

*WITHIN-SESSION CHANGES IN KEY AND LEVER PRESSING FOR WATER DURING SEVERAL MULTIPLE VARIABLE-INTERVAL SCHEDULES*

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Rats pressed keys or levers for water reinforcers delivered by several multiple variable-interval schedules. The programmed rate of reinforcement varied from 15 to 240 reinforcers per hour in different conditions. Responding usually increased and then decreased within experimental sessions. As for food reinforcers, the within-session changes in both lever and key pressing were smaller, peaked later, and were more symmetrical around the middle of the session for lower than for higher rates of reinforcement. When schedules provided high rates of reinforcement, some quantitative differences appeared in the within-session changes for lever and key pressing and for food and water. These results imply that basically similar factors produce within-session changes in responding for lever and key pressing and for food and water. The nature of the reinforcer and the choice of response can also influence the quantitative properties of within-session changes at high rates of reinforcement. Finally, the results show that the application of Herrnstein's (1970) equation to rates of responding averaged over the session requires careful consideration.

*Key words:* within-session patterns, multiple schedule, variable-interval schedule, food reinforcers, water reinforcers, key press, lever press, rats

Rate of responding averaged over the session is a frequently used dependent variable in operant psychology (e.g., Herrnstein, 1970). Recently, the exclusive use of this measure has been challenged by the observation of systematic changes in response rates within experimental sessions (e.g., McSweeney, Hatfield, & Allen, 1990). Within-session changes in responding show that measures based on session averages may disguise systematic changes in responding at a finer level of analysis.

The present experiment extends our knowledge of within-session changes in responding. It asks whether responding changes systematically within sessions when rats press levers and keys for water reinforcers delivered by several multiple variable-interval (VI) VI schedules.

This experiment contributes to our knowledge in several ways. First, the experiment will help to determine the generality of within-session changes in responding by studying these changes for a new reinforcer, water. Past

studies of within-session changes have examined responding for food. Determining the generality of within-session changes will help to establish their importance. If the changes are reported for only a few subjects responding on a few procedures, then they may reflect properties specific to those subjects and procedures. If they are reported more generally, then the changes may be more generally important.

Second, the experiment will help to determine whether similar factors produce within-session changes for lever and key pressing and for responding for food and water reinforcers. Within-session changes in responding have been reported for subjects ranging from cockroaches to humans responding on a variety of procedures, including positive reinforcement, avoidance, punishment, extinction, discrimination, delayed matching to sample, concept formation, maze and alley running, and laboratory analogues of foraging (McSweeney & Roll, 1993). Unfortunately, finding within-session changes does not establish that the changes are produced by the same theoretical variables under all of these conditions. This requires a functional analysis that studies responding at several levels of an independent variable (e.g., Bitterman, 1960, 1965). One or two similarities across species, responses, or reinforcers might occur by

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chance, but finding many functional similarities cannot be dismissed as an artifact and provides stronger evidence for a shared explanation. The present experiment compared within-session changes in response rates for key and lever pressing at several different rates of reinforcement. It also compared the present results for water to past results observed in subjects responding for food. Therefore, it determined whether similar relationships emerge in within-session changes in responding when subjects make two different responses for two different reinforcers.

Third, the present experiment investigated at least one potential theoretical implication of within-session changes in responding. Some theories predict that response rates will increase monotonically with increases in the rate of reinforcement (e.g., Herrnstein, 1970). Other theories predict that response rates will increase up to a point and then decrease with further increases in reinforcement (e.g., Baum, 1981; Staddon, 1979). Finding within-session changes in responding implies that there may be more than one answer to this question, depending on how data are collected and analyzed. For example, McSweeney (1992) found that response rates increased monotonically with increases in rates of reinforcement when responding was measured early in the session and food served as the reinforcer. Response rates decreased at high rates of reinforcement when responding was measured later in the session. The present experiment attempted to replicate this finding when subjects responded for water reinforcers.

The present experiment used multiple VI VI schedules so that the results can be compared to past results with subjects responding for food reinforcers. Within-session changes in responding for food are large and orderly when subjects respond on multiple VI VI schedules (e.g., McSweeney, 1992). Although within-session changes in responding have been reported when subjects respond on simple schedules for food reinforcers (McSweeney, Roll, & Weatherly, 1994), these changes are not always statistically significant when the schedules provide low rates of reinforcement.

## METHOD

### *Subjects*

Ten experimentally naive male rats bred from Sprague-Dawley stock began the experiment. Five rats pressed a lever and 5 rats pressed a key for water reinforcers. One subject in the lever-pressing group died during the first experimental condition. Thereafter only 4 subjects pressed levers. All subjects were approximately 120 days old at the beginning of the experiment. They had free access to food in their home cages but were water deprived as described below. Because body weight was not held constant, subjects gained weight during the experiment and were approximately 25% heavier at the end of the experiment than at the beginning.

### *Apparatus*

The apparatus was an enclosure (21 cm by 21.5 cm by 24 cm) equipped with a lever and a key. An opening (6 cm diameter) allowed access to a 0.25-ml dipper. The opening was centered in the experimental panel, 4 cm above the floor. Two 5-W lights were located behind Plexiglas panels (2 cm diameter), 3 cm from each side of the panel and 5.5 cm from the top. The left Plexiglas was clear, and the right was frosted. A Plexiglas key (2.5 cm diameter), that required a force of approximately 0.25 N to operate, was located 2 cm below the left light. A lever (3.5 cm wide), that required a force of approximately 0.30 N to operate, extended 2 cm into the chamber, 3 cm below the right light. The apparatus was enclosed in a sound-attenuating chamber. A ventilating fan masked noises from outside. A SYM<sup>®</sup> microcomputer, located in another room, controlled the experimental events and recorded the data.

### *Procedure*

The key-press subjects were trained to press the key by the method of successive approximations. The rate of reinforcement for pressing was gradually reduced until subjects responded on a VI 30-s schedule.

When the experiment began, subjects pressed the key for water delivered on a multiple VI VI schedule in which components alternated every 5 min. A light above the key was on during the first component and off during the second. Twelve components were

Table 1

Rates of key and lever pressing (presses per minute) and the standard error of the mean (in parentheses) for each rat over the last five sessions for which each multiple VI VI schedule was available. Results for the mean of all rats are also presented.

Subject	VI 15 s	VI 30 s	VI 60 s	VI 120 s	VI 240 s
<b>Key pressing</b>					
61	12.9 (0.4)	14.9 (0.7)	14.0 (0.9)	7.7 (0.8)	3.1 (0.3)
62	31.3 (2.7)	61.2 (3.9)	36.8 (3.4)	38.8 (2.6)	3.9 (0.6)
63	8.6 (1.0)	20.7 (4.0)	13.0 (2.0)	5.6 (0.2)	1.6 (0.2)
64	3.4 (0.3)	10.7 (2.9)	6.2 (0.7)	5.9 (0.5)	2.6 (0.3)
65	10.0 (0.9)	11.5 (1.5)	10.1 (0.8)	9.1 (0.6)	5.9 (0.8)
<i>M</i>	13.2	23.8	16.0	13.4	3.4
<b>Lever pressing</b>					
161	8.5 (0.5)	10.4 (1.1)	11.7 (1.5)	6.2 (0.4)	1.9 (0.2)
162	11.4 (0.6)	8.8 (0.6)	7.8 (0.8)	4.6 (0.3)	1.2 (0.3)
163	19.4 (3.5)	14.9 (0.5)	14.1 (0.7)	13.6 (0.9)	1.3 (0.2)
164	6.5 (0.8)	8.7 (0.8)	10.2 (1.6)	10.0 (0.6)	2.6 (0.3)
<i>M</i>	11.5	10.7	11.0	8.6	1.8

presented per session (60 min); sessions were conducted daily, six times per week. Reinforcement was 5-s access to the dipper, which contained water. The component timer did not advance during reinforcement. Subjects responded on the following schedules in the following order: multiple VI 30 s VI 30 s, multiple VI 120 s VI 120 s, multiple VI 240 s VI 240 s, multiple VI 15 s VI 15 s, and multiple VI 60 s VI 60 s. Each schedule was presented for 30 sessions. All interreinforcer intervals were programmed according to a 25-interval series (Fleshler & Hoffman, 1962). The VI schedules used for the two components were independent of each other.

Sessions were conducted during the morning hours. When all rats had completed their daily session (approximately noon), they were all given one half hour of access to water in their home cages. When the sessions conducted on Saturday were completed, subjects were given 24 hr of access to water. This procedure ensured that subjects had been deprived of water since approximately noon of the preceding day during all experimental sessions.

The same procedure was used in the experiment for lever pressing, which was conducted after that for key pressing. The procedural details for both experiments (the use of multiple schedules, conducting 30 sessions per condition, the range of programmed rates of reinforcement) were selected to be similar to those used in the past to study responding for food (McSweeney, 1992; Mc-

Sweeney, Roll, & Cannon, 1994). The present results will be compared to the results of those past studies.

## RESULTS

Table 1 presents the mean rates of key and lever pressing (presses per minute) and the standard error of the mean for each subject responding at each VI schedule value. These results, and all of those to follow, were calculated over the final five sessions for which each schedule was presented. The mean rate of responding averaged over all subjects is also presented. The average size of the standard error of the mean (Table 1) was approximately 9.3% of the average response rate for both lever and key pressing. The schedules also exerted good control over behavior. Rates of lever pressing were usually slower for schedules that presented low rates of reinforcement than for schedules that provided higher rates. Rates of key pressing increased with increases in the rates of reinforcement up to a point and then decreased with further increases in rate of reinforcement.

Figures 1 and 2 present the percentage of total-session key and lever presses, respectively, during successive components for individual subjects. Percentages were calculated by dividing the number of responses during a component by the total number of responses during the session and multiplying by 100. Percentages have been presented here and

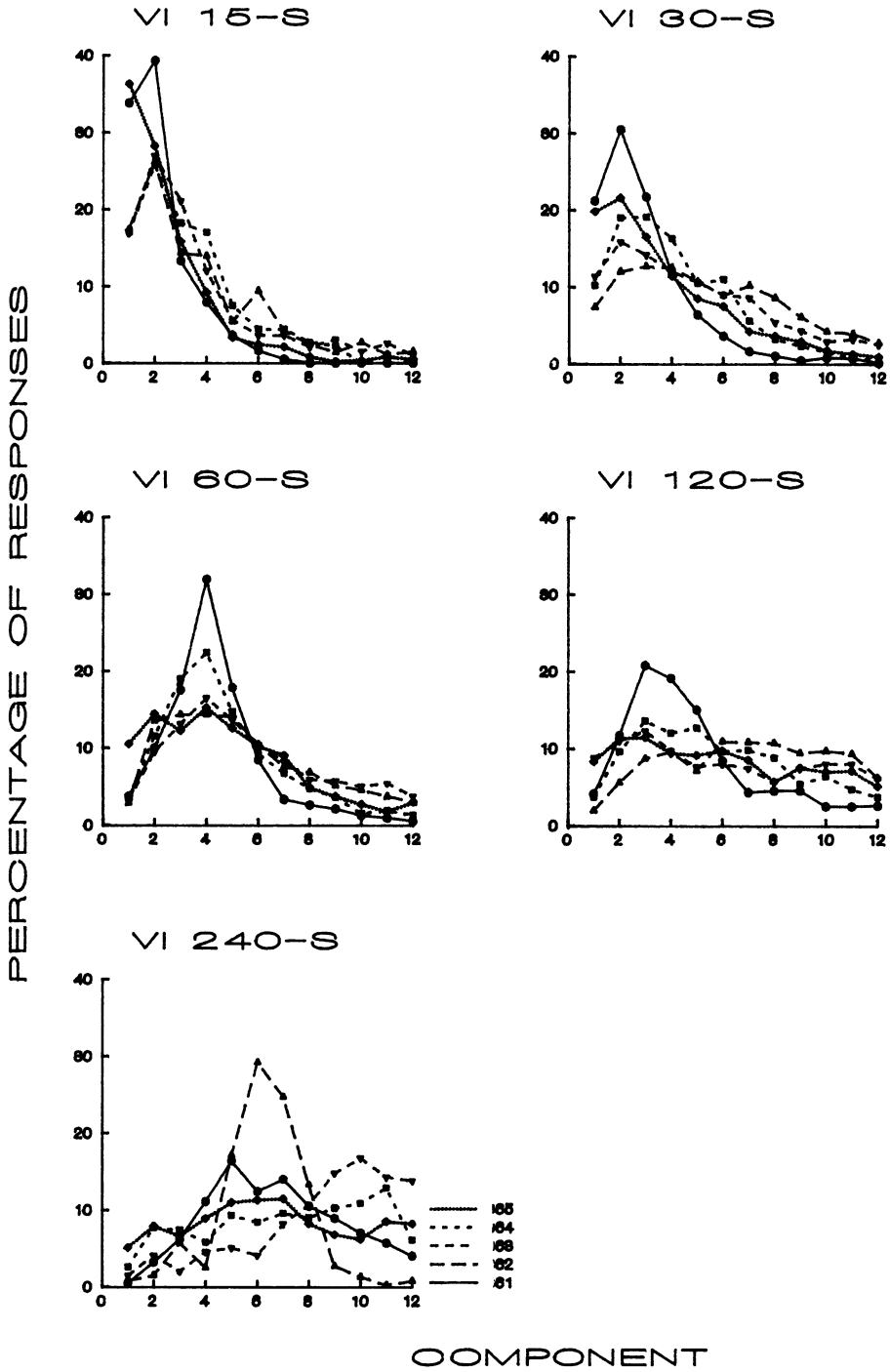


Fig. 1. Percentage of total-session key presses during successive components for individual subjects. Each set of axes presents the results for one schedule. Each function presents the results for an individual subject responding during the last five sessions for which that schedule was available.

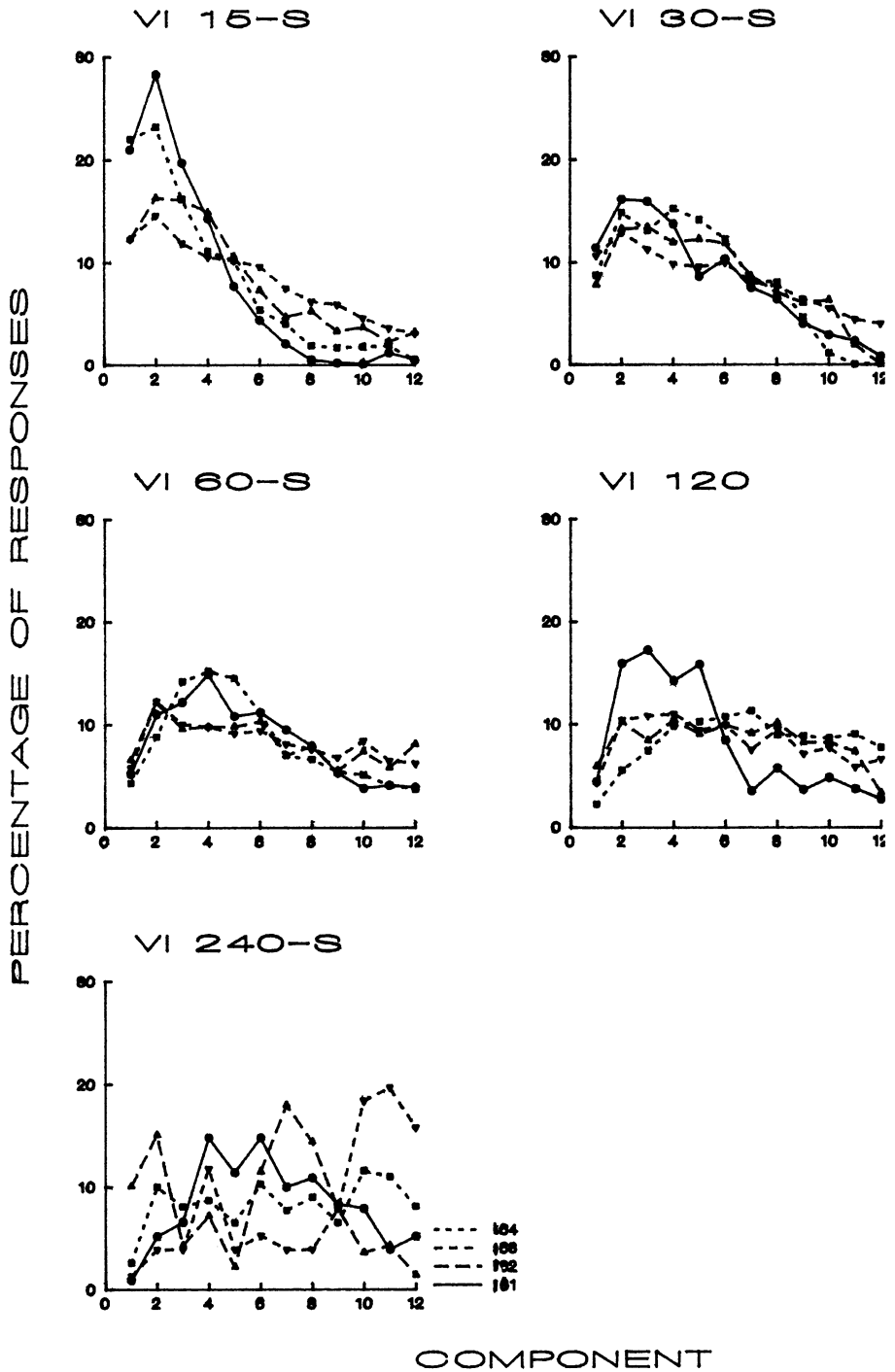


Fig. 2. Percentage of total-session lever presses during successive components for individual subjects. Each set of axes presents the results for one schedule. Each function presents the results for an individual subject responding during the last five sessions for which that schedule was available.

throughout this paper so that differences in the absolute rates of responding would not obscure similarities in the within-session changes in responding. The absolute rates (number of responses per component) at which each subject responded during each component of each multiple schedule and the standard error of the mean of those rates can be found in the Appendix.

Figures 1 and 2 show that large and systematic changes in responding occurred within experimental sessions. Although there is some variability in the form of these changes for individual subjects, responding usually increased to a peak and then decreased. The results of one-way (component) within-subject analyses of variance (ANOVA) applied to the rates of responding by individual subjects confirmed that the rates of key pressing changed significantly ( $p < .05$ ) within sessions for all schedules except the multiple VI 120 s VI 120 s:  $F(11, 44) = 9.204, p < .001$ , multiple VI 15 s VI 15 s;  $F(11, 44) = 10.516, p < .001$ , multiple VI 30 s VI 30 s;  $F(11, 44) = 8.843, p < .001$ , multiple VI 60 s VI 60 s;  $F(11, 44) = 1.580, p < .138$ , multiple VI 120 s VI 120 s;  $F(11, 44) = 2.589, p < .012$ , multiple VI 240 s VI 240 s. The rates of lever pressing changed significantly for all schedules except the multiple VI 240 s VI 240 s:  $F(11, 33) = 33.993, p < .001$ , multiple VI 15 s VI 15 s;  $F(11, 33) = 36.294, p < .001$ , multiple VI 30 s VI 30 s;  $F(11, 33) = 9.182, p < .001$ , multiple VI 60 s VI 60 s;  $F(11, 33) = 3.367, p < .003$ , multiple VI 120 s VI 120 s;  $F(11, 33) = 1.203, p < .323$ , multiple VI 240 s VI 240 s. These ANOVAs were applied to rates of responding (see Appendix), rather than to the percentages in Figures 1 and 2, because percentages are bounded and cannot be assumed to be normally distributed.

There are two potential explanations for the two failures to find statistically significant changes in response rates within sessions: Responding may not have changed significantly for individual subjects, or responding may have changed significantly but peaked at different times in the session for different subjects. Examination of Figure 1 suggests that responding changed significantly within sessions for individual subjects pressing keys on the multiple VI 120-s VI 120-s schedule. This was confirmed by one-way within-subject ANOVAs applied to the rates of responding by

individual subjects during the last five sessions for which this schedule was available. These ANOVAs were significant ( $p < .05$ ) for each subject:  $F(11, 44) = 11.976, p < .001$ , Subject 61;  $F(11, 44) = 13.296, p < .001$ , Subject 62;  $F(11, 44) = 3.100, p < .004$ , Subject 63;  $F(11, 44) = 5.872, p < .001$ , Subject 64;  $F(11, 44) = 5.431, p < .001$ , Subject 65. Examination of Figure 2 suggests that lever pressing changed within sessions for subjects pressing levers on the multiple VI 240-s VI 240-s schedule, but that these changes were not systematic increases followed by decreases. Instead, responding changed erratically within sessions. One-way within-subject ANOVAs applied to the rates of pressing by individual subjects during the last five sessions for which the multiple VI 240-s VI 240-s schedule was available confirmed that lever pressing changed significantly within the sessions for all subjects except 164:  $F(11, 44) = 7.340, p < .001$ , Subject 161;  $F(11, 44) = 2.013, p < .050$ , Subject 162;  $F(11, 44) = 2.051, p < .046$ , Subject 163;  $F(11, 44) = 1.198, p < .317$ , Subject 164.

Figure 3 presents the percentage of total-session responses during successive components for the first session during which subjects responded on the present procedures and for the last five sessions for which the first multiple VI 30-s VI 30-s schedule was presented. The top set of axes contains the results for key pressing; the bottom set displays the results for lever pressing. Percentages have been calculated as for Figures 1 and 2. Results are those for the mean of all subjects. Within-session changes in responding were present during the first session of training, and further experience with the schedule of reinforcement modified the form of those changes and moved their peaks.

Figure 4 compares the percentage of total-session responses during successive components when subjects pressed keys and levers. Each set of axes presents the results for a particular multiple schedule. Percentages were calculated using the results for the mean of all subjects. Group-average within-session changes in responding shared a number of characteristics for both key and lever pressing. First, the peak rate of pressing usually occurred during the same component for the two responses; these peaks occurred earlier in the session for higher than for lower rates

of reinforcement. The peak rate of key pressing occurred during the second, second, fourth, third, and sixth components for the multiple VI 15-s VI 15-s, multiple VI 30-s VI 30-s, multiple VI 60-s VI 60-s, multiple VI 120-s VI 120-s, and multiple VI 240-s VI 240-s schedules, respectively. The peak rate of lever pressing occurred during the second, second, fourth, fifth, and sixth components for the same schedules in the same order.

Second, within-session changes were larger when subjects responded for higher than for lower rates of reinforcement. When the highest percentage was divided by the lowest percentage of responses, key pressing changed by a factor of 32.3, 8.3, 7.1, 3.0, and 5.4 for the multiple VI 15-s VI 15-s, multiple VI 30-s VI 30-s, multiple VI 60-s VI 60-s, multiple VI 120-s VI 120-s, and multiple VI 240-s VI 240-s schedules, respectively. Lever pressing changed by a factor of 8.2, 8.8, 2.4, 2.8, and 3.3 for the same schedules presented in the same order.

Third, within-session changes became more symmetrical around the middle of the session as the rate of reinforcement decreased. Subjects emitted a total of 91, 74, 74, 53, and 48% of their total-session key presses during the first half of the session for the multiple VI 15-s VI 15-s, multiple VI 30-s VI 30-s, multiple VI 60-s VI 60-s, multiple VI 120-s VI 120-s, and multiple VI 240-s VI 240-s schedules, respectively. Subjects emitted a total of 79, 71, 62, 56, and 46% of their total-session lever presses during the first half of the session for the same schedules listed in the same order. All percentages are those for the mean of all subjects.

In spite of these similarities, some differences also appeared. In particular, responding sometimes changed by a smaller amount within sessions for lever than for key pressing. To determine whether these differences were significant, two-way (Operandum  $\times$  Component) mixed-model ANOVAs were applied to the rates of responding by individual subjects. The interaction terms of these analyses showed that the within-session patterns of responding differed significantly ( $p < .05$ ) for lever and key pressing for the three schedules that provided the highest rates of reinforcement:  $F(11, 77) = 1.946, p < .046$ , multiple VI 15 s VI 15 s;  $F(11, 77) = 3.228, p < .001$ , multiple VI 30 s VI 30 s;  $F(11, 77) = 2.869, p$

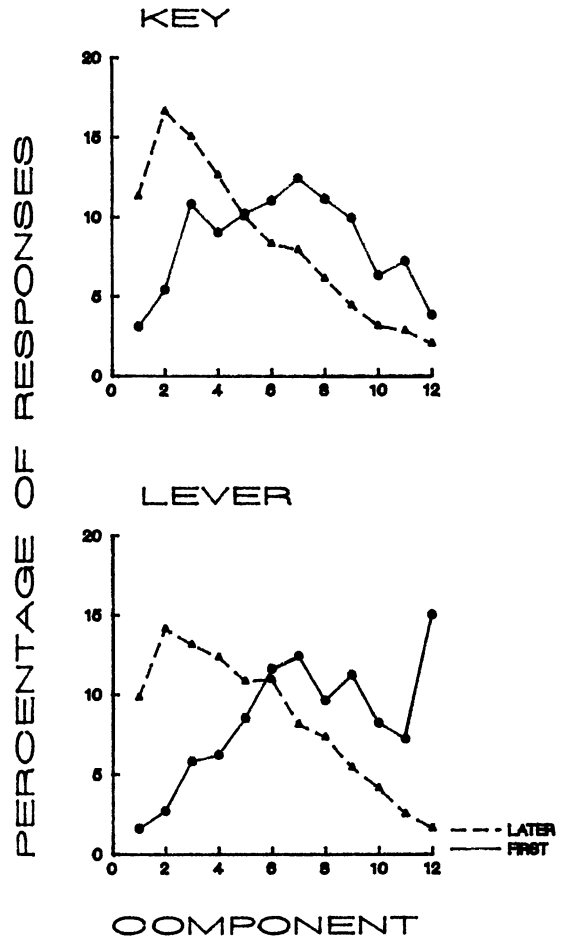


Fig. 3. Percentage of total-session responses in successive components during the first session of training (solid line) and during the last five sessions for which the first multiple VI 30-s VI 30-s schedule was available (dashed line). The top set of axes contains the results for key pressing; the bottom set displays the results for lever pressing. Results have been averaged over all subjects.

$< .003$ , multiple VI 60 s VI 60 s;  $F(11, 77) = 0.289, p < .986$ , multiple VI 120 s VI 120 s;  $F(11, 77) = 1.428, p < .178$ , multiple VI 240 s VI 240 s. Therefore, the type of operandum consistently altered the within-session patterns of responding only at relatively high programmed rates of reinforcement.

Figures 5 and 6 are within-session changes in responding for food and water. Figure 5 compares the percentage of total-session key presses during successive components in the present experiment to the percentage of total-session key presses for sweetened condensed milk in the study by McSweeney, Roll,

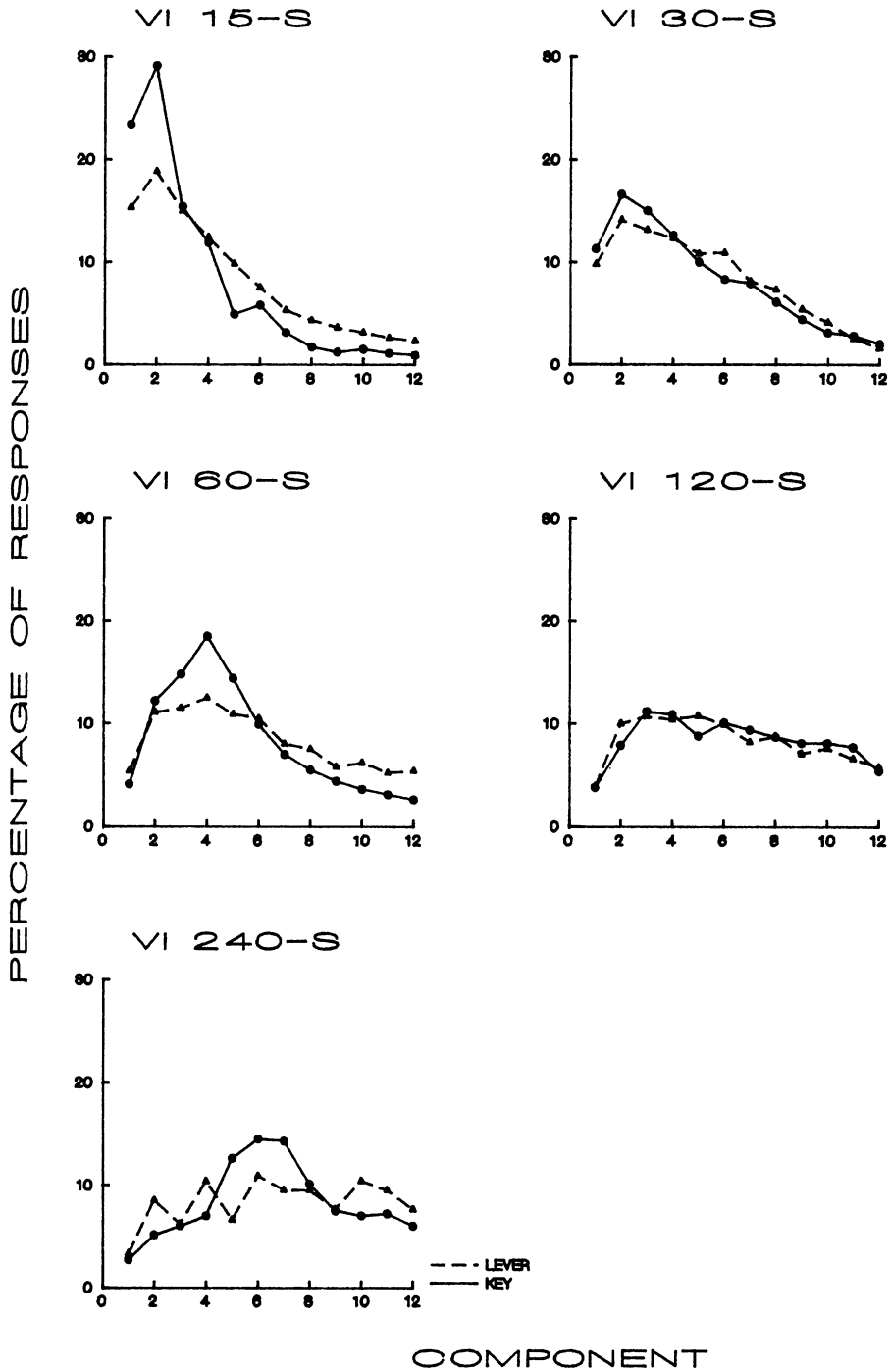


Fig. 4. Percentage of total-session responses during successive components when subjects pressed keys (solid line) or levers (dashed line) for water. Percentages were calculated using the results for the mean for all subjects. Each set of axes presents the results for one multiple schedule.



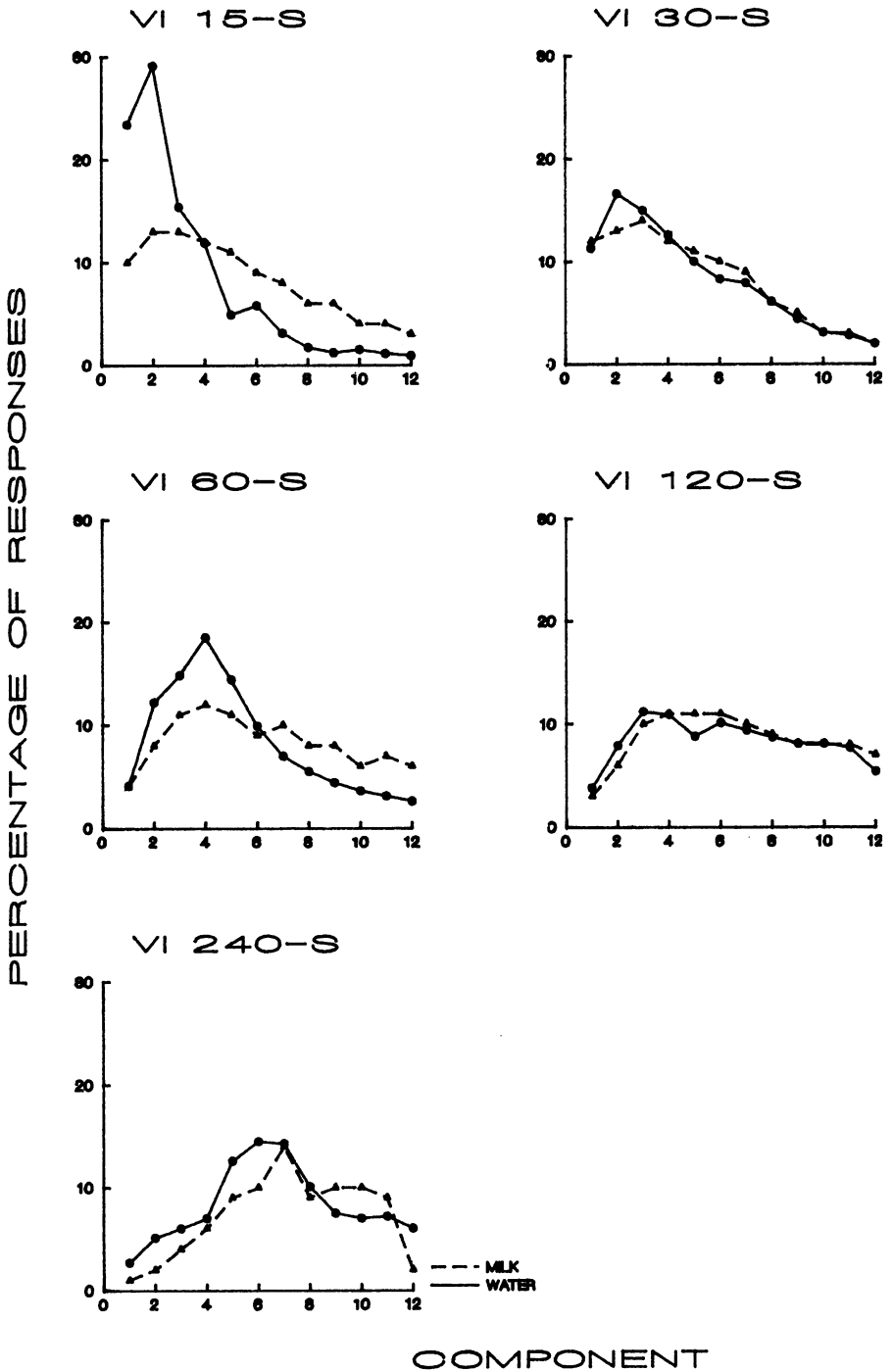


Fig. 5. Percentage of total-session responses during successive components when subjects pressed keys for water (circles) or sweetened condensed milk (triangles). The results for water have been taken from the present experiment. Those for milk are from McSweeney, Roll, and Cannon (1994). Each set of axes presents the results for one multiple schedule. Percentages have been calculated using the results for the mean of all subjects.

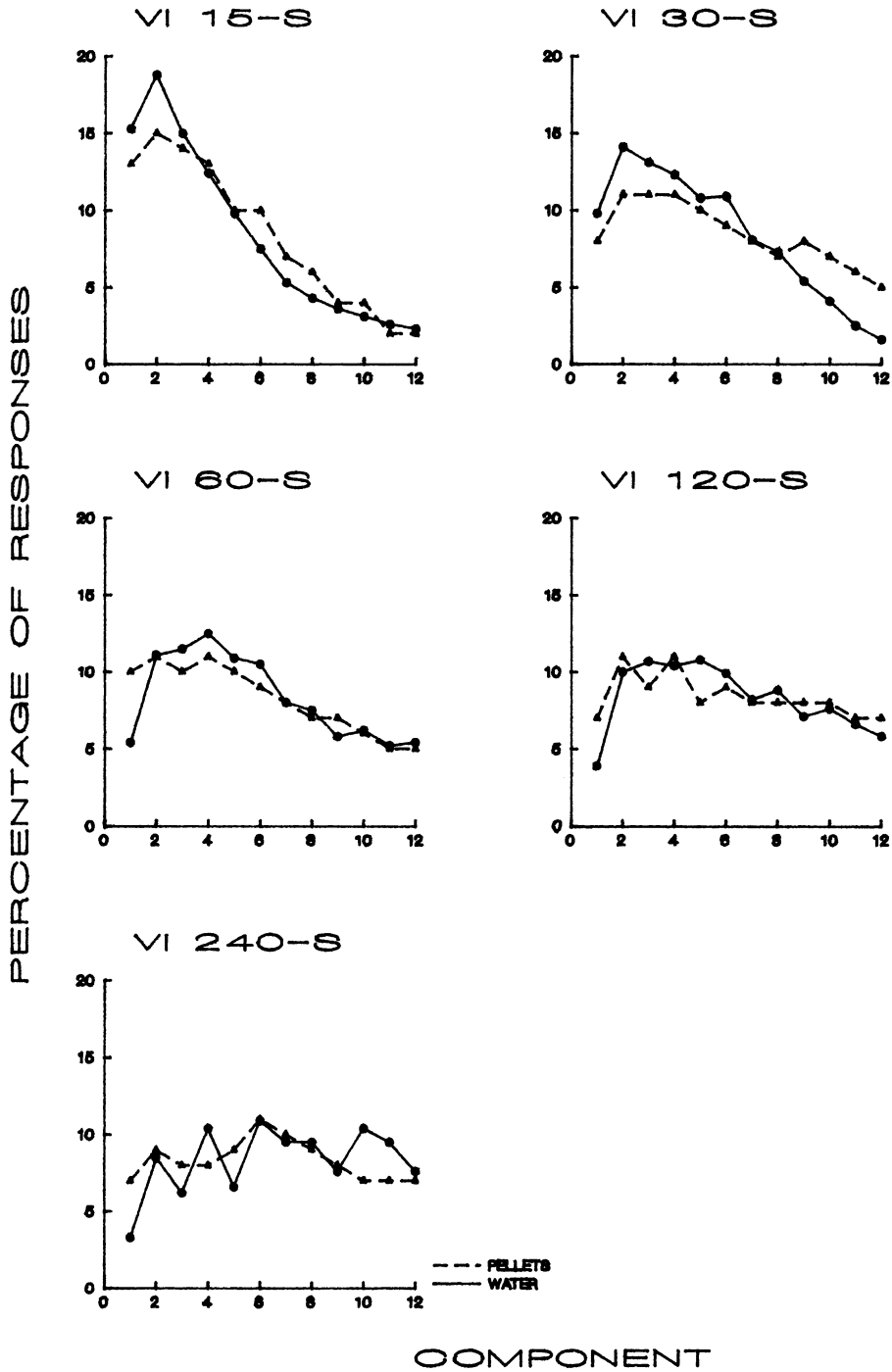


Fig. 6. Percentage of total-session responses during successive components when subjects pressed levers for water (circles) or pellets (triangles). The results for water have been taken from the present experiment. Those for pellets are from McSweeney (1992). Each set of axes presents the results for one multiple schedule. Percentages have been calculated using the results for the mean of all subjects.

and Cannon (1994). Figure 6 compares the percentage of total-session lever presses during successive components in the present experiment to the percentage of total-session lever presses for Noyes pellets in the study by McSweeney (1992). The percentages were calculated using the data for the mean of all subjects.

Figures 5 and 6 show that the within-session changes in responding were qualitatively similar for food and water reinforcers. As just described, the within-session changes in responding for water were smaller, peaked later, and were more symmetrical around the middle of the session for schedules that provided lower rates of reinforcement than for those that provided higher rates of reinforcement. These characteristics also appear in Figures 5 and 6 for the changes in responding when food served as the reinforcer. (See McSweeney, 1992, and McