

*WITHIN-SESSION CHANGES IN RESPONDING DURING
CONCURRENT SCHEDULES WITH DIFFERENT REINFORCERS IN
THE COMPONENTS*

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Rats and pigeons responded on several concurrent schedules that provided different reinforcers in the two components (food and water for rats, Experiment 1; wheat and mixed grain for pigeons, Experiment 2). The rate of responding and the time spent responding on each component usually changed within the session. The within-session changes in response rates and time spent responding usually followed different patterns for the two components of a concurrent schedule. For most subjects, the bias and sensitivity to reinforcement parameters of the generalized matching law, as well as the percentage of the variance accounted for, decreased within the session. Negative sensitivity parameters were sometimes found late in the session for the concurrent food-water schedules. These results imply that within-session changes in responding could cause problems for assessing the validity of quantitative theories of concurrent-schedule responding when the components provide different reinforcers. They question changes in a general motivational state, such as arousal, as a complete explanation for within-session changes in responding. The results are compatible with satiation for, or sensitization-habituation to, the reinforcers as explanations.

Key words: concurrent schedule, within-session patterns of responding, matching law, lever press, key peck, rats, pigeons

The present experiments were conducted to examine within-session changes in response rates and time spent responding during concurrent schedules that provided different reinforcers in the two components. The experiments determined whether the within-session patterns were similar or different for the different reinforcers. The answer to this question is important for two reasons.

First, the answer may help to identify the theoretical variables that produce within-session patterns of responding. Suppose, for example, that within-session changes are produced by changes in a general motivational state of the animal, such as arousal (e.g., Duffy, 1962). If changes in a single state produce the within-session changes in responding during both components of a concurrent schedule, then those changes should be similar for the two components. In contrast, suppose that within-session changes are produced by satiation for the reinforcer or by sensitization-habituation to aspects of the experimental situation that are presented repeatedly (e.g., reinforcers) or for a prolonged period (e.g.,

the experimental enclosure, McSweeney, Hinson, & Cannon, in press). In that case, within-session patterns might differ for the two components. Rates of satiation might differ for reinforcers that differ in caloric density, taste, stomach load, and so forth. Rates of sensitization-habituation depend on the preparation under study (e.g., Hinde, 1970) and might differ for different reinforcers.

Second, the answer to whether responding changes in a similar or different pattern has implications for quantitative theories of concurrent-schedule responding. Many of these theories attempt to predict the ratio of the rates of responding during the two components averaged over the session (e.g., Herrnstein, 1970). One example, the generalized matching law (Baum, 1974), appears in Equation 1.

$$\frac{P_1}{P_2} = \frac{T_1}{T_2} = a \left(\frac{R_1}{R_2} \right)^b \quad (1)$$

P_1 , T_1 , and R_1 are the rates of responding emitted, the time spent responding on, and the rates of reinforcement obtained from the first component, respectively. P_2 , T_2 , and R_2 refer to the same variables for the other component. The a and b parameters are bias and sensitivity to reinforcement, respectively. Bias represents preference for a component that

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is not explained by differences in the rates of reinforcement provided by the components. Sensitivity represents the degree to which preference changes with changes in the ratio of the rates of reinforcement.

Within-session changes in responding could cause problems for assessing the validity of quantitative theories, such as Equation 1, if the changes occur differently for the two components. Suppose that concurrent-schedule responding increases to a peak and then decreases within experimental sessions, as responding often does during multiple and simple schedules (e.g., McSweeney, 1992). Suppose also that the peak rate of responding occurs earlier in the session and that within-session changes are larger for components that provide more highly preferred reinforcers than for those that provide less preferred reinforcers. In that case, the ratio of the more preferred to the less preferred response rate would not be constant, but would increase to a peak and then decrease within the session. If the peak rate of responding was reached at a constant time after the beginning of a session regardless of session length (McSweeney, 1992; McSweeney, Roll, & Cannon, 1994), then the ratio of response rates would also differ for sessions of different lengths when the ratio was calculated across the entire session.

Within-session changes in responding would cause fewer problems for evaluating quantitative theories if the changes occurred similarly for the two components. Suppose, for example, that within-session changes are related to changes in a multiplier that modulates the absolute rates at which subjects respond. If this multiplier changed in the same way within the session for the two components of a concurrent schedule, then its effect would cancel when the ratios of the rates of responding were calculated.

McSweeney, Weatherly, and Roll (1995) and McSweeney, Weatherly, and Swindell (1996b) studied responding by rats and pigeons during concurrent schedules that provided a wide range of rates of reinforcement. They reported that the within-session patterns of responding were usually similar for the two components of a concurrent schedule regardless of whether similar (McSweeney *et al.*, 1996b) or different (McSweeney *et al.*, 1995) types of responses produced reinforc-

ers in the two components, and regardless of whether reinforcers were delivered at similar or different rates during those components.

The present experiments were designed to find out whether a similar conclusion would be reached if the two components provided different reinforcers. Heyman (1993) provided preliminary information on this topic. He studied responding on concurrent schedules that provided ethanol in one component and sucrose in the other. Rate of responding changed differently within the session for the two components when response rate was plotted as a function of the number of obtained ethanol reinforcers.

The present experiments extended this finding. They were designed to examine within-session changes in responding for non-drug reinforcers (food and water for rats in Experiment 1; wheat and mixed grain for pigeons in Experiment 2). Within-session patterns of time spent responding were examined, as were within-session patterns of response rates. The ratio of the programmed rates of reinforcement was varied so that the generalized matching law could be fit to the data. Subjects were also exposed to schedules that delivered rates of reinforcement within the range of values typically studied. In Heyman's (1993) experiment the variable-interval (VI) schedules comprising the concurrent pair were unusually short (VI 5 s). Finally, two species of subjects and four types of reinforcers were examined to determine the generality of the results.

EXPERIMENT 1

Experiment 1 examined responding when rats pressed levers during concurrent schedules that provided food in one component and water in the other.

Method

Subjects. The subjects were 5 experimentally naive male rats, bred from Sprague-Dawley stock. They were maintained at approximately 85% of their free-feeding weights by post-session feedings given when all subjects had completed their daily sessions. Weights were established immediately before the start of the experiment, which began when subjects were approximately 120 days old. During days when a session was conducted, subjects were

given 30 min of access to water when all subjects had completed the experimental session. During days when a session was not conducted, subjects were given free access to water all day. Subjects were housed individually and were exposed to a 12:12 hr light/dark cycle.

Apparatus. The apparatus was a two-lever operant conditioning chamber, measuring 29 cm by 23 cm by 21.5 cm. Two levers (5.5 cm by 1.5 cm) were located 11.5 cm above the floor. The left lever was 5 cm from the left wall; the right lever was 2.5 cm from the right wall. The levers were made of clear Plexiglas and could be illuminated by lights centered inside of them. An opening (5.5 cm diameter) allowed access to a 0.25-ml dipper. The opening was located 3 cm above the floor and 8.5 cm from the right wall. A rectangular food cup (4.5 cm wide) extended 4 cm into the chamber, 5 cm above the floor and 2.5 cm from the left wall. The cup was 1.5 cm deep. A houselight (3 cm diameter) was located 3 cm from the top of the chamber and 11.5 cm from the right wall. The apparatus was enclosed in a sound-attenuating chamber. An exhaust fan masked noises from outside. Experimental events were presented and data were recorded by MED Associates software run by an IBM®-compatible 486 computer, located in another room.

Procedure. Subjects were trained to press the left and the right levers by a shaping-by-successive-approximations procedure. The reinforcer obtained by pressing the left lever was one 45-mg Noyes pellet. The reinforcer obtained by pressing the right lever was 5-s access to the 0.25-ml dipper that contained water. The rate of reinforcement obtained by pressing each lever was gradually reduced until subjects responded at a steady rate on a VI 60-s schedule. Then the experiment began.

In the first condition, subjects responded on a concurrent VI 60-s VI 60-s schedule. The lights in the left and right levers were illuminated at all times during the session, except during presentation of the water reinforcers. Reinforcers were scheduled according to two 25-interval Fleshler and Hoffman (1962) series. The series used for each lever was independent of that used for the other lever. A 3-s changeover delay (COD), during which responses were not reinforced, followed all changes from one operandum to

the other. Sessions were 60 min long, excluding the time of dipper presentation, and were conducted daily, five to six times per week. The chamber was illuminated throughout the session by a houselight.

When subjects had responded on the concurrent VI 60-s VI 60-s schedule for 30 sessions, they were exposed to the following schedules in the following order: concurrent VI 15 s VI 240 s, concurrent VI 120 s VI 30 s, concurrent VI 30 s VI 120 s, concurrent VI 240 s VI 15 s, and concurrent VI 60 s VI 60 s. Here, and throughout this paper, the water component is listed first, and the food component is listed second. Each schedule was studied for 30 sessions.

Results and Discussion

Figures 1 and 2 present the within-session patterns of responding for each subject during each component of each concurrent schedule. Response rates were calculated by dividing the number of responses in each component by the total session time. The time for which the dipper was available was excluded from these calculations. Figures 1 and 2 show that subjects often responded at different average rates during the two components of a concurrent schedule. These differences could be attributed to several differences between the components, including the type of reinforcer provided, the rate of reinforcement obtained, the response operandum used, and so forth. The rate of responding, averaged over the session, usually increased with increases in the rates of reinforcement provided by the components for both food and water. The mean rates of responding for food, averaged over all subjects, were 2.1, 1.5, 5.2, 7.5, and 5.8 responses per minute during the VI 240-s, VI 120-s, VI 60-s, VI 30-s, and VI 15-s components, respectively. The mean rates of responding for water were 1.4, 2.9, 3.7, 3.6, and 3.5 responses per minute for the same components presented in the same order.

Figures 1 and 2 show that rate of responding often changed within the session. Although there is some variability in the form of the changes from subject to subject and from schedule to schedule, responding for food primarily increased early in the session. It then increased further, remained relatively constant, or decreased somewhat later in the

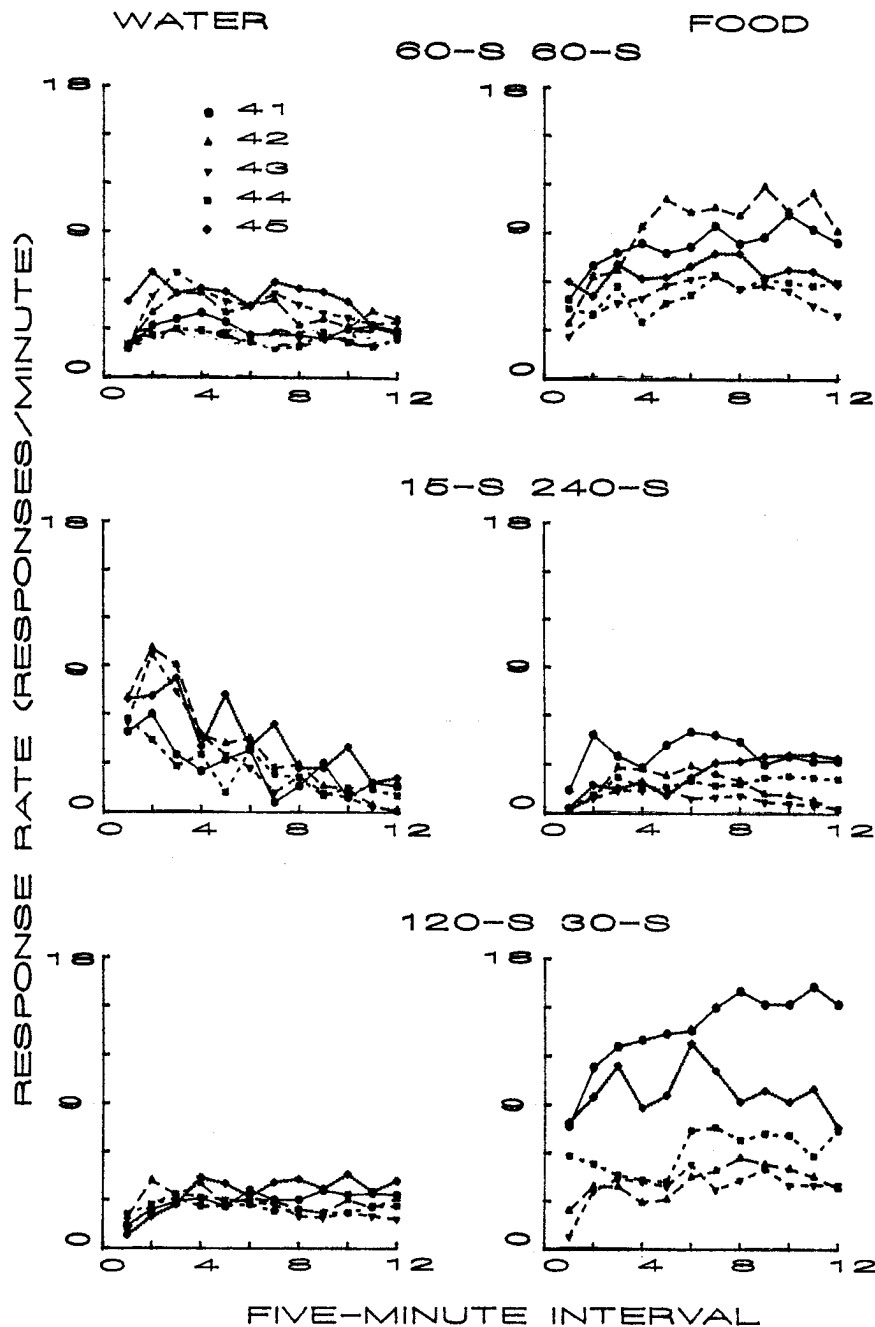


Fig. 1. Rates of responding (responses per minute) during successive 5-min intervals in the session for individual rats responding on each component of the first concurrent VI 60-s VI 60-s schedule, the concurrent VI 15-s VI 240-s schedule, and the concurrent VI 120-s VI 30-s schedule in Experiment 1. Each row of two graphs presents the results for a concurrent schedule. Responding during the water component appears on the left; responding during the food component appears on the right. Each curve presents the results for an individual rat. These results, and all of those that follow, have been averaged over the last five sessions for which a schedule was available.

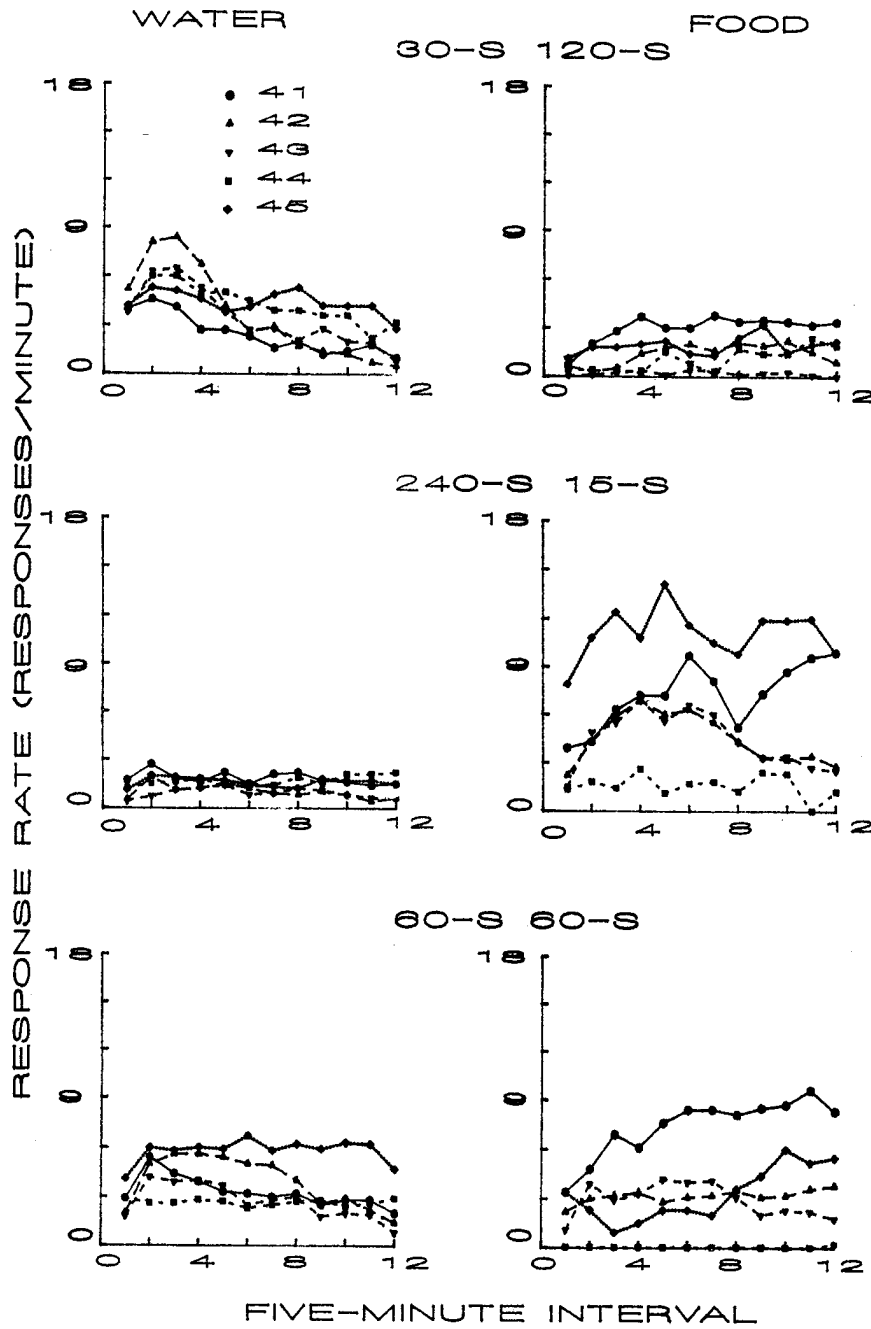


Fig. 2. Rates of responding (responses per minute) during successive 5-min intervals in the session for individual rats responding on the concurrent VI 30-s VI 120-s schedule, concurrent VI 240-s VI 15-s schedule, and the second concurrent VI 60-s VI 60-s schedule in Experiment 1. Results are presented as in Figure 1.

session. Responding for water also increased early in the session and then decreased or remained relatively constant.

Figure 3 compares the within-session pat-

terns of responding during the two components of each concurrent schedule for the mean of all subjects. Percentages of total-session responses are presented so that the dif-

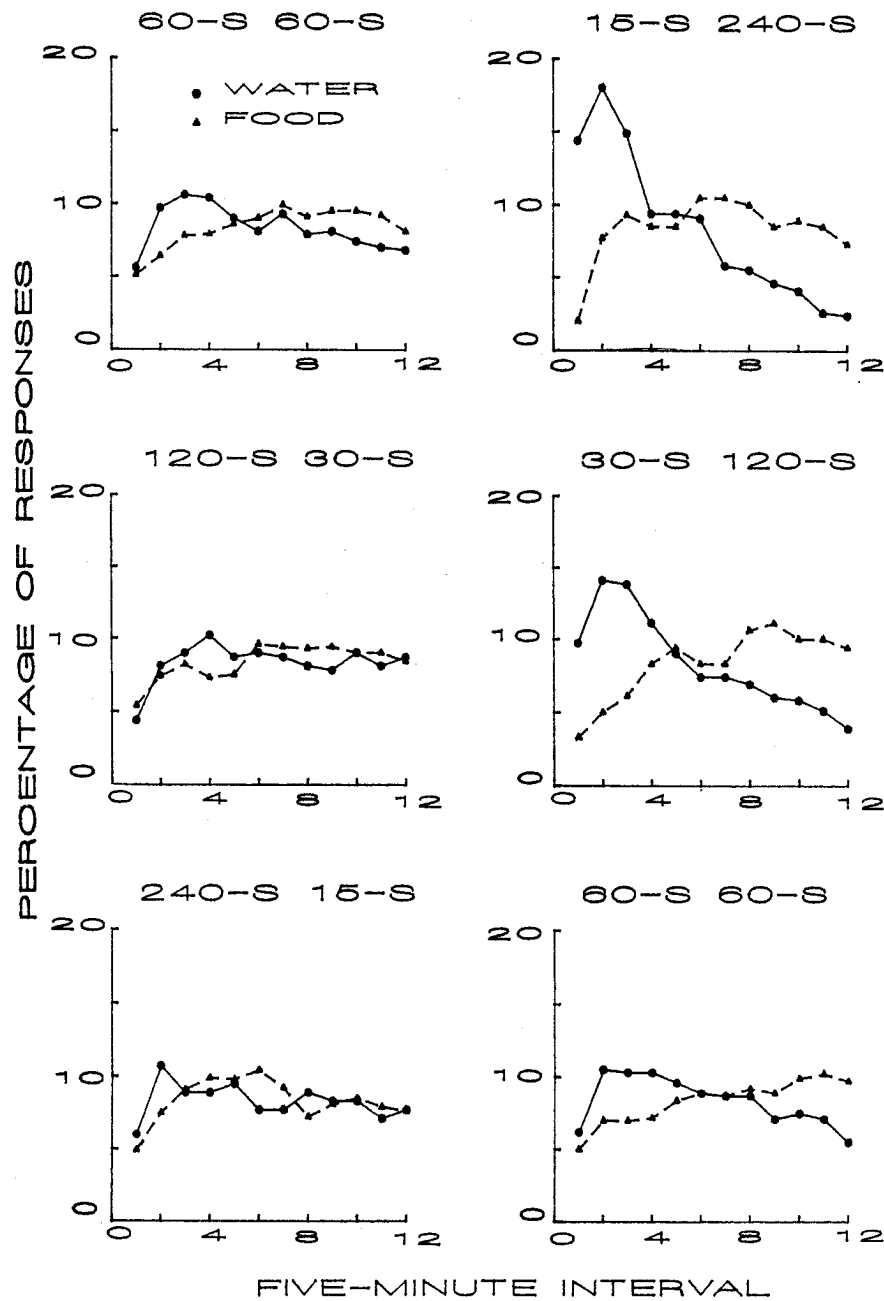


Fig. 3. Percentage of total-session responses during successive 5-min intervals in the session, calculated for the mean of all subjects responding on the water (solid line) and food (dashed line) components of each concurrent schedule in Experiment 1. Each graph presents the results for a different schedule. Percentages were calculated by dividing the number of responses for water (or food) during a 5-min interval by the total number of responses for water (or food) during the session and multiplying by 100%.

ferences in the absolute rates of responding between the components (Figures 1 and 2) would not obscure similarities or differences in the within-session patterns of responding for the two components.

Figure 3 shows that within-session changes in responding were larger during components that provided higher rates of reinforcement (e.g., VI 15 s and VI 30 s) than during components that provided lower rates (e.g., VI 120 s and VI 240 s). It also shows that the within-session patterns of responding differed for the two components, even when the components provided the same rates of reinforcement (concurrent VI 60-s VI 60-s schedules). This conclusion was confirmed by the results of two-way (Component \times Interval) within-subject analyses of variance (ANOVAs) applied to the rates of responding during each component of each concurrent schedule. The main effect of 5-min interval was significant for each schedule: $F(11, 44) = 4.912$, first concurrent VI 60-s VI 60-s schedule; $F(11, 44) = 7.679$, concurrent VI 15-s VI 240-s schedule; $F(11, 44) = 5.918$, concurrent VI 120-s VI 30-s schedule; $F(11, 44) = 6.290$, concurrent VI 30-s VI 120-s schedule; and $F(11, 44) = 3.553$, concurrent VI 240-s VI 15-s schedule, indicating that responding usually changed significantly within the session. The exception was the second concurrent VI 60-s VI 60-s schedule, $F(11, 44) = 1.515$. The interaction term was significant for each schedule: $F(11, 44) = 7.227$, $F(11, 44) = 13.940$, $F(11, 44) = 2.239$, $F(11, 44) = 9.496$, $F(11, 44) = 2.446$, $F(11, 44) = 3.546$ (presented in the order listed above), indicating that the within-session patterns of responding differed for the two components of each schedule. The main effect of component was significant for the first concurrent VI 60-s VI 60-s schedule, $F(1, 4) = 11.549$, the concurrent VI 30-s VI 120-s schedule, $F(1, 4) = 9.362$, and the concurrent VI 240-s VI 15-s schedule, $F(1, 4) = 7.774$, indicating that absolute response rates averaged over the session sometimes differed for the components. Here, and throughout this paper, results will be considered to be significant when $p < .05$.

Figure 4 presents within-session changes in time spent responding on the water component. Time spent responding on the water component was determined by a timer that started when the subject responded on the

water component and stopped when the subject responded on the food component. The timer for food started when the subject responded for food and stopped when the subject responded for water. Results have been presented only for water because the time spent responding for food and water summed to the 300 total seconds available for all 5-min intervals except the first. The time to the first response was not included in the time spent responding for either food or water in the first interval.

Figure 4 shows that the time spent responding for water often changed within the session. When water was provided at a high rate, subjects responded mainly for water early in the session but shifted to responding mainly for food later. When water was provided at a lower rate, the time spent responding on the water component either increased or remained relatively constant across the session. One-way (5-min interval) within-subject ANOVAs applied to the time spent responding for water failed to reach significance only for the first concurrent VI 60-s VI 60-s schedule, $F(11, 44) = 1.597$. The ANOVAs were significant for all other schedules: $F(11, 44) = 15.506$, concurrent VI 15-s VI 240-s schedule; $F(11, 44) = 3.213$, concurrent VI 120-s VI 30-s schedule; $F(11, 44) = 5.263$, concurrent VI 30-s VI 120-s schedule; $F(11, 44) = 2.592$, concurrent VI 240-s VI 15-s schedule; and $F(11, 44) = 3.087$, second concurrent VI 60-s VI 60-s schedule.

Finding different within-session patterns of responding for food and water implies that the parameters and fit of the generalized matching law might not be constant across the session. Figures 5 and 6 confirm this conclusion. Figure 5 presents the parameters of the generalized matching law and the percentage of the variance accounted for when results were calculated for the mean of all subjects. To compute these parameters, a mean rate of responding and a mean time spent responding were calculated over all subjects responding on each component of each concurrent schedule. A linear least squares procedure was used to fit the generalized matching law to the logarithms of the ratios of these means. The left graphs (response matching) present the results when the generalized matching law was fit to the ratio of response rates. The right graphs

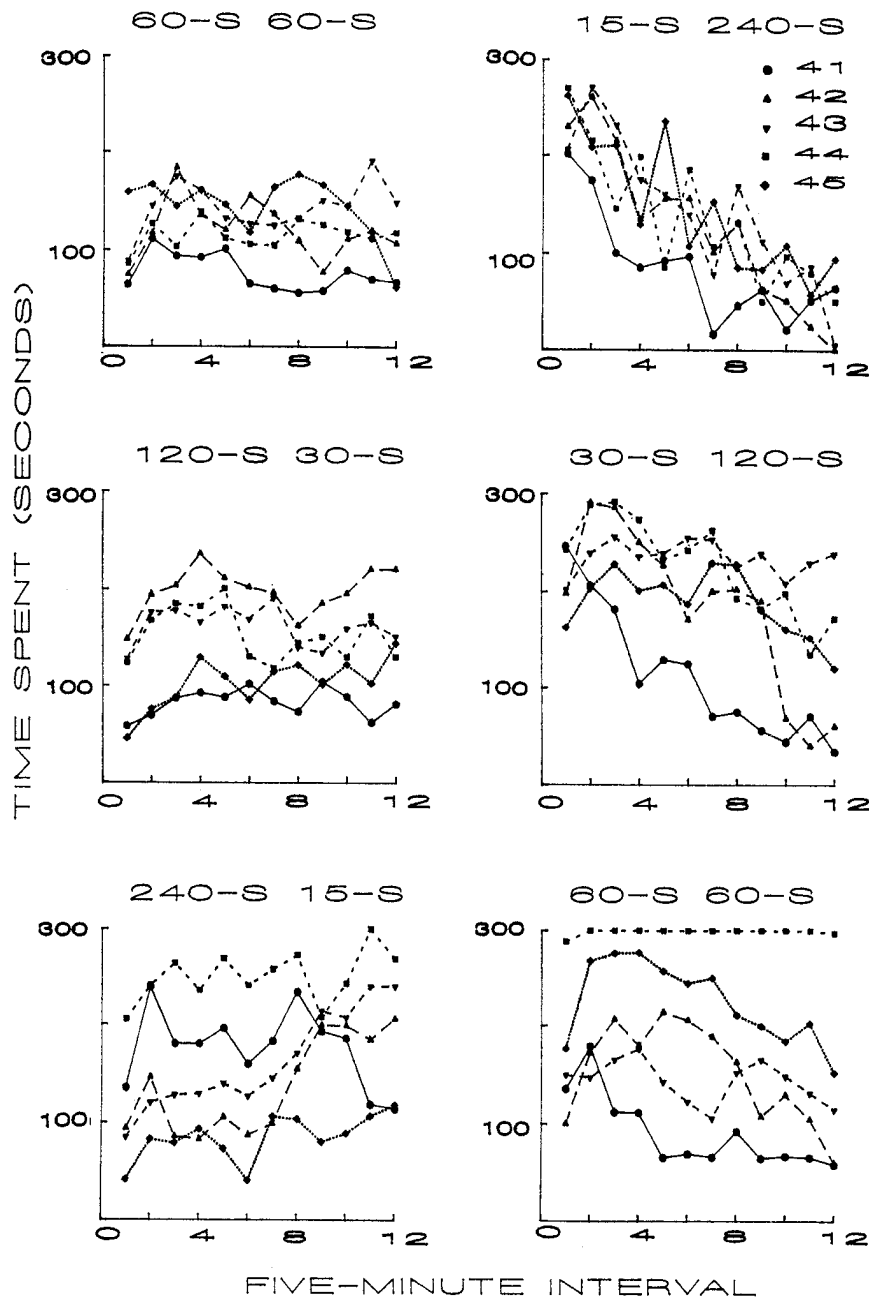


Fig. 4. Time spent responding on the water component (seconds) during successive 5-min intervals in the session in Experiment 1. Each curve presents the results for an individual subject. Each graph presents the results for a concurrent schedule. The schedule for the water component appears before the schedule for the food component in the label for the graph.

(time matching) present the results when the generalized matching law was fit to the ratio of the times spent responding. In all cases, results for water were divided by those for

food. Figure 6 presents the results when a similar procedure was used to fit the generalized matching law to data for individual subjects. Because results were somewhat variable

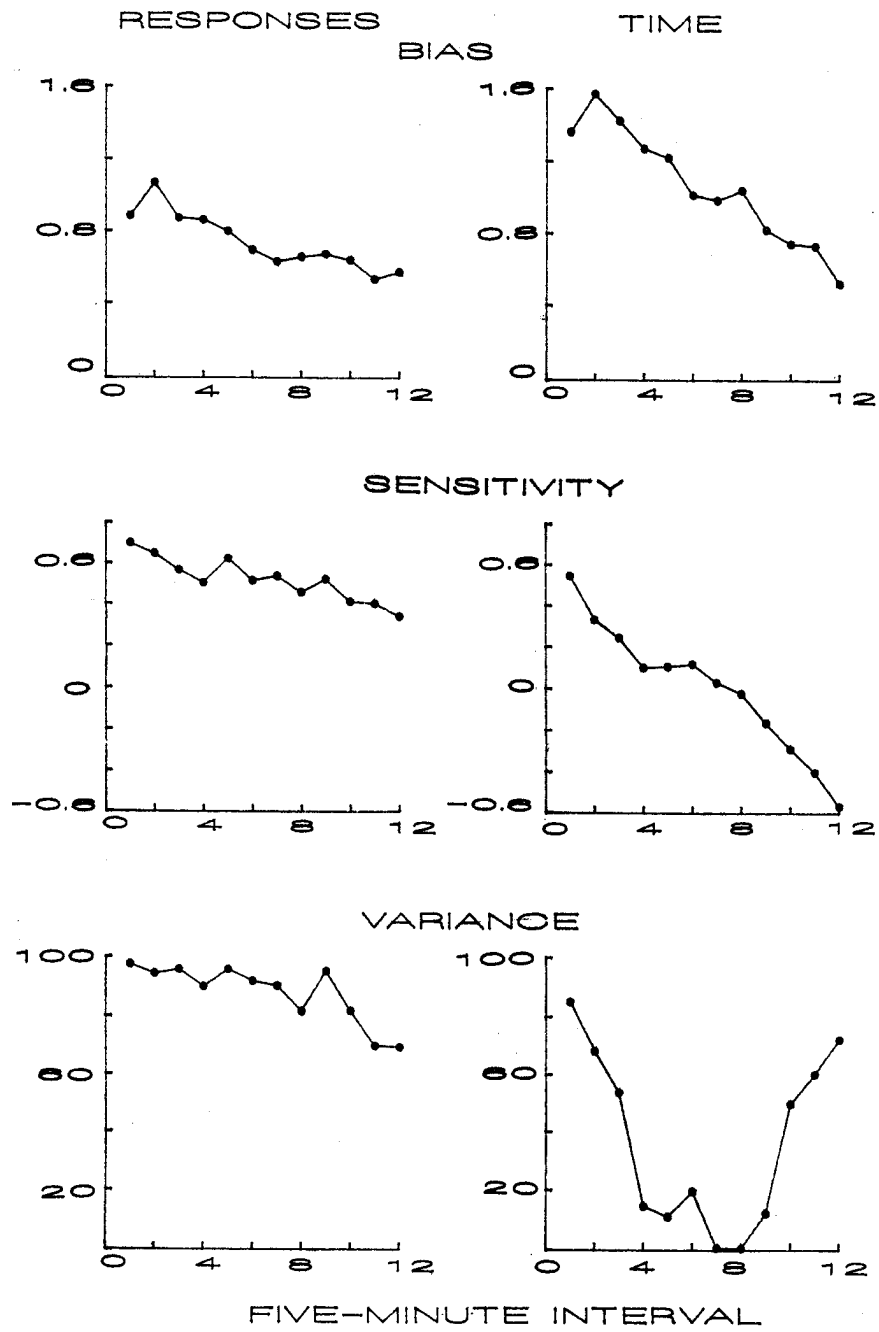


Fig. 5. The bias (top graphs) and sensitivity (middle graphs) parameters of the generalized matching law, as well as the percentage of the variance accounted for (bottom graphs), during successive 5-min intervals when the generalized matching law was applied to the ratios of the rates of responding (left graphs) and to the ratios of the times spent responding (right graphs) for the mean of all rats in Experiment 1.

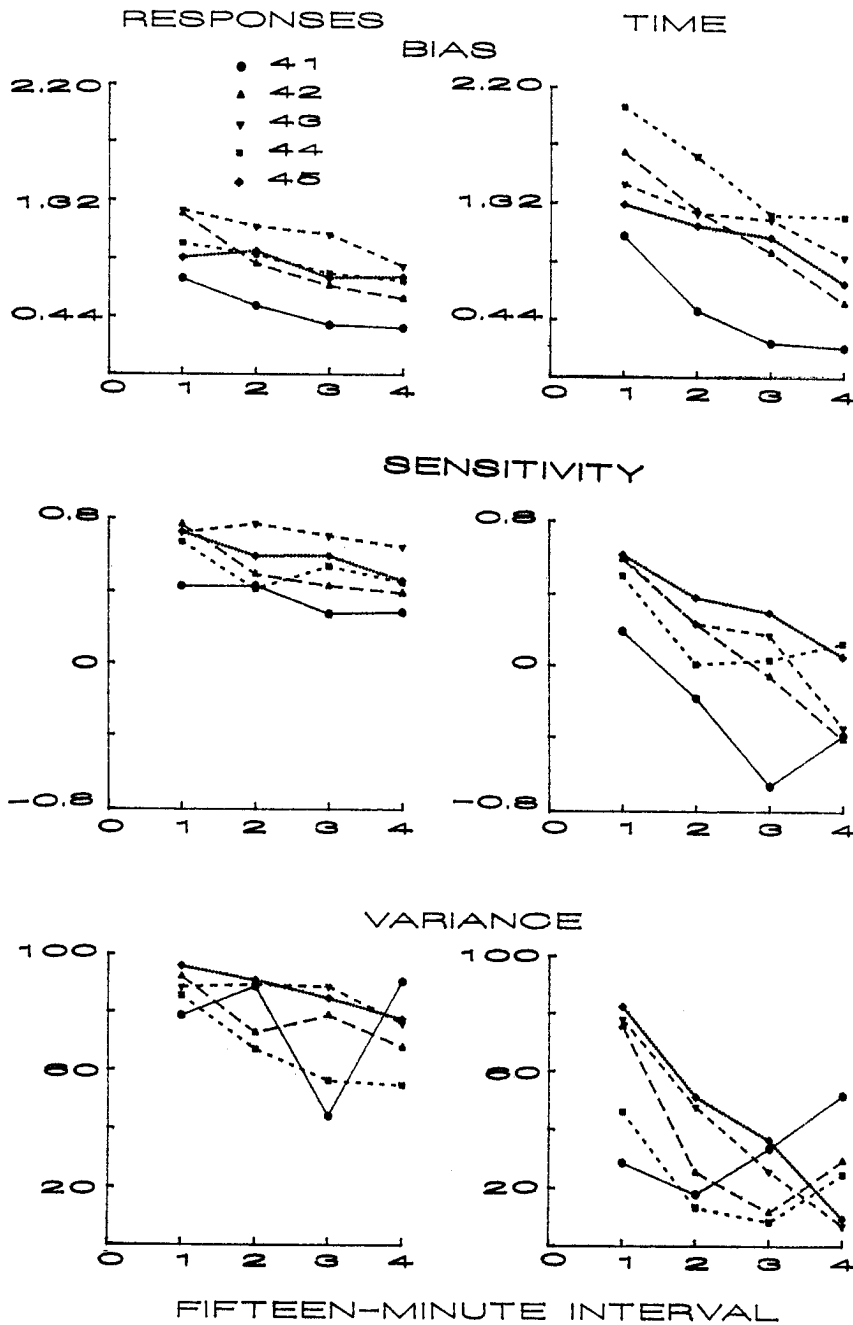


Fig. 6. The bias (top graphs) and sensitivity (middle graphs) parameters of the generalized matching law, as well as the percentage of the variance accounted for (bottom graphs), when the generalized matching law was applied to the ratios of the rates of responding (left graphs) and to the ratios of the times spent responding (right graphs) for individual rats in Experiment 1. These parameters were calculated from the data in successive 5-min intervals. Each plotted point is a mean of three successive 5-min intervals. Each curve presents the results for an individual rat.

when ratios were calculated over intervals as short as 5 min, Figure 6 presents the results when the parameters or fits, calculated for each 5-min interval, were averaged over three successive 5-min intervals.

Figures 5 and 6 show that the bias and sensitivity parameters mainly decreased from the beginning to the end of the session for all subjects and for the mean of all subjects, for both response and time matching. The decreases in the size of both parameters were steeper for time matching than for response matching. Bias was sometimes greater than 1 early in the session and less than 1 later, indicating that bias shifted from one component to the other as the session progressed. The percentage of variance accounted for usually decreased across the session, with late-session increases for some subjects and for the mean of all subjects. The sensitivity parameters were sometimes negative late in the session for time matching. Finally, the size of the sensitivity parameter was small (less than 0.8) relative to the size usually reported when the components of concurrent schedules provide the same type of reinforcers and results are averaged over the session. For example, Taylor and Davison (1983) reported that the mean size of the sensitivity parameter was 0.97 for response matching and 0.96 for time matching for experiments that used relatively standard procedures and that scheduled reinforcers according to an exponential progression similar to that used here.

EXPERIMENT 2

Experiment 2 examined responding when pigeons pecked keys during concurrent schedules that provided wheat in one component and mixed grain in the other.

Method

Subjects. The subjects were 3 experimentally experienced pigeons, maintained at approximately 85% of their free-feeding body weights by postsession feedings delivered when all subjects had completed the daily session. Subjects were housed individually and were exposed to a 12:12 hr light/dark cycle.

Apparatus. The apparatus was a three-key experimental enclosure, measuring 32.5 by 30.5 by 35.5 cm. Three response keys (2.5 cm diameter) were located 23.5 cm above the

floor and 7.5 cm apart. The left and right keys were located 6.5 cm from the left and right walls, respectively. A force of approximately 0.25 N was required to operate each key. Two openings (6.5 cm by 4 cm) allowed access to food magazines. They were located 9.5 cm below the left and right keys. A light behind a panel (4.5 cm diameter) served as the houselight. It was located 0.75 cm from the left wall and 23 cm above the floor. The experimental panel 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 run by an IBM[®]-compatible 486 computer, located in another room.

Procedure. Subjects had pecked keys in previous experiments. Therefore, they were placed directly on the experimental procedure. Subjects responded on the following concurrent schedules in the following order: concurrent VI 60 s VI 60 s, concurrent VI 15 s VI 240 s, concurrent VI 120 s VI 30 s, concurrent VI 30 s VI 120 s, concurrent VI 240 s VI 15 s, and concurrent VI 60 s VI 60 s. Here and throughout this paper, responding on the right key produced the reinforcers for the component listed first (5-s access to wheat, obtained from the right magazine). Responding on the left key produced the reinforcers for the component listed second (5-s access to mixed grain, obtained from the left magazine). The left and right keys were illuminated with white light except when a reinforcer was presented. Reinforcers were scheduled according to an independent 25-interval Fleshler and Hoffman (1962) series for each component. A 3-s COD, during which no responses were reinforced, followed all changes from one operandum to the other. Sessions were 60 min long, excluding reinforcement time, and were conducted daily, five to six times per week. Each concurrent schedule was presented for 30 sessions. The chamber was illuminated throughout the session by the houselight.

Results and Discussion

Figures 7 and 8 present the within-session patterns of responding for each subject responding during each component of each concurrent schedule. Response rates were calculated as in Figures 1 and 2. Again, the

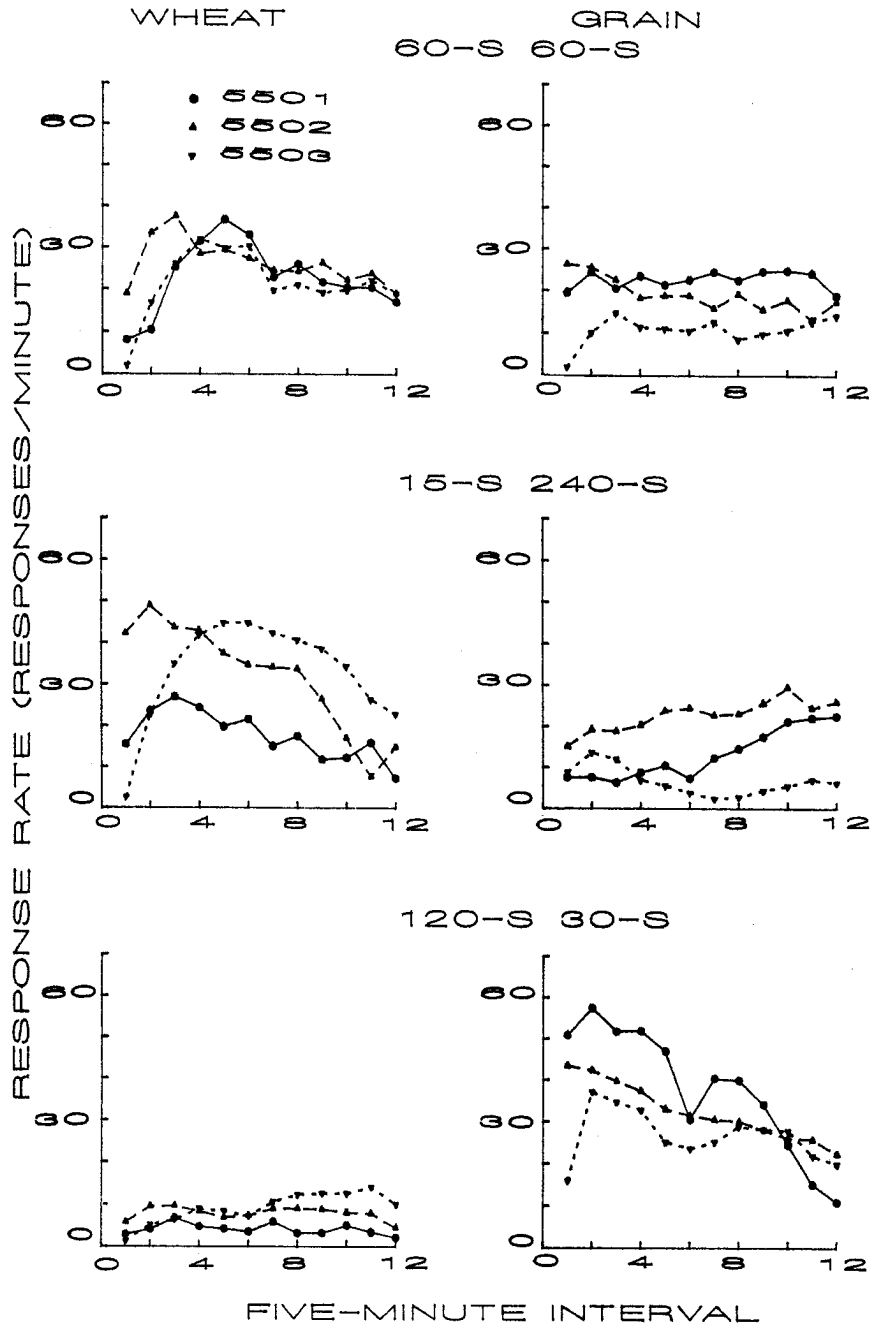


Fig. 7. Rates of responding (responses per minute) during successive 5-min intervals in the session for individual pigeons responding on each component of the first concurrent VI 60-s VI 60-s schedule, the concurrent VI 15-s VI 240-s schedule, and the concurrent VI 120-s VI 30-s schedule in Experiment 2. Each row of two graphs represents responding during a single concurrent schedule. Responding during the wheat component appears on the left; responding during the mixed grain component appears on the right. The labels present the schedule in the wheat component before the schedule in the mixed grain component. Each curve presents the results for an individual pigeon.

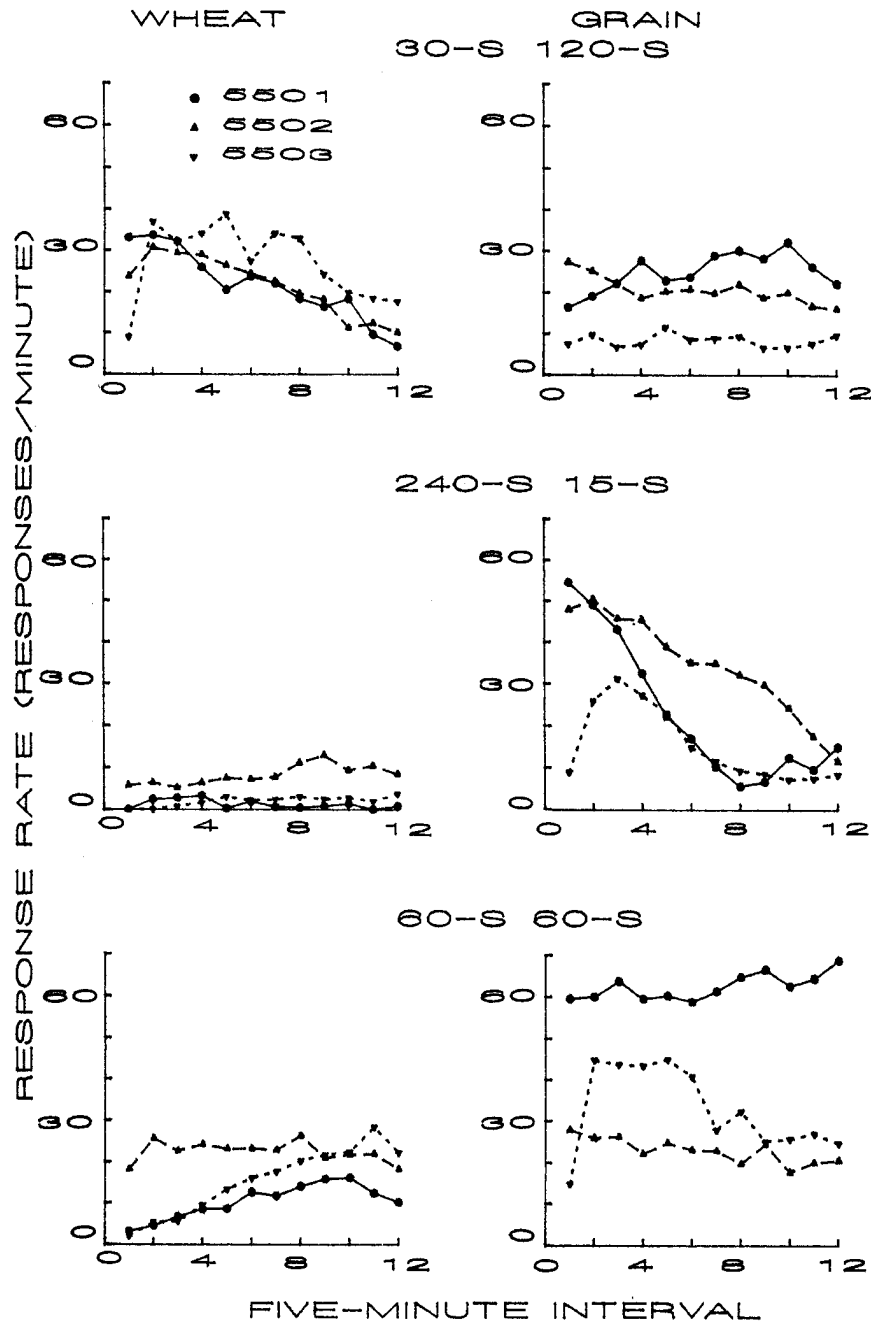


Fig. 8. Rates of responding (responses per minute) during successive 5-min intervals in the session for individual pigeons responding on each component of the concurrent VI 30-s VI 120-s schedule, the concurrent VI 240-s VI 15-s schedule, and the second concurrent VI 60-s VI 60-s schedule in Experiment 2. Results are presented as in Figure 7.

time for which reinforcement was available was excluded from total session time. These figures show that subjects responded at different average rates during the two compo-

nents. This difference could be attributed to differences in the reinforcers, the response operanda, the obtained rates of reinforcement, and so forth, available on the two com-

ponents. Rates of responding, averaged across the session, usually increased with increases in the rates of reinforcement provided by the component. The mean rates of responding for wheat were 3.8, 7.0, 19.8, 23.4, and 27.6 responses per minute for the VI 240-s, VI 120-s, VI 60-s, VI 30-s, and VI 15-s schedules, respectively. The mean rates of responding for mixed grain were 14.1, 18.0, 28.4, 32.3, and 24.2 responses per minute for the same schedules presented in the same order.

Figure 9 compares the within-session patterns of responding during the two components of each concurrent schedule. Again, percentages have been presented instead of absolute response rates so that differences in the absolute rates of responding averaged over the session (Figures 7 and 8) would not obscure similarities or differences in the within-session patterns of responding. Although there is some variability in the form of the within-session changes in responding from subject to subject and from schedule to schedule, Figures 7, 8, and 9 show that response rates often changed within the session. The changes were also larger when the components provided higher (e.g., VI 15 s and VI 30 s) rather than lower (e.g., VI 120 s and VI 240 s) rates of reinforcement.

Figure 9 shows that the within-session patterns of responding often differed for the components. This impression was confirmed by the results two-way (Component \times Interval) within-subject ANOVAs applied to the rates of responding during each concurrent schedule. The main effect of 5-min interval was significant for each schedule: $F(11, 22) = 2.542$, first concurrent VI 60-s VI 60-s schedule; $F(11, 22) = 2.696$, concurrent VI 120-s VI 30-s schedule; $F(11, 22) = 4.028$, concurrent VI 30-s VI 120-s schedule; $F(11, 22) = 4.447$, concurrent VI 240-s VI 15-s schedule. The exceptions were for the concurrent VI 15-s VI 240-s schedule, $F(11, 22) = 1.605$, and the second concurrent VI 60-s VI 60-s schedule, $F(11, 22) = 1.182$. These results indicate that responding usually changed significantly within the session. The interaction terms were also significant for all schedules, $F(11, 22) = 6.332$, $F(11, 22) = 6.001$, $F(11, 22) = 2.710$, and $F(11, 22) = 7.840$ (presented in the same order as above) except for the concurrent VI 15-s VI 240-s schedule, $F(11, 22)$

$= 1.760$, and the second concurrent VI 60-s VI 60-s schedule, $F(11, 22) = 1.334$. This indicates that the within-session patterns of responding often differed for the two components. The main effect of component was significant for the concurrent VI 120-s VI 30-s schedule, $F(1, 2) = 29.147$, and the concurrent VI 240-s VI 15-s schedule, $F(1, 2) = 28.699$, indicating that the absolute rates of responding averaged over the session sometimes differed for the two components.

Figure 10 presents within-session patterns of time spent responding on the wheat component for individual subjects. Again, results have been presented only for the wheat component because the time spent responding on the two components must sum to the 300 total seconds available for all 5-min intervals except the first. Figure 10 shows that the time spent responding for wheat changed within the session, often increasing and then decreasing. One-way (5-min interval) within-subject ANOVAs applied to the time spent responding for wheat were significant for the first, $F(11, 22) = 5.605$, and the second, $F(11, 22) = 5.423$, concurrent VI 60-s VI 60-s schedules but not for the concurrent VI 15-s VI 240-s schedule, $F(11, 22) = 1.262$, the concurrent VI 120-s VI 30-s schedule, $F(11, 22) = 1.144$, the concurrent VI 30-s VI 120-s schedule, $F(11, 22) = 1.529$, and the concurrent VI 240-s VI 15-s schedule, $F(11, 22) = 1.424$.

Examination of Figure 10 suggests that the time spent responding may have changed significantly within sessions for individual subjects even when the change was not significant for the mean of all subjects. This was confirmed by the results of one-way (5-min interval) ANOVAs applied to the time spent responding on the wheat component by individual subjects during the last five sessions for which a concurrent schedule was available. ANOVAs were calculated only for schedules with nonsignificant effects of time for the mean of all subjects. Time spent responding for wheat changed significantly within the session for all schedules for Pigeon 5502, $F(11, 44) = 17.781$, concurrent VI 15-s VI 240-s schedule; $F(11, 44) = 2.198$, concurrent VI 120-s VI 30-s schedule; $F(11, 44) = 5.425$, concurrent VI 30-s VI 120-s schedule; $F(11, 44) = 4.519$, concurrent VI 240-s VI 15-s schedule; and Pigeon 5503, $F(11, 44) = 5.796$,

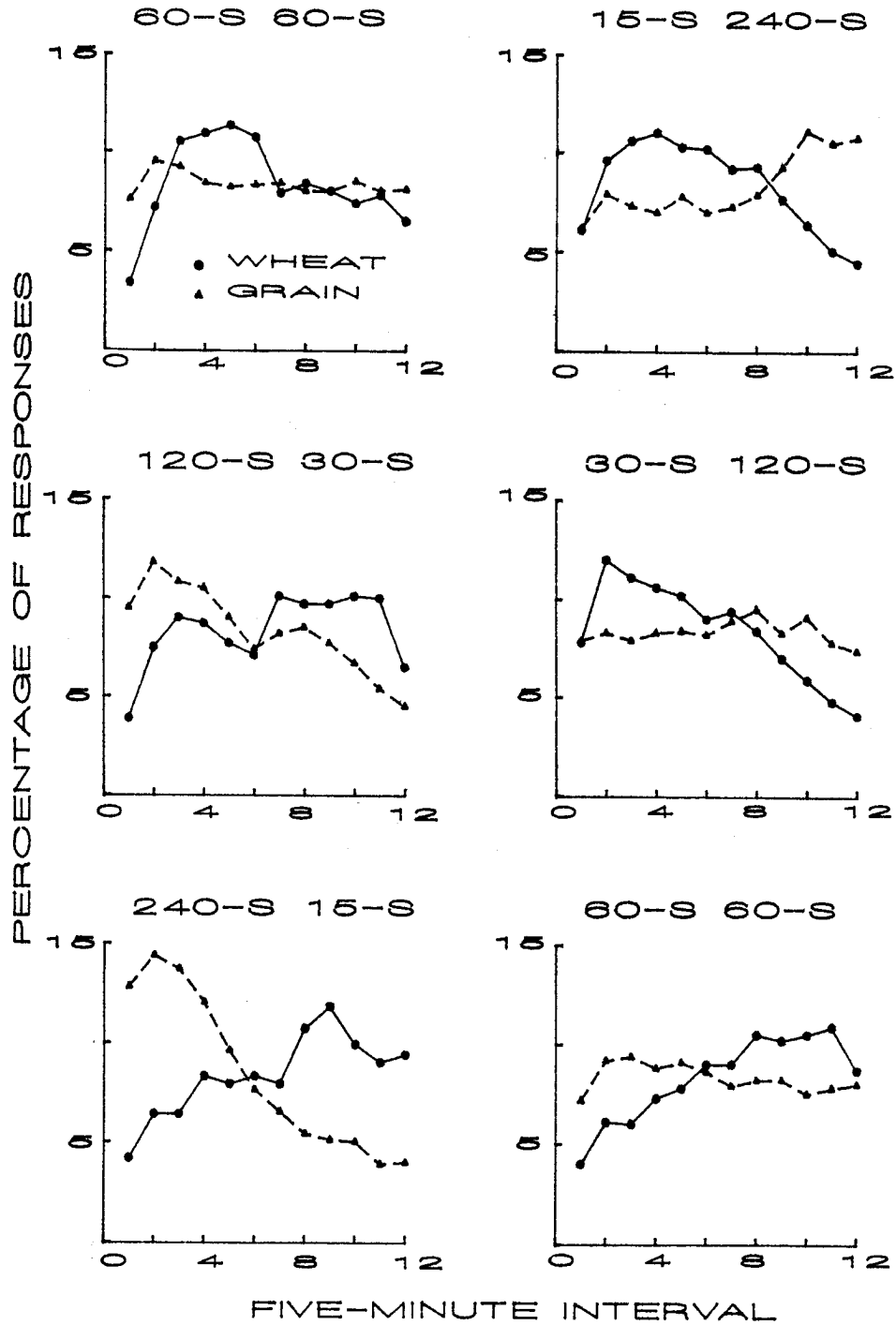


Fig. 9. Percentage of total-session responses during successive 5-min intervals, calculated for the mean of all subjects responding on the wheat (solid line) and mixed grain (dashed line) components of each concurrent schedule in Experiment 2. Each graph presents the results for a different schedule. The labels on the graphs present the wheat schedule before the mixed grain schedule. Percentages are calculated and presented as in Figure 3.

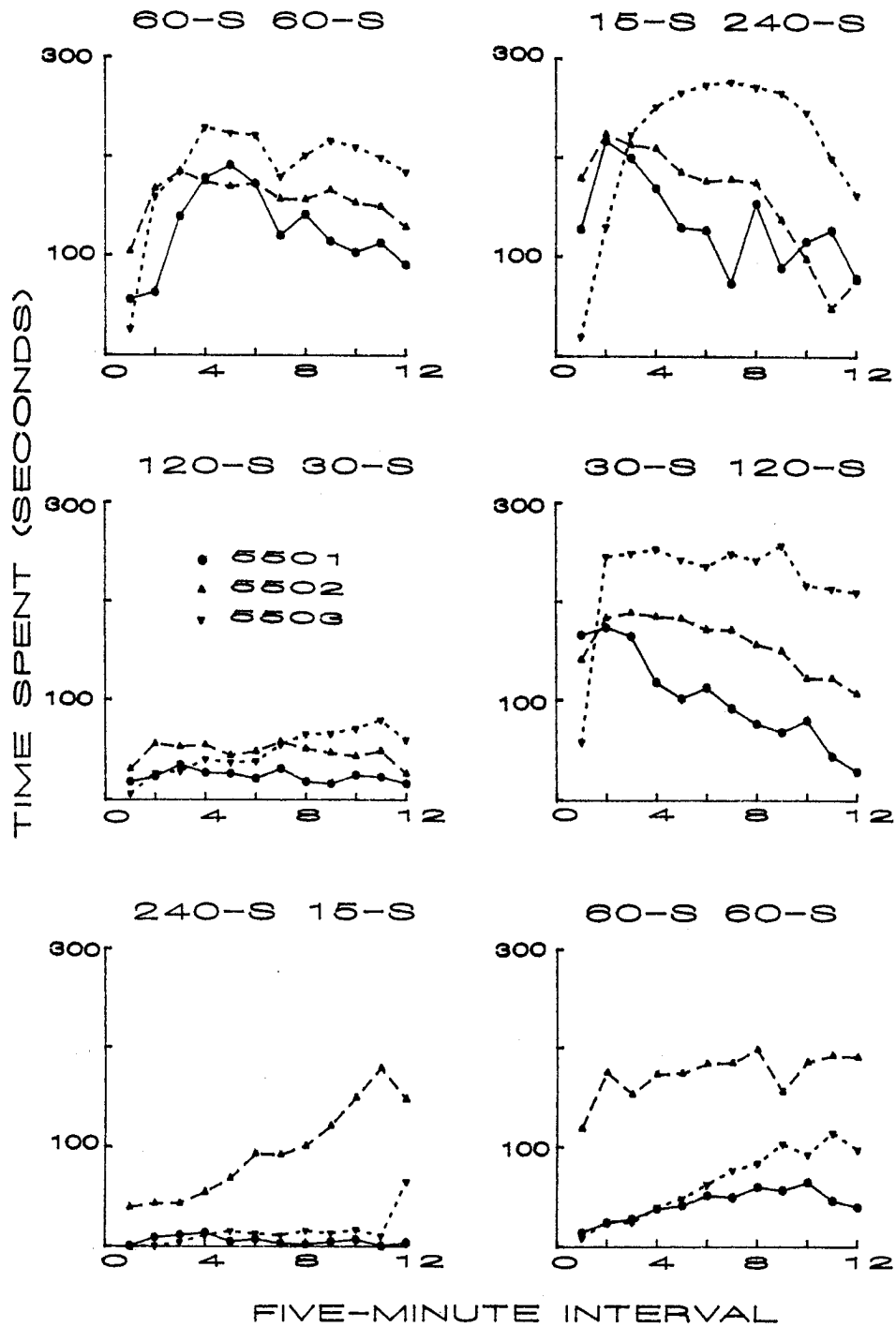


Fig. 10. The time spent responding on the wheat component (seconds) during successive 5-min intervals in the session in Experiment 2. Each function presents the results for an individual pigeon. Each graph presents the results for a concurrent schedule. The schedule of wheat reinforcement is presented before the schedule of mixed grain reinforcement in the labels for the graphs.

$F(11, 44) = 7.264$, $F(11, 44) = 19.779$, $F(8, 32) = 2.915$ (presented in the same order as above). Time spent responding for wheat changed significantly for Pigeon 5501 only on the concurrent VI 30-s VI 120-s schedule, $F(11, 44) = 8.211$. Fewer degrees of freedom appear for Pigeon 5503 on the concurrent VI 240-s VI 15-s schedule because this subject did not respond on the wheat component throughout the session during that schedule.

Figures 11 and 12 present within-session changes in the parameters and fit of the generalized matching law. Figure 11 presents the results calculated for the mean of all subjects, and Figure 12 presents the results for individual subjects. Results were analyzed and presented as in Figures 5 and 6. Results for wheat were divided by those for mixed grain. The size of the sensitivity parameter decreased from the beginning to the end of the session for all subjects, although the size of the change was small for Pigeon 5503 when time matching was considered. The percentage of the variance decreased for 2 subjects but increased for Pigeon 5503. The bias parameter also changed differently across the session for different subjects, resulting in erratic changes in the bias parameter for the mean of all subjects. As in Experiment 1, the sensitivity parameters were small (usually less than 0.8) relative to those observed for concurrent schedules that provide the same reinforcers in the two components when results are averaged over the session. Unlike the results presented in Experiment 1, the sensitivity parameters were not negative late in the session and the bias parameters were usually less than 1 throughout the session.

GENERAL DISCUSSION

Implications for Within-Session Changes in Responding

Rate of responding and time spent responding usually changed within sessions when rats responded on concurrent food-water schedules (Experiment 1) and when pigeons responded on concurrent wheat-mixed grain schedules (Experiment 2). This extends the generality of within-session changes in responding to concurrent schedules that provide different reinforcers in the two components and to time spent responding as a measure of behavior.

Different within-session patterns of responding were usually reported for the two components of the concurrent food-water and the concurrent wheat-mixed grain schedules. These results are similar to those reported by Heyman (1993) for concurrent ethanol-sucrose schedules. The results differ from the similar patterns of responding found for concurrent schedules that provide the same reinforcers in the two components (McSweeney et al., 1995, 1996b).

Finding different within-session patterns in the two components questions the idea that changes in a general motivational variable, such as arousal, provide a complete account for within-session changes in responding. Arousal can refer to a state of the organism (e.g., Duffy, 1962). If within-session changes in responding for food and water (or wheat and mixed grain) were both produced solely by changes in a single state, then the patterns of responding should have been similar during the two components.

McSweeney, Swindell, and Weatherly (in press) also reported results that question an arousal-based interpretation of within-session changes in responding. They studied within-session changes in operant responding when adjunctive drinking or wheel running was also available. The rates of operant and adjunctive responding often changed within experimental sessions. The correlation between the rates of these two types of behavior, calculated over the session, was inconsistently positive and negative. It was not strongly positive, as would be expected if changes in a single variable, such as arousal, produced the within-session changes in both types of behavior.

Finding different within-session changes in responding for different reinforcers is more compatible with explanations for these changes in terms of sensitization-habituation to, or satiation for, the reinforcer. As argued earlier, these processes might occur at different rates for different reinforcers. To clarify the difference between sensitization-habituation and satiation, satiation can refer to a decrease in consumption when an ingestive stimulus (e.g., food, water) is presented repeatedly. Sensitization-habituation refers to an increase (sensitization) followed by a decrease (habituation) in responding to a stimulus when that stimulus is presented repeat-

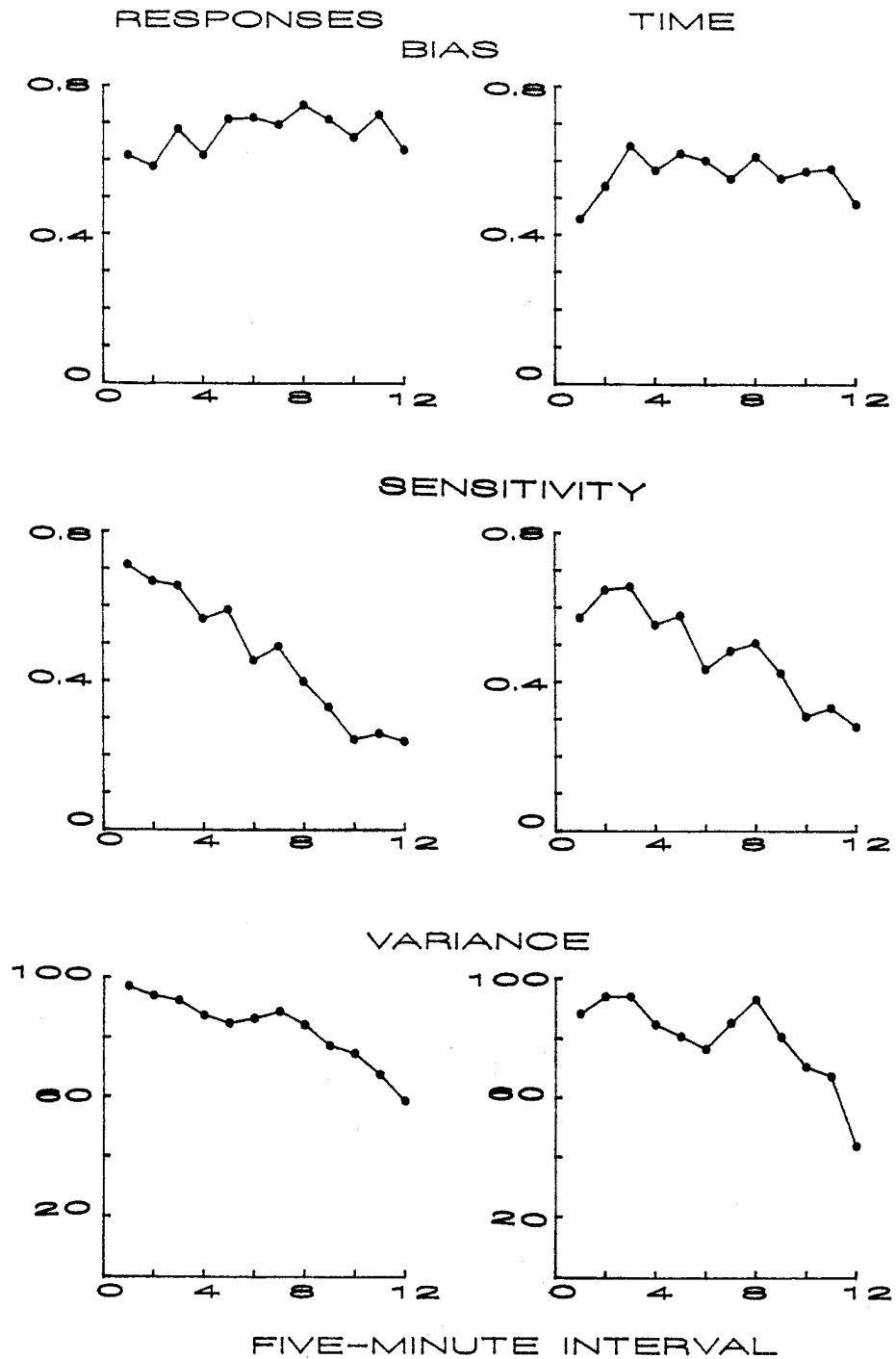


Fig. 11. The bias (top graphs) and sensitivity (middle graphs) parameters of the generalized matching law, as well as the percentage of the variance accounted for (bottom graphs), during successive 5-min intervals when the generalized matching law was applied to the ratios of the rates of responding (left graphs) and to the ratios of the times spent responding (right graphs) for the mean of all pigeons in Experiment 2.

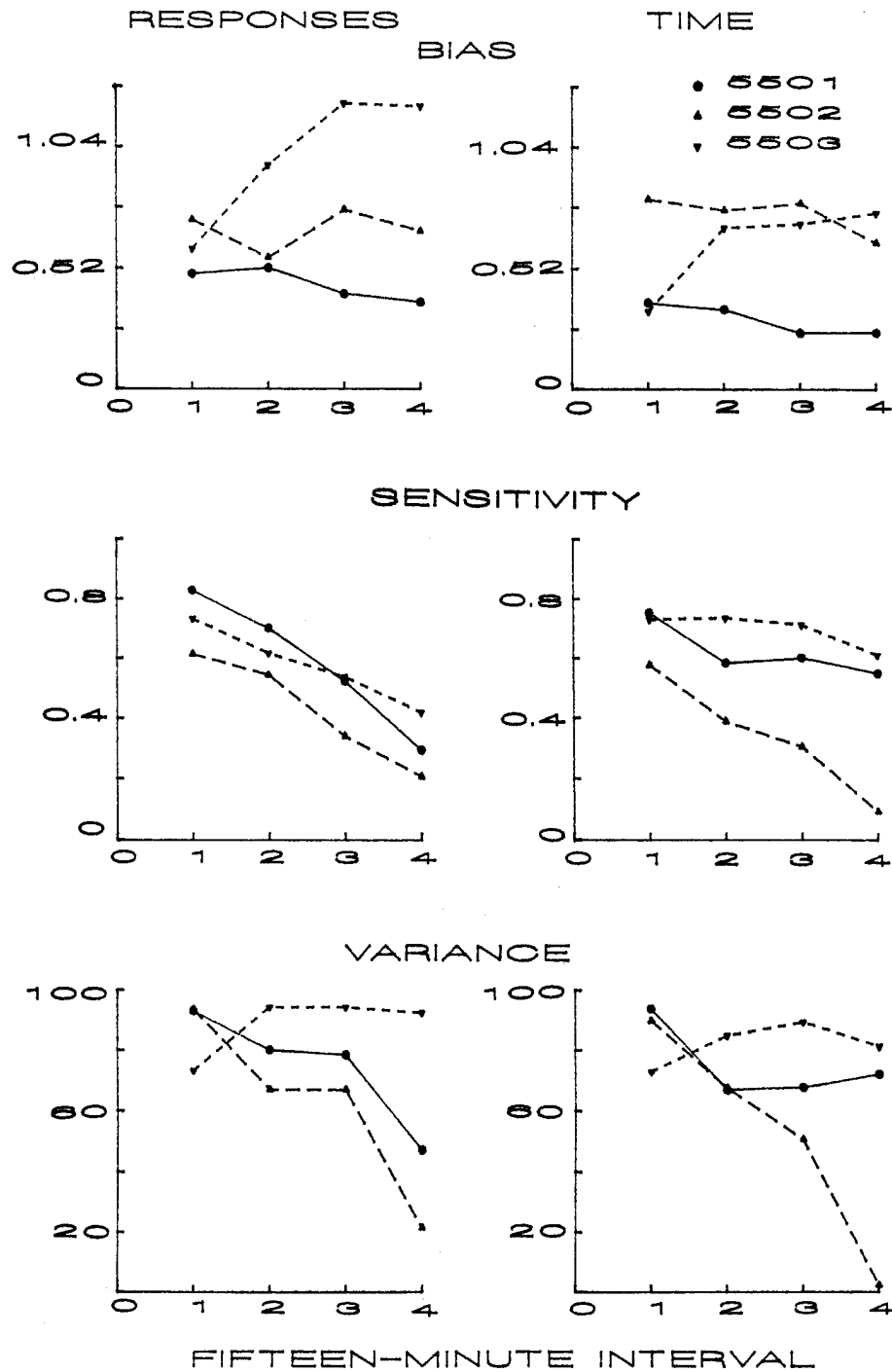


Fig. 12. The bias (top graphs) and sensitivity (middle graphs) parameters of the generalized matching law, as well as the percentage of the variance accounted for (bottom graphs), when the generalized matching law was applied to the ratios of the rates of responding (left graphs) and to the ratios of the times spent responding (right graphs) for individual pigeons in Experiment 2. These parameters were calculated from the data in successive 5-min intervals. Each plotted point is a mean of three successive 5-min intervals. Each curve presents the results for an individual pigeon.

edly or for a prolonged time. Because reinforcers are stimuli, sensitization-habituation might occur in their presence, producing systematic changes in their strength or value when they are repeatedly presented within sessions (e.g., McSweeney, Weatherly, & Swindell, 1996a). It should be noted that sensitization-habituation to the sensory characteristics of an ingestive stimulus may contribute to satiation for that stimulus, but additional factors such as gastric fill, nutritional state, and postingestive consequences also contribute to satiation (e.g., Swithers-Mulvey & Hall, 1993).

McSweeney, Hinson, and Cannon (in press) argued that sensitization-habituation provides a better explanation than satiation for within-session changes in responding under the moderate conditions (e.g., intermediate rates of reinforcement) employed in most studies. First, the empirical characteristics of the within-session patterns of operant responding are similar to the empirical characteristics of behavior reported in the literature on sensitization-habituation. Second, within-session changes have been reported even when no reinforcers are delivered (e.g., Schoenfeld, Antonitis, & Bersh, 1950). Sensitization-habituation, but not satiation, can account for these changes because it can occur in the presence of noningestive stimuli such as the experimental enclosure. Finally, many factors that alter the rate of satiation for food (e.g., the caloric density of the food, the subjects' level of food deprivation, the size of a prefeeding) do not alter within-session patterns of operant responding (Roll, McSweeney, Johnson, & Weatherly, 1995).

It should be noted that McSweeney, Hinson, and Cannon (in press) did not argue that factors other than sensitization-habituation never contribute to within-session changes in responding. Most studies of within-session changes provide easy-to-manipulate operanda and intermediate amounts of reinforcement (e.g., one Noyes pellet per reinforcer and approximately one reinforcer per minute). Under these conditions, sensitization-habituation to the stimulus properties of the reinforcer (and possibly to other stimuli, such as the experimental enclosure) may be largely responsible for the within-session changes in responding. However, under more extreme conditions (e.g., very large re-

inforcers, difficult responses), other variables (e.g., other factors related to satiation, fatigue) might also play a role.

Implications for Quantitative Theories

The parameters and fit of the generalized matching law reported here were generally consistent with those reported in past studies that provided different reinforcers in the components of concurrent schedules. For example, negative sensitivity parameters were sometimes reported in Experiment 1. Negative sensitivity parameters have been reported for monkeys responding in a closed economy on three-component concurrent food-food-water schedules (Hursh, 1978). The present sensitivity parameters were also somewhat smaller than those reported in studies that provided the same reinforcers in the two components. Matthews and Temple (1979) reported relatively small sensitivity parameters when cows responded on concurrent schedules that provided different types of food in the two components.

Figures 5, 6, 11, and 12 show that the parameters and fit of at least one quantitative theory, the generalized matching law, changed within experimental sessions. The size of bias decreased from the beginning to the end of the session for all individual rats and for 2 of 3 pigeons. The sensitivity parameter decreased from the beginning to the end of the session for all subjects, although some of these changes were small. The percentage of the variance accounted for by the generalized matching law also decreased from the beginning to the end of the session for all subjects except Rat 41 and Pigeon 5503. In some cases, the percentage was lowest towards the middle of the session and increased again later.

As argued earlier, these results imply that the fit and parameters of the generalized matching law may vary with session length. Shorter sessions may predominantly sample early-session time when the parameters are large and the fit is good. Longer sessions may include more of the late-session time. The results also indicate that applying the generalized matching law to data calculated over the whole session may neglect molecular and dynamic changes in the processes that govern responding for different reinforcers. A full account of the present data will undoubtedly

depend on understanding these processes. For example, dynamic food-water interactions may have contributed to the results of Experiment 1. In addition, the similarity of the results in Experiments 1 and 2 suggests that a factor common to food-water and wheat-mixed grain interactions also contributed.

An understanding of these processes is not available at this time. Instead, the present discussion will center on the implications of the present results for the generalized matching law. Even this discussion must be interpreted with care, however. There are many possible explanations for within-session changes in the parameters and fit of the generalized matching law. For example, late-session decreases in the percentage of variance accounted for might have contributed to the late-session decreases in the size of sensitivity parameters (but see the results for Rat 41 and Pigeon 5503). As a result, all of the present conclusions should be regarded as tentative without further study.

The present within-session changes in bias are generally consistent with Baum's (1974) interpretation of that parameter. Baum defined bias as preference for a component that is not explained by the rates of reinforcement provided by the components. He argued that the use of qualitatively different reinforcers in the components could result in a bias parameter that differed from 1. His interpretation could accommodate the present results if the relative values of the two reinforcers changed within the session.

Baum (1974) suggested that changes in deprivation for the reinforcer alter the sensitivity parameter. The present results, combined with those of past studies, show that the relation between deprivation and sensitivity may be complex. Charman and Davison (1983) and Herrnstein and Loveland (1974, as interpreted by Baum, 1974) found that sensitivity increased to approach 1 as deprivation for the programmed reinforcer decreased. In contrast, the present results showed that sensitivity decreased with decreases in deprivation if it is assumed that subjects were less deprived late in the session, after consuming many reinforcers, than they were earlier in the session. However, deprivation probably changed at different rates for the different types of reinforcers presented in

the two components of this study. Such differential changes might substantially complicate the relation between deprivation and the size of the sensitivity parameter.

Finding negative sensitivity parameters in Experiment 1, but not in Experiment 2, is consistent with Hursh's (1980, 1984) argument that negative parameters occur when reinforcers are complements rather than substitutes. Reinforcers are complements if increasing the availability of one increases the demand for the other. They are substitutes if increasing the availability of one decreases the demand for the other. Food and water should be complements, but similar types of food should be substitutes (Hursh, 1980, p. 235). Therefore, as reported, negative sensitivity parameters should have been found in Experiment 1, which provided complements, but not in Experiment 2, which provided substitutes.

If confirmed by future experiments, finding negative sensitivity parameters for time matching for some subjects in Experiment 1 would question whether negative sensitivity parameters occur in closed, but not in open, economies (Hursh, 1978). In an open economy, subjects are given extrasession food and water. In a closed economy, subjects obtain their entire daily ration of food and water during the experimental session. Experiment 1 employed an open economy and reported negative sensitivity parameters.

The bias parameter and the percentage of the variance accounted for increased across the session for Pigeon 5503, the opposite of the pattern reported for the other subjects. The reason for this difference is not known. One possibility is that different processes produce the within-session patterns for different subjects. A more parsimonious explanation is that the variables that produce the within-session patterns change at different rates for different subjects. The results of several studies, including the present one, show that within-session patterns may take several forms. Responding may increase, decrease, or increase and then decrease within the session. These findings suggest that two independent processes, one governing the increase and one governing the decrease in responding, produce most of the within-session changes (e.g., McSweeney, Hinson, & Cannon, in press). If these processes occur at somewhat different

rates for different subjects, as they might if the changes were produced by sensitization-habituation (e.g., Hinde, 1970), then the within-session changes in response rates would take a different form for different subjects. As a result, different within-session changes in the ratios of the rates of responding, and therefore, the parameters and fit of the generalized matching law, might be expected for different subjects.

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