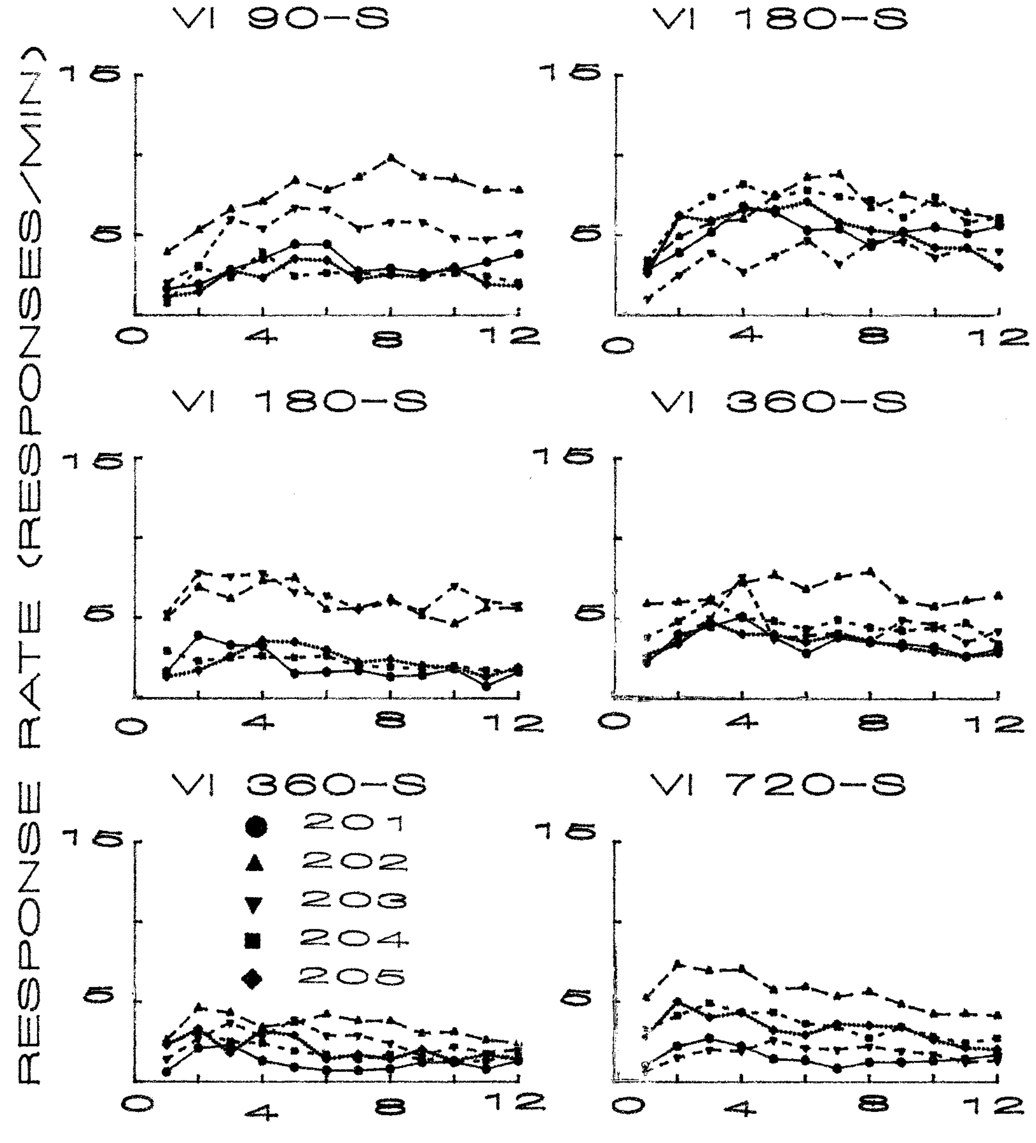

Fig. 2. Rates of lever pressing (responses per minute) during successive 5-min intervals in the session for each subject responding on each component of the concurrent VI 90-s VI 180-s, concurrent VI 180-s VI 360-s, and concurrent VI 360-s VI 720-s schedules in Experiment 1. Each panel presents the results for a component schedule; each curve presents the results for an individual subject. Results for the two components of a concurrent schedule are presented adjacently.

low, have been averaged over the last five sessions for which each schedule was available.

Figure 3 presents the rates of responding throughout the session for the mean of all subjects responding on each component of each concurrent schedule. It shows that, on average, response rates were higher on the right lever, even though that lever provided the lower rate of reinforcement. This bias probably occurred because the right lever was closer to the dipper that produced reinforcers. This bias did not distort the interpretation of the present results. Similar conclusions about within-session changes in

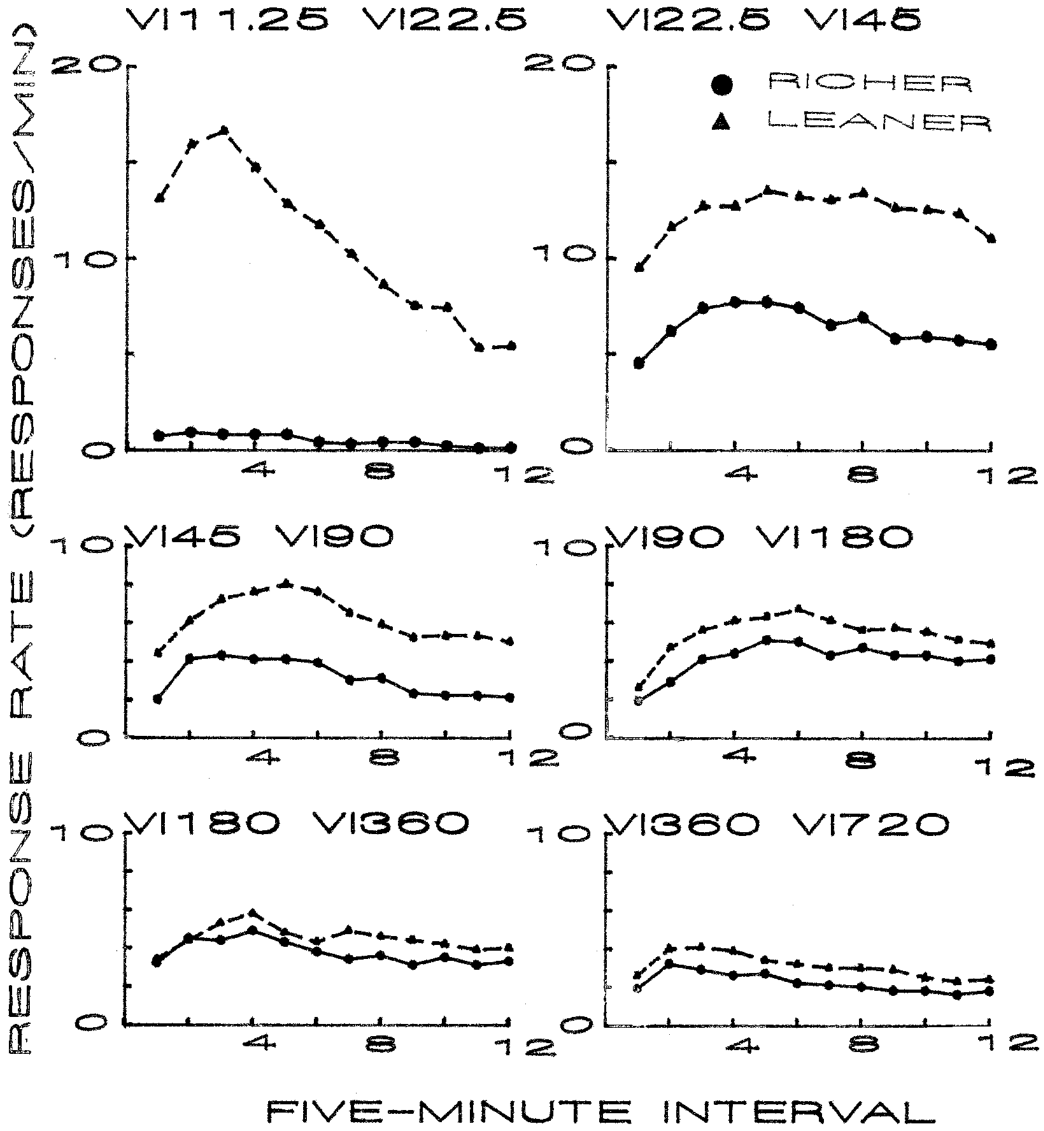

Fig. 3. Rates of lever pressing (responses per minute) on the richer (solid line) and leaner (dashed line) components during successive 5-min intervals in the session for the mean of all rats responding in Experiment 1. Each panel presents the results for a concurrent schedule.

responding were reached for rats and pigeons, even though rats displayed this bias and pigeons did not.

The sum of the rates of responding varied directly with the programmed rates of reinforcement except during the richest schedule (i.e., concurrent VI 11.25 s VI 22.5 s). The sums of the rates of responding during the two components, averaged over the session, were 11.3, 18.8, 9.3, 9.5, 8.3, and 5.3 responses per minute for the mean of all subjects responding on the schedules presented from richest to leanest. Figure 3 shows that the lower total responding on the concurrent VI 11.25-s VI 22.5-s schedule occurred because subjects responded little on one of the components. It is not known why this occurred, but the high rates of reinforcement programmed for each component meant that subjects did not have to respond on both components to collect a high rate of reinforcement.

Figures 1, 2, and 3 show that the rates of

Table 2

Results of two-way (component by 5-min interval) analyses of variance applied to the rates of responding by individual rats and pigeons responding on each concurrent schedule.

		Rats		Pigeons	
Schedule	Source	*df*	Result	*df*	Result
VI 11.25 s VI 22.5 s	Component (C)	1, 4	71.87***	1, 3	1.23
	Time (T)	11, 44	16.76***	11, 33	3.25**
	C × T	11, 44	10.14***	11, 33	0.81
VI 22.5 s VI 45 s	Component (C)	1, 4	7.72*	1, 3	0.28
	Time (T)	11, 44	4.36***	11, 33	7.57***
	C × T	11, 44	1.33	11, 33	0.16
VI 45 s VI 90 s	Component (C)	1, 4	6.48	1, 3	2.19
	Time (T)	11, 44	6.11***	11, 33	3.52**
	C × T	11, 44	1.27	11, 33	1.54
VI 90 s VI 180 s	Component (C)	1, 4	1.40	1, 3	3.03
	Time (T)	11, 44	10.38***	11, 33	1.78
	C × T	11, 44	0.84	11, 33	0.64
VI 180 s VI 360 s	Component (C)	1, 4	0.86	1, 3	0.62
	Time (T)	11, 44	6.90***	11, 33	3.05**
	C × T	11, 44	1.87	11, 33	2.90**
VI 360 s VI 720 s	Component (C)	1, 4	3.23	1, 3	4.77
	Time (T)	11, 44	8.45***	11, 33	1.71
	C × T	11, 44	0.78	11, 33	0.89

* $p < .05$, ** $p < .01$, *** $p < .001$.

responding usually changed within experimental sessions. Response rates primarily decreased, primarily increased, or increased and then decreased for different subjects responding on different schedules. The decreases in response rate were particularly steep for the VI 22.5-s schedule. The within-session patterns of responding were generally flatter for components that provided lower rates of reinforcement.

Figure 3 also shows that the within-session patterns of responding were similar for the two components of each concurrent schedule. This visual impression was confirmed by two-way (Component × Time) within-subject analyses of variance (ANOVAs) applied to the rates of responding by individual subjects. The results of these ANOVAs appear in Table 2. The interaction terms (C × T) were not significant for any schedule except for the concurrent VI 11.25 s VI 22.5 s, indicating that the form of the within-session changes in responding usually did not differ significantly for the two components. The main effect of time was also significant for all schedules, confirming that the rate of responding changed significantly within the session. Throughout this paper, results will be considered to be significant when $p < .05$.

Figure 4 compares the within-session changes in total responding during some of the present concurrent schedules to the within-session changes in responding during some of the VI schedules in McSweeney et al. (1996). Response rates were converted to percentages so that differences in the absolute rates of responding on the concurrent and VI schedules would not obscure similarities in the within-session patterns of responding. Percentages were calculated by dividing the number of responses during a 5-min interval for the mean of all subjects by the total number of responses during the session and multiplying by 100%. Schedules were compared only when the sum of the rates of reinforcement obtained from the components of the concurrent schedule were not statistically different from the rates of reinforcement obtained from the VI schedule. Subjects obtained most of the programmed reinforcers from both the VI and concurrent schedules at low programmed rates of reinforcement. Therefore, the results for the VI 120-s schedule have been compared to the results for the concurrent VI 180-s VI 360-s schedule (labeled VI 120 s). The results for the VI 240-s schedule have been compared to the results for the concurrent VI 360-s VI 720-s schedule (labeled VI 240 s). As is commonly found (e.g., Alsop & Elliffe, 1988), subjects failed to

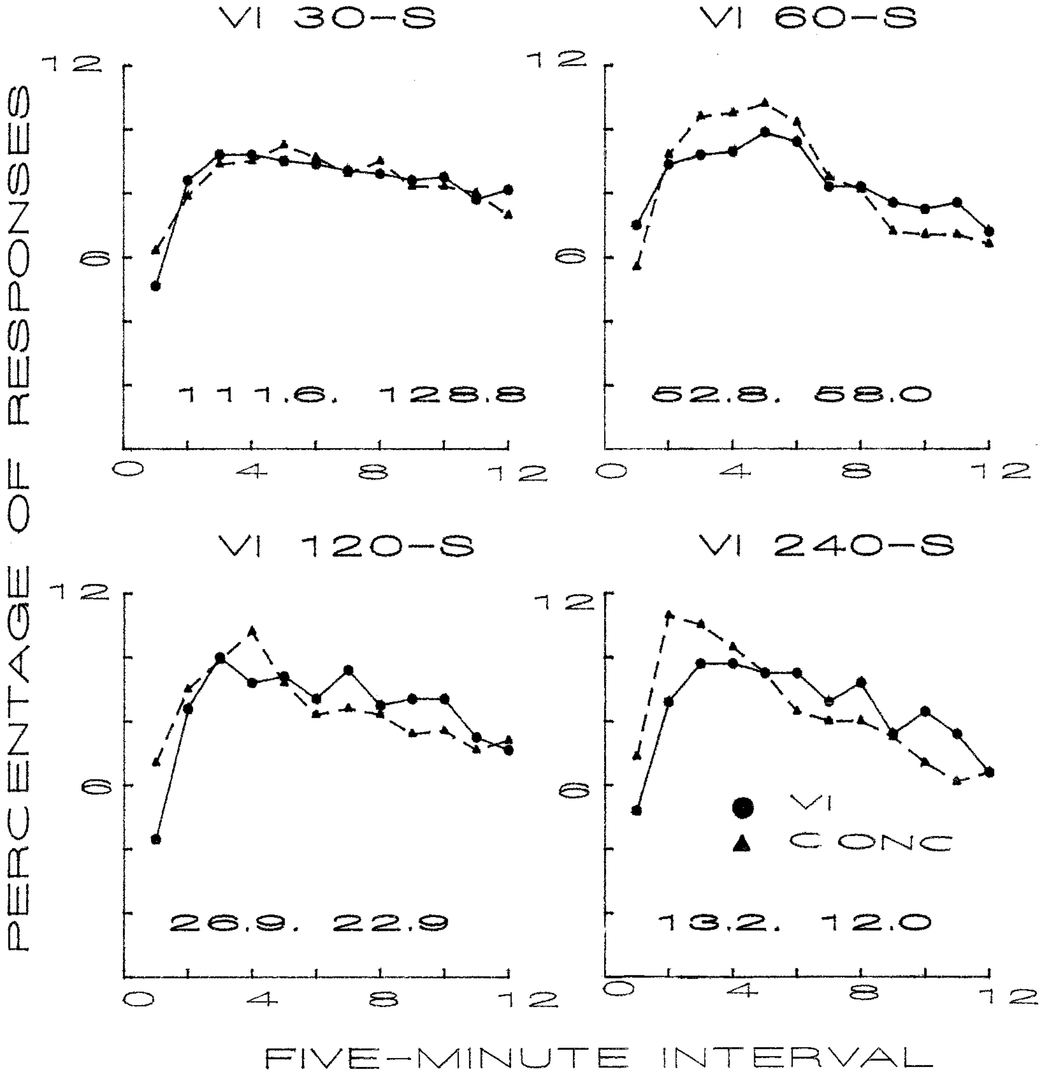

Fig. 4. Percentage of total-session presses during successive 5-min intervals in the session for the sum of the rates of pressing during the two components of a concurrent schedule (dashed line) and for the rates of pressing during VI schedules (solid lines) that provided similar total rates of reinforcement. The mean rates of reinforcement (reinforcers per hour) obtained from the VI (left) and concurrent (right) schedules appear on each panel. Results for concurrent schedules were taken from Experiment 1. Results for VI schedules were calculated from data summarized in McSweeney et al. (1996). All results are those for the mean of all rats.

obtain all of the programmed reinforcers from the concurrent schedules at higher programmed rates of reinforcement. As a result, responding during the VI 30-s schedule was compared to responding during the concurrent VI 22.5-s VI 45-s schedule (labeled VI 30 s), and responding during the VI 60-s schedule was compared to responding during the concurrent VI 45-s VI 90-s schedule (labeled VI 60 s). Results are not presented for the other concurrent schedules because the sum of the rates of reinforcement obtained from these schedules differed from the rates obtained from all of the VI schedules presented by McSweeney et al. (1996). Figure 4 shows that the within-session patterns of responding were similar when subjects responded on concurrent VI VI schedules and on VI schedules that provided similar total obtained rates of reinforcement.

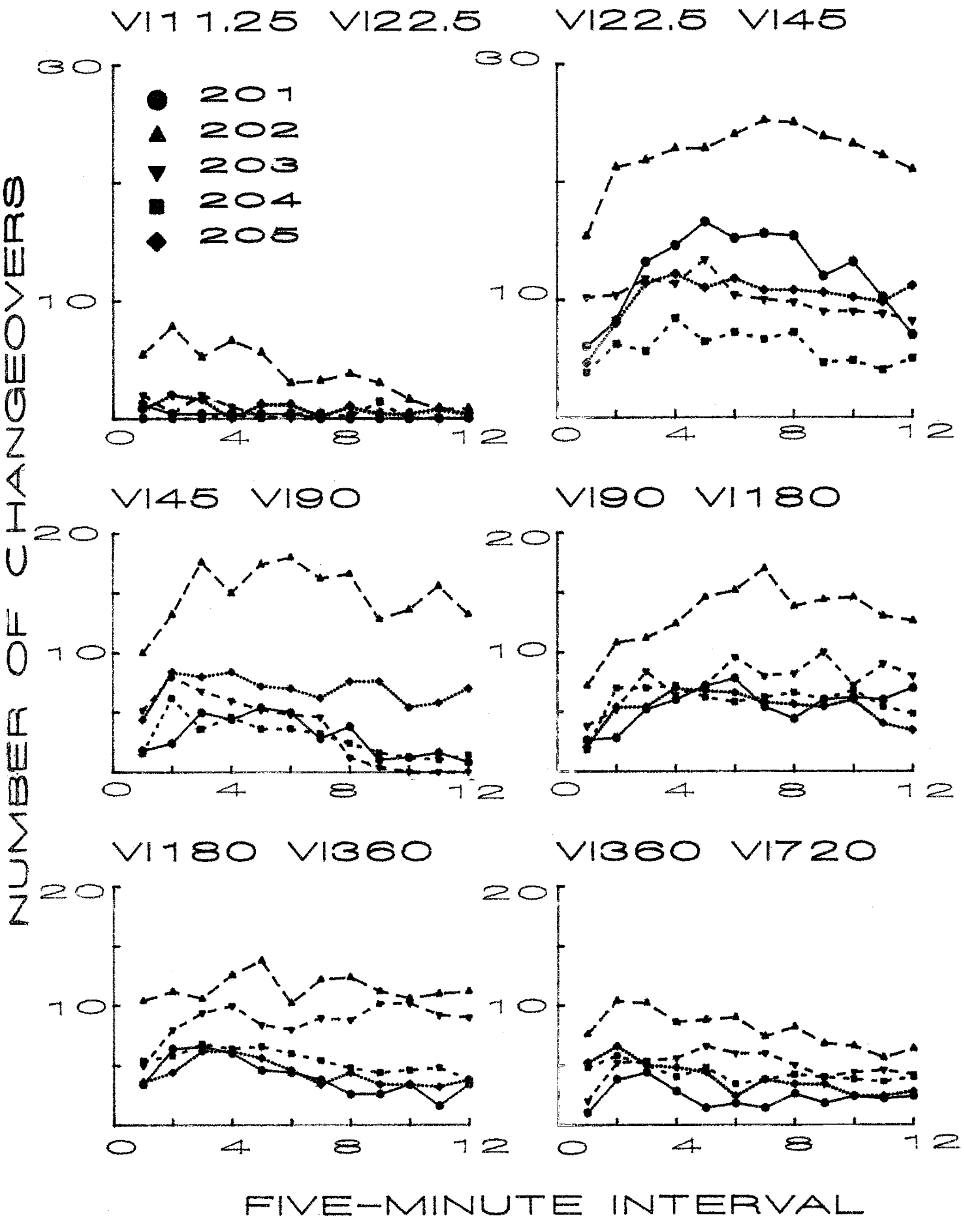

Fig. 5. Number of changeovers during successive 5-min intervals in the session for each rat responding on each concurrent schedule in Experiment 1. Each panel presents the results for a concurrent schedule. Each curve presents the results for an individual rat.

Figure 5 presents the number of changeovers throughout the session for individual subjects. The number of changeovers is the number of times that the subject switched levers, not the number of completed changeover delays. Except for the richest schedule, the trend was for the average number of changeovers per session to decrease as the programmed rate of reinforcement decreased. There were, however, reversals of this trend. The mean numbers of changeovers per session, averaged over all subjects, were 13.7, 146.0, 74.8, 89.8, 81.8, and 56.2 for the richest to the leanest schedule.

As for response rates, the number of changeovers primarily decreased, primarily increased, or increased and then decreased within sessions for different subjects responding on different schedules. One-way (time) within-subject ANOVAs showed that the number of changeovers changed significantly within the session for each schedule, $F(11, 44) = 2.00$; $F(11, 44) = 5.99$; $F(11, 44) = 5.00$; $F(11, 44) = 7.01$; $F(11, 44) = 3.05$; $F(11, 44) = 4.34$; for schedules presented from richest to leanest.

Figure 6 compares the within-session pattern of changeovers to the within-session pattern of instrumental responding. Percentages are presented so that differences in the absolute rates of responding and changing over would not obscure similarities in the within-session patterns of responding. Percentages were calculated by dividing the number of changeovers (or sum of responding) during a 5-min interval by the total number of changeovers (or sum of responding) during the session and multiplying by 100%. Figure 6 shows that the within-session patterns of intrumental responding and changing over were similar except for the richest schedule.

EXPERIMENT 2

Method

Subjects. The subjects were 4 experimentally experienced pigeons. They were housed individually with free access to water in their home cages. Subjects were maintained at approximately 85% of their free-feeding body weights by postsession feedings delivered when all subjects had completed their sessions for the day. They were exposed to a 12:12 hr light/dark cycle.

Apparatus and procedure. The apparatus was a two-key two-treadle experimental enclosure, measuring 27 cm by 30 cm by 29.5 cm. The two keys were Plexiglas panels (2.5 cm diameter) located 4 cm below the ceiling and 12.5 cm from each other. The left key was 6.0 cm from the left wall and could be illuminated by red light. The right key was 6.5 cm from the right wall and could be illuminated by blue light. Each key was operated when a force of approximately 0.25 N was applied to its center. A treadle was located 15.5 cm below each key. The treadles will not be described because they were not used in this experiment. An opening (5 cm by 4 cm), 12.5 cm from the right wall and 3 cm above the floor, allowed access to the food magazine. A houselight (1 cm diameter), located 0.5 cm from the left wall and 0.5 cm from the ceiling, illuminated the chamber. The experimental enclosure was housed in a sound-attenuating chamber. A ventilating fan masked noises from outside. Experimental events were controlled and data were recorded by MED Associates® software on an IBM®-compatible computer.

Procedural details for pigeons were identical to those for rats, with the following exceptions. First, subjects obtained reinforcers (5-s access to mixed grain) by pecking the left and right keys rather than by pressing the left and right levers. Second, although the same schedules were conducted in the same order, the key that provided the higher rate of reinforcement alternated with each change of schedule. During the first concurrent VI 45-s VI 90-s schedule, the VI 90-s schedule appeared on the left key.

Results and Discussion

Figures 7 and 8 present the rates of responding throughout the session for individual subjects. Results were calculated and presented as in Figures 1 and 2. Figure 9 presents the rates of responding throughout the session for the mean of all subjects responding on each component of each concurrent schedule. Results were calculated and presented as in Figure 3.

Figure 9 shows that subjects usually responded faster on the component of the concurrent schedule that provided the higher rate of reinforcement. However, unlike the results for rats (Figures 1, 2, and 3), the total rates of responding varied inversely with the programmed rates of reinforcement. The sums of the rates of responding during the two components were 12.2, 15.0, 28.0, 27.0, 40.1, and 68.1 responses per minute for the mean of all subjects responding on the richest to the leanest schedule. This finding will be discussed below.

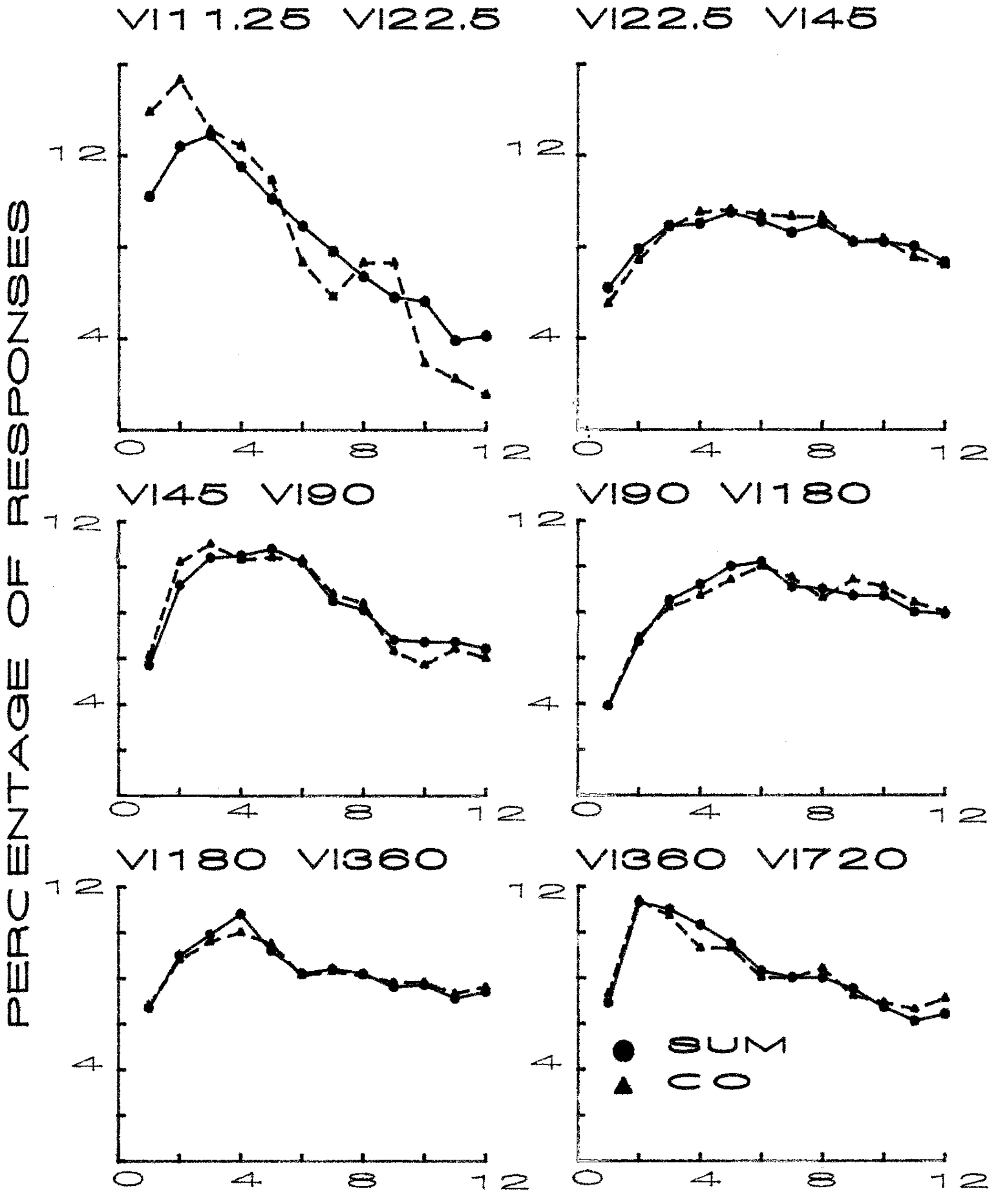

Fig. 6. Perentage of total-session changeovers (dashed line) and percentage of total-session responding (solid line) during successive 5-min intervals in the session during Experiment 1. Each panel presents the results for the mean of all subjects responding on a concurrent schedule.

Figures 7, 8, and 9 show that rate of responding often changed within experimental sessions. Again, rates of responding primarily decreased, primarily increased, or increased and then decreased for different subjects responding on different schedules. Figure 9 shows that the within-session patterns of responding were similar for the two compo-

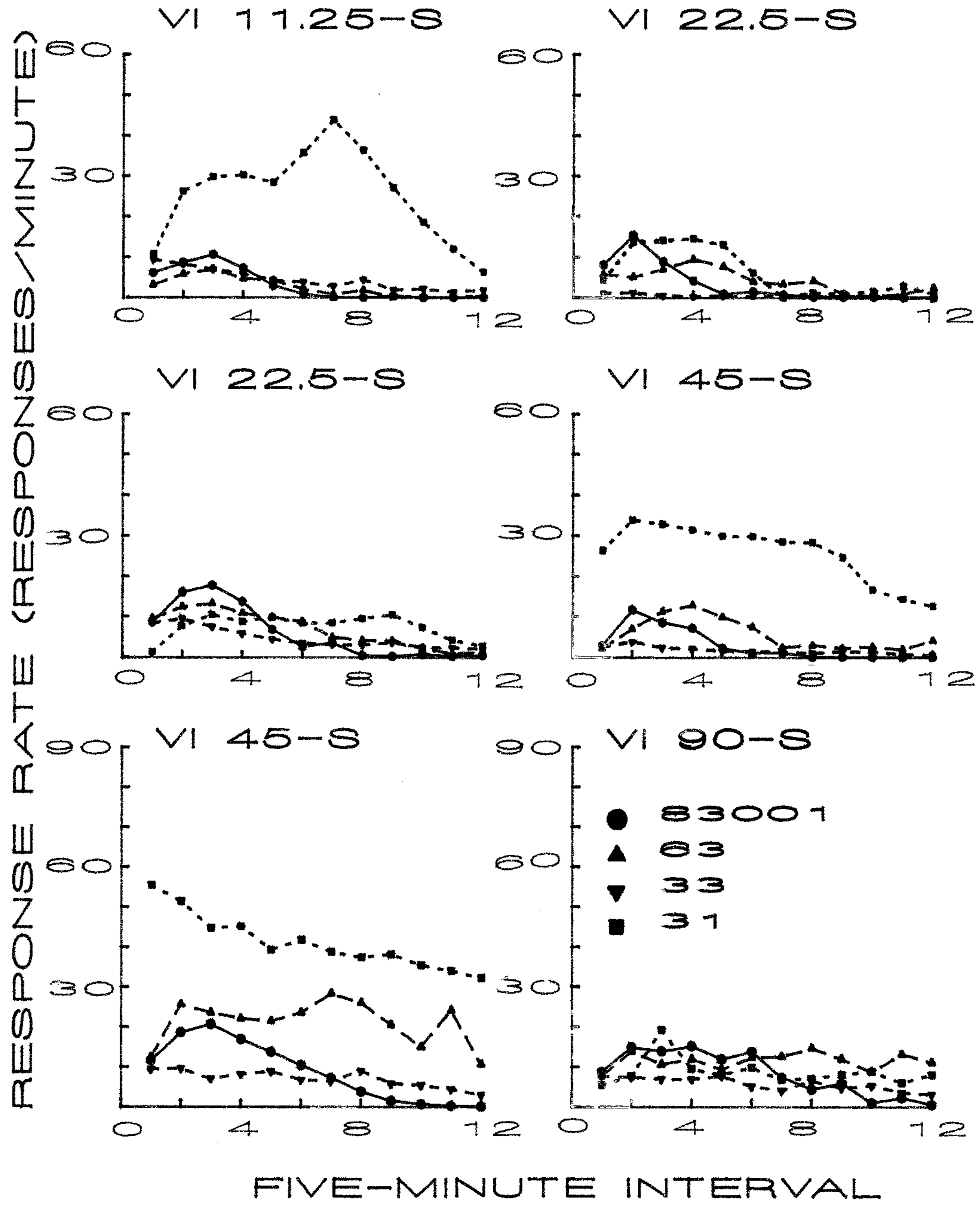

Fig. 7. Rates of key pecking (responses per minute) during successive 5-min intervals in the session for each subject responding on each component of the concurrent VI 11.25-s VI 22.5-s, concurrent VI 22.5-s VI 45-s, and concurrent VI 45-s VI 90-s schedules in Experiment 2. Each panel presents the results for a component schedule; each curve presents the results for an individual pigeon. Results for the two components of a concurrent schedule are presented adjacently.

nents of each concurrent schedule. Again, this visual impression was confirmed by the results of two-way (Component × Time) within-subject ANOVAs that appear in Table 2. The interaction terms of these ANOVAs were not significant for any schedule except for the concurrent VI 180 s VI 360 s, indicating that the within-session patterns of responding

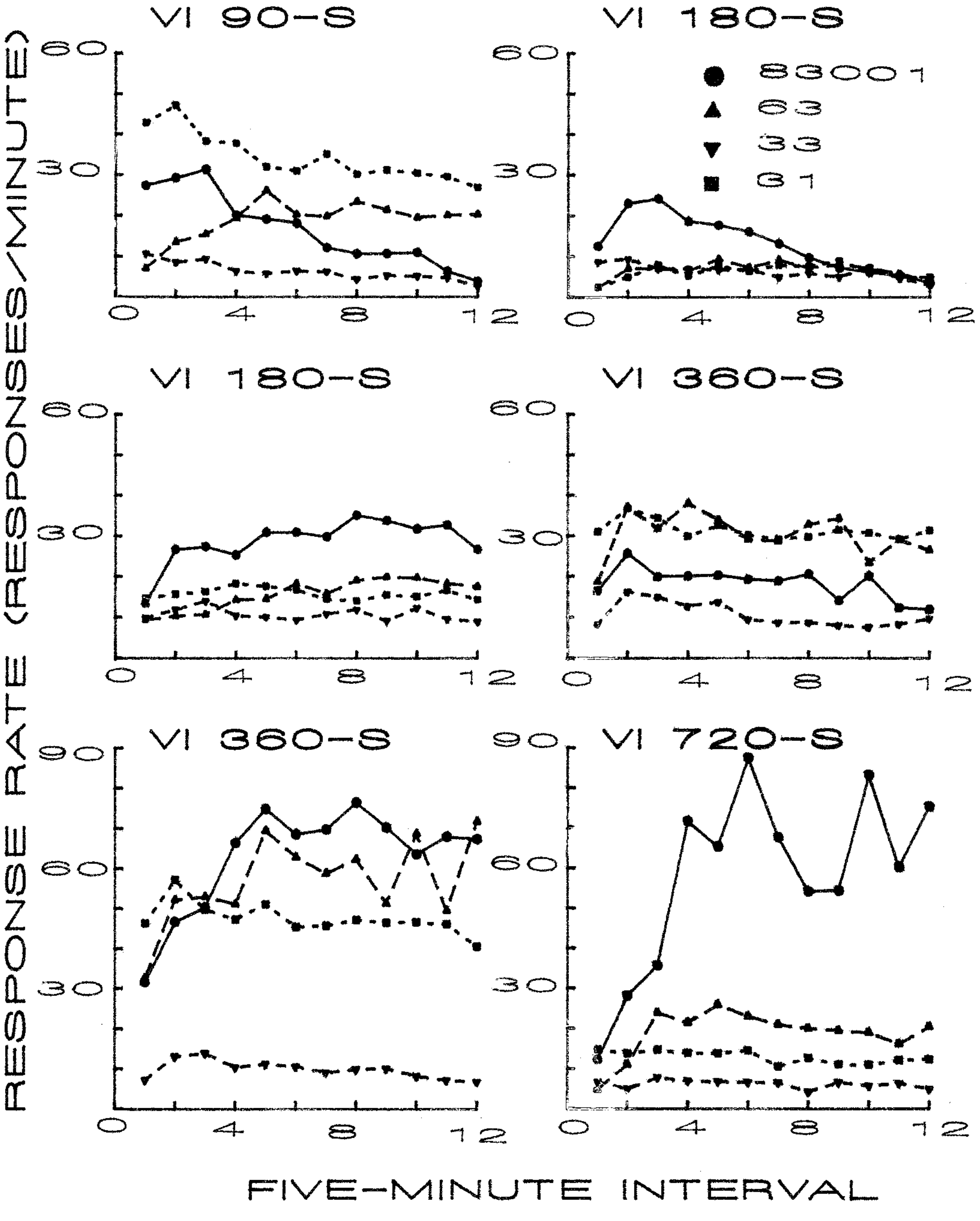

Fig. 8. Rates of key pecking (responses per minute) during successive 5-min intervals in the session for each subject responding on each component of the concurrent VI 90-s VI 180-s, concurrent VI 180-s VI 360-s, and concurrent VI 360-s VI 720-s schedules in Experiment 2. Each panel presents the results for a component schedule; each curve presents the results for an individual pigeon. Results for the two components of a concurrent schedule are presented adjacently.

usually did not differ significantly for the two components of the concurrent schedules. The main effect of elapsed session time was significant for all schedules except the concurrent VI 90 s VI 180 s and the concurrent VI 360 s VI 720 s, indicating that response rate changed significantly within sessions for four of the six schedules.

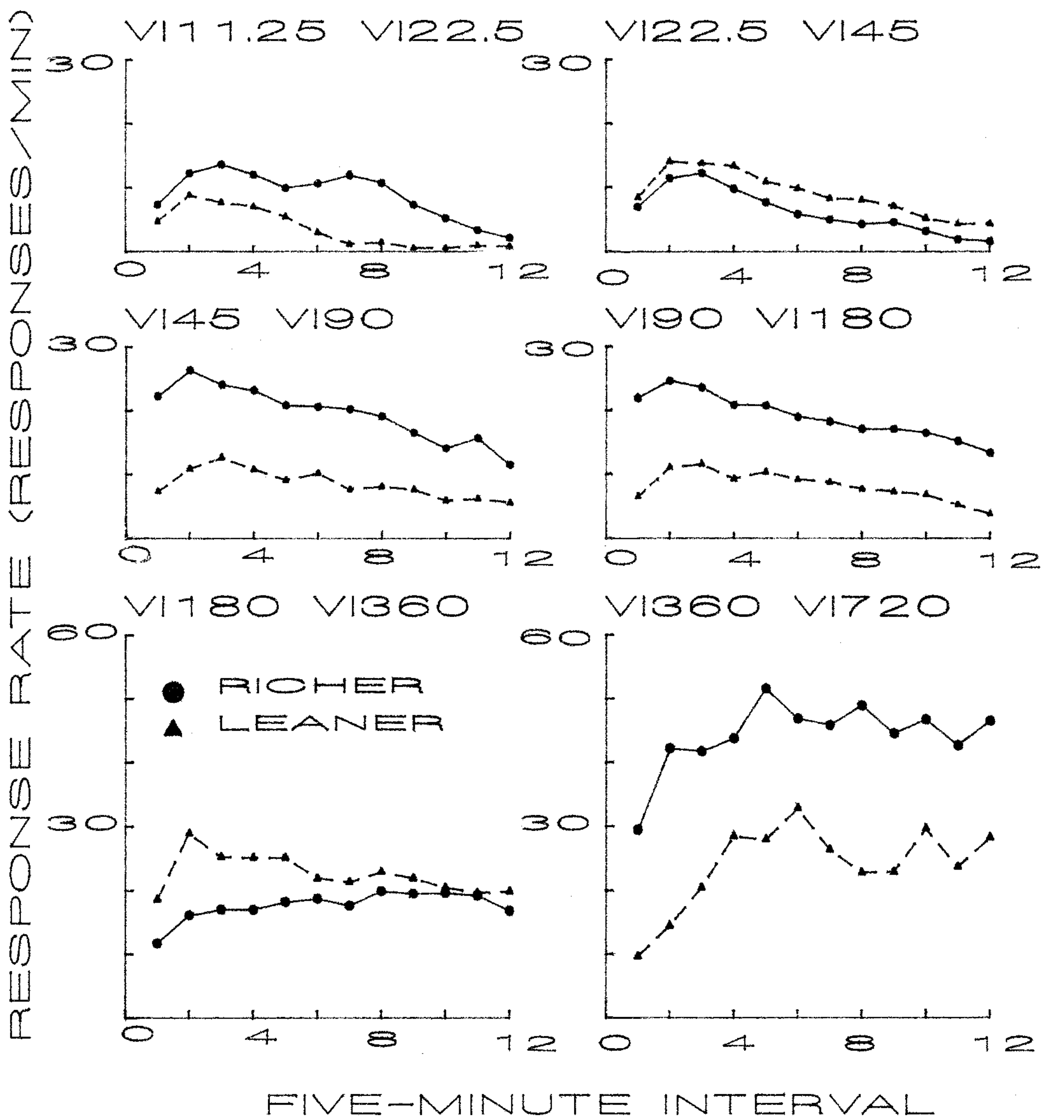

Fig. 9. Rates of key pecking (responses per minute) on the richer (solid line) and leaner (dashed line) components during successive 5-min intervals in the experimental session for the mean of all pigeons in Experiment 2. Each panel presents the results for a concurrent schedule.

Examination of Figures 7 and 8 suggests that responding often changed within sessions for individual subjects even during the concurrent VI 90-s VI 180-s and concurrent VI 360-s VI 720-s schedules. This conclusion was supported by the results of two-way within-subject ANOVAs applied to the rates of responding by individual subjects during the last five sessions for which each of these schedules was available. Responding changed significantly within sessions for all subjects responding on both the concurrent VI 90-s VI 180-s schedule, *F*(11, 44) = 17.65, Subject 83001; *F*(11, 44) = 5.83, Subject 63; *F*(11, 44) = 3.05, Subject 33; *F*(11, 44) = 4.81, Subject 31, and the concurrent VI 360-s VI 720-s schedule, *F*(11, 44) = 6.49, Subject 83001; *F*(11, 44) = 2.67, Subject 63; *F*(11, 44) = 3.94, Subject 33; *F*(11, 44) = 2.47, Subject 31. Therefore, the sum of the rates of responding during the two components changed significantly within sessions for individual subjects,

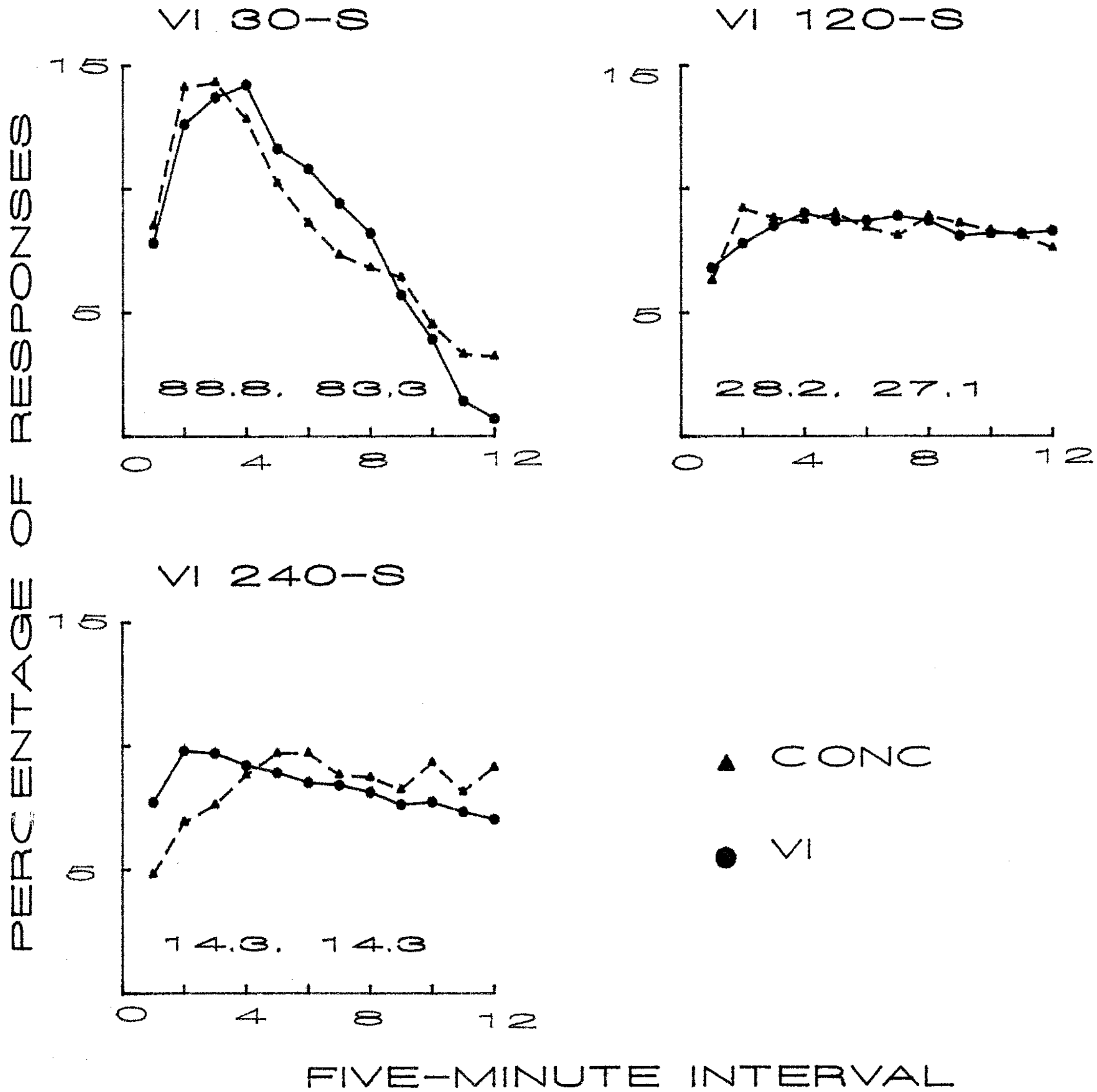

Fig. 10. Percentage of total-session pecks during successive 5-min intervals in the session for the sum of the rates of pecking during the components of a concurrent schedule (dashed line) and for the rates of responding during a VI schedule (solid line) that provided a similar rate of reinforcement. Rates of reinforcement (reinforcers per hour) obtained from the VI (left) and the concurrent schedule (right) appear on each panel. Results for the concurrent schedules were taken from Experiment 2; results for VI schedules were calculated from data summarized in McSweeney et al. (1996). All results are those for the mean of all subjects.

even when the changes were not significant for the mean of all subjects.

Figure 10 compares the within-session changes in responding on the present concurrent schedules to data previously reported on within-session changes during VI schedules from which subjects obtained similar rates of reinforcement (McSweeney et al., 1996). The schedules compared are the same as those compared in Figure 4 on the axes with the same label. Figure 10 shows that within-session changes in responding were usually similar for schedules that provided similar total obtained rates of reinforcement.

Figure 11 presents the number of changeovers throughout the session for individual subjects. Results have been presented as in Figure 5. Figure 11 shows that the average

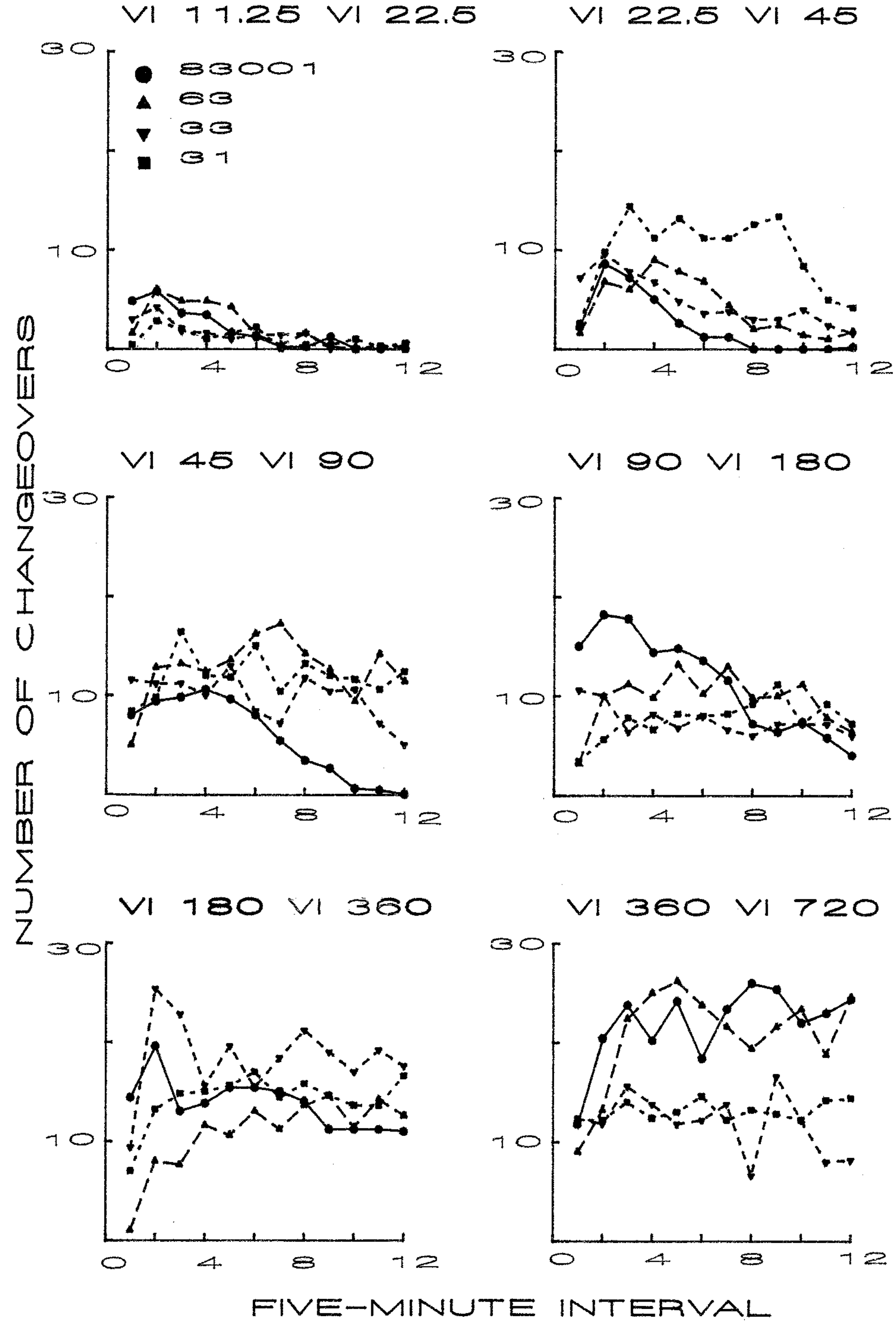

Fig. 11. Number of changeovers during successive 5-min intervals in the session for each pigeon responding on each concurrent schedule in Experiment 2. Each panel presents the results for a concurrent schedule. Each curve presents the results for an individual pigeon.

number of changeovers per session increased as the programmed rate of reinforcement decreased. The numbers of changeovers per session for the mean of all subjects were 19.5, 63.7, 120.6, 108.9, 172.0, and 203.4 for the richest to the leanest schedule. The number of changeovers sometimes changed significantly within the session. One-way (time) within-subject ANOVAs applied to the number of changeovers by individual subjects were significant for three schedules, $F(11, 33) = 7.55$, concurrent VI 11.25 s VI 22.5 s; $F(11, 33) = 4.63$, concurrent VI 22.5 s VI 45 s; $F(11, 33) = 2.34$, concurrent VI 180 s VI 360 s, but not for the other three, $F(11, 33) = 1.65$, concurrent VI 45 s VI 90 s; $F(11, 33) = 1.01$, concurrent VI 90 s VI 180 s; $F(11, 33) = 1.87$, concurrent VI 360 s VI 720 s).

Again, examination of Figure 11 suggests that the number of changeovers often changed within sessions for individual subjects, even during the schedules that showed nonsignificant changes for the mean of all subjects. To test this, one-way (time) within-subject ANOVAs were applied to the rates of changing over by individual subjects during the last five sessions for which each of the three nonsignificant schedules were available. Results were significant for all subjects responding on all schedules, except for Subject 33 responding on the concurrent VI 90-s VI 180-s schedule, $F(11, 44) = 0.66$, and the concurrent VI 360-s VI 720-s schedule, $F(11, 44) = 0.99$, and for Subject 31 responding on the concurrent VI 360-s VI 720-s schedule, $F(11, 44) = 0.82$. Therefore, the number of changeovers changed significantly within the session for several individual subjects, even when the results were not significant for the mean of all subjects.

Figure 12 compares the within-session changes in the number of changeovers to the within-session changes in instrumental responding. Results have been calculated and presented as in Figure 6. The within-session changes in responding and changing over were similar for all schedules except for the concurrent VI 11.25 s VI 22.5 s.

GENERAL DISCUSSION

Within-Session Patterns of Responding

The present experiments showed that responding usually changed significantly within sessions when subjects responded on concurrent schedules. This extends the generality of within-session changes to relatively standard concurrent schedules that provide a wide range of programmed rates of reinforcement.

The experiments also showed that responding usually changed similarly within sessions for the two components of each concurrent schedule (Figures 3 and 9 and Table 2). As argued earlier, this implies that within-session changes in responding may not confound the predictions of theories that describe the ratios of the rates of responding during the components of concurrent schedules (e.g., the matching law). It also suggests that the within-session patterns of responding are determined by a process that combines the reinforcers obtained from both components. Such a combination would be the same for both components, yielding similar within-session changes in responding. Figures 4 and 10 suggest that the combination is approximately a simple summation. The within-session patterns for the sum of responding during the present concurrent schedules were similar to the patterns during VI schedules that provided a similar total rate of reinforcement.

Finding that the within-session patterns of responding were determined by the sum of the reinforcers is consistent with, but does not compel, an interpretation for these patterns in terms of arousal (e.g., Killeen, Hanson, & Osborne, 1978), satiation (e.g., Reese & Hogenson, 1962), or sensitization-habituation (e.g., Thompson & Spencer, 1966) to the reinforcer. Either satiation for, or sensitization-habituation to, a reinforcer might alter operant response rate by changing the effectiveness of that reinforcer. The presentation of a reinforcer should contribute to each of these processes, regardless of which component provided that reinforcer. Therefore, responding should be based on total reinforcement, regardless of source. To clarify the difference between sensitization-habituation to a reinforcer and satiation for that reinforcer, sensitization-habituation usually refers to an increase followed by a decrease in responding to a repeatedly presented stimulus. Satiation usually refers to the decline in consumption of an ingestive stimulus such as food or water. Sensitization-habituation to the sensory aspects of the ingestive stimulus may contribute to satiation for that stimulus, but

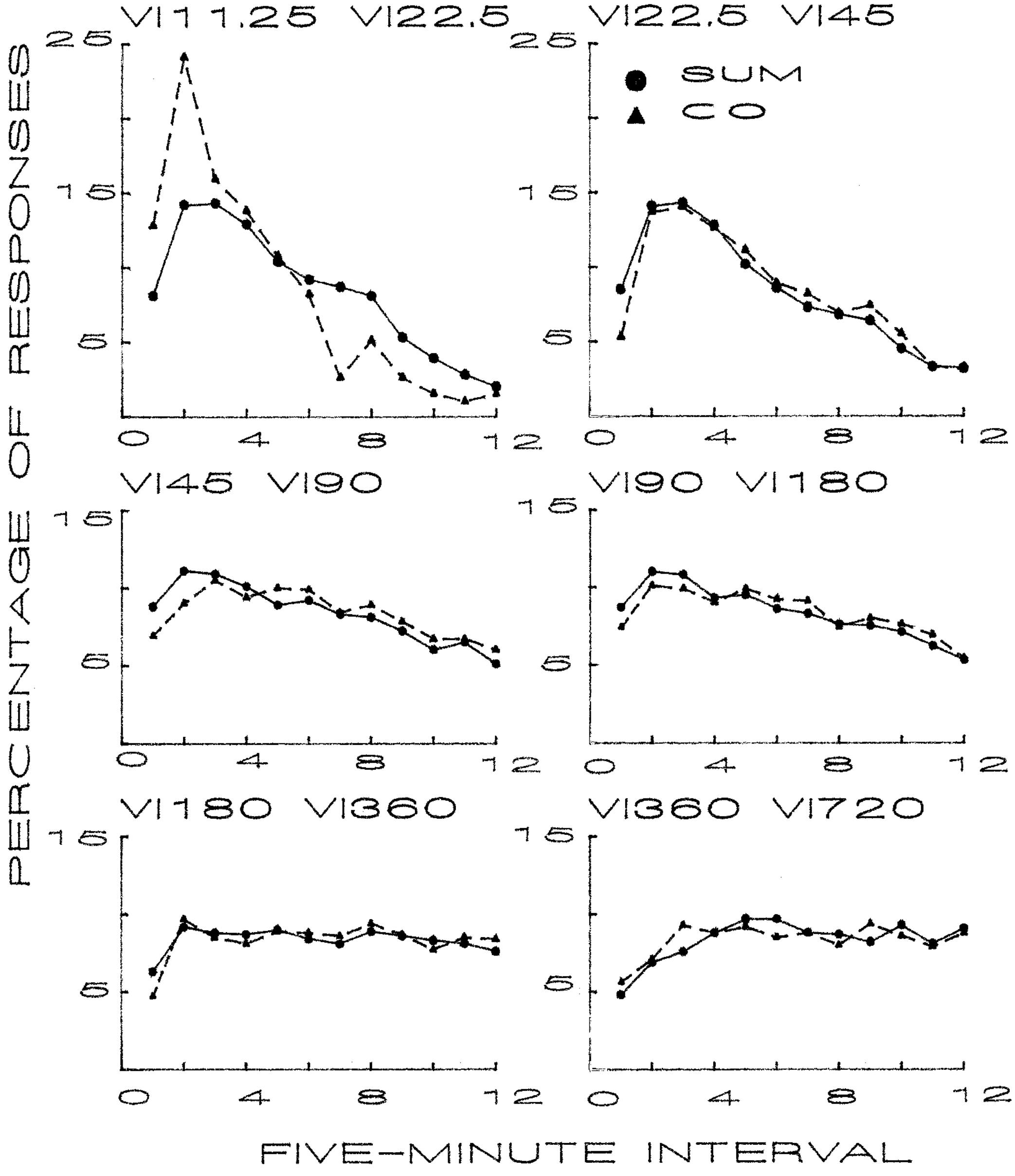

Fig. 12. Perentage of total-session changeovers (dashed line) and total-session responding (solid line) during successive 5-min intervals in the session in Experiment 2. Each panel presents the results for a concurrent schedule.

other factors (e.g., gastric fill, nutritional state, postingestive factors, etc.) also contribute (e.g., Swithers & Hall, 1994).

McSweeney, Hinson, and Cannon (in press) argued that sensitization-habituation to aspects of the experimental procedure that are presented repeatedly (e.g., reinforcers) or for a prolonged time (e.g., the experimental chamber) provides a better explanation than satiation for the within-session changes in operant responding. First, they showed that the empirical characteristics of the within-session patterns of operant responding are similar to the empirical characteristics of behavior that have been reported in the literature on sensitization-habituation. Second, they argued that sensitization-habituation, but not satiation, can account for within-session changes in responding that are sometimes reported when no reinforcers are given (e.g., Schoenfeld, Antonitis, & Bersh, 1950). Finally, they showed that several factors that influence the consumption of ingestive stimuli (i.e., factors that alter satiation) have little or no effect on within-session patterns of operant responding. For example, in three experiments, Roll, McSweeney, Johnson, and Weatherly (1995) varied the caloric density of the reinforcer, varied the size of the reinforcer, and varied the subject's deprivation either by feeding before the session or by varying the percentage of free-feeding body weight at which the subject responded. Prefeeding, varying body weights, and changing the caloric density of the reinforcer had no effect on the within-session pattern of responding. Varying reinforcer size altered within-session patterns, but only when the size of the reinforcer increased by a factor of five, not by a factor of three. In each experiment, the rate of responding averaged over the session changed appropriately with the experimental manipulation. For example, the average rate of responding was higher when subjects responded at 75% than at 85% or 95% of their free-feeding weights. Therefore, it is unlikely that the experimental manipulations failed to alter the level of satiation. Future experiments should thoroughly test sensitization-habituation as an explanation for the within-session patterns of operant responding.

Changeovers

The present experiments reported two similarities between instrumental responses and changeovers. First, the within-session changes were similar for these two measures (see Figures 6 and 12). Second, both measures changed similarly with changes in the sum of the rates of reinforcement. That is, changeovers and instrumental responding both varied directly with the total rate of reinforcement for rats and inversely for pigeons (Figures 3, 5, 9, and 11). Past studies that have held the ratio of the rates of reinforcement provided by the components constant while varying the total rate of reinforcement have also reported both a direct (e.g., Alsop & Elliffe, 1988) and an inverse (e.g., Temple, Scown, & Foster, 1995, compare the concurrent VI 30-s VI 60-s schedule to the concurrent VI 120-s VI 60-s schedule; Tustin & Davison, 1979) relation between rate of changeover and total rate of reinforcement.

Eventually a complete theory of concurrent-schedule responding must account for these similarities between the rate of changeover and the rate of instrumental responding. A thorough discussion of the many models of changeovers (e.g., Davison, 1991; Heyman, 1979; Hunter & Davison, 1978; Myerson & Miezin, 1980) is beyond the scope of this paper. However, one point should be noted. The present results imply that the rate of changeover is more directly related to the rate of responding than to the rate of reinforcement. That is, the rate of changeover sometimes varied inversely and sometimes directly with changes in the rate of reinforcement, but it always varied directly with changes in the rate of responding. Additional studies are needed to verify this conclusion.

Absolute Response Rates

The present paper is not primarily concerned with changes in rate of responding averaged over the session. However, the direct relation between the sum of the average rates of responding and the total rate of reinforcement for rats (Figure 3) and the inverse relation for pigeons (Figure 9) deserve comment. Each of these results has been reported in the past. When the ratio of the rates of reinforcement programmed for the two components was held constant, the sum of the rates of responding during the two components increased (e.g., Alsop & Elliffe, 1988; McSweeney, 1977), decreased (e.g., Temple et al., 1995, compare responding during the concurrent VI 30-s VI 60-s schedule to responding during the concurrent VI 60-s VI 120-s schedule for the 4-s COD), or varied inconsistently (e.g., Fantino, Squires, Delbrück, & Peterson, 1972) with increases in the sum of the obtained rates of reinforcement.

The reason for the variable relation between total responding and total reinforcement during concurrent schedules is unknown. One possibility is that satiation or habituation for the reinforcer might have produced the inverse relation found in the present study (Experiment 2). Figure 7 shows that most pigeons stopped responding late in the session during components that provided high rates of reinforcement, as they might if they had become satiated or habituated. The relatively low rates of responding early in these sessions could be explained by arguing that satiation or habituation did not entirely dissipate between sessions.

Examination of the subjects' body weights both supports and contradicts an explanation in terms of satiation. Subjects were somewhat heavier when responding on the richest schedule (M = 340.0 g) than on the leanest schedule (M = 306.2 g), as would be expected if subjects were more satiated during the richest schedule. However, body weight changed little across the four richest schedules. Mean weights were 340.0, 343.9, 344.6, and 340.6 g when these schedules were presented from richest to leanest. Nevertheless, rate of responding varied inversely with the programmed rate of reinforcement for these schedules. The sums of the rates of responding during the two components were 12.2, 15.0, 28.0, and 27.0 responses per minute for the mean of all subjects responding on these schedules, presented in the same order.

Examination of the obtained rates of reinforcement also questions satiation as an explanation for the inverse relation between responding and reinforcement. As indicated earlier, the present subjects, like those in past experiments (e.g., Alsop & Elliffe, 1988), often failed to obtain all of the programmed reinforcers when responding at high rates of reinforcement. The mean obtained rates of reinforcement were 104.4, 83.3, 79.2, 46.8, 27.1, and 14.3 reinforcers per hour for pigeons responding on the concurrent schedules, presented from richest to leanest. The total amount of reinforcement obtained from these schedules falls within the range that often produces a direct relation between responding and reinforcement when subjects respond on simple VI schedules (e.g., Catania & Reynolds, 1968).

An alternative possibility is that rate of reinforcement does not exert a direct effect on rate of responding, as assumed by many theories (e.g., Herrnstein, 1970). Such a conclusion would be consistent with a growing body of evidence. To begin with, responding does not always increase with increases in the programmed rates of reinforcement, even when subjects respond on simple VI schedules. Instead, some studies report (e.g., Dougan & McSweeney, 1985; McSweeney & Melville, 1991) and several theories predict (e.g., Baum, 1981; Staddon, 1979) that responding will increase to a peak and then decrease with further increases in the rate of reinforcement. All possible relations between rate of responding and programmed rate of reinforcement have been reported when subjects respond on fixed-interval schedules. Some studies report no relation (e.g., Catania & Reynolds, 1968, Experiment 4); others report a direct relation (e.g., Lowe, Harzem, & Spencer, 1979); and still others report an inverse relation (e.g., McSweeney, Roll, & Weatherly, 1994). Finally, rate of responding usually varies inversely, not directly, with rate of reinforcement when subjects respond on ratio schedules, at least over moderate ratio sizes (e.g., Timberlake, 1977). These inconsistencies have led several authors to question whether rate of reinforcement exerts a fundamental control over rate of responding. Many alternatives should be examined in future studies. For example, rate of reinforcement may control running response rate (rate of responding calculated only over the time when the animal is responding) rather than overall response rate (e.g., Baum, 1993).

Regardless of their explanation, the different relations between rate of reponding and rate of reinforcement for rats and pigeons did not distort the present conclusions about the within-session changes in instrumental responding or changing over. Similar conclusions about within-session changes were reached for rats and pigeons in spite of the different relations between responding and reinforcement for these species.

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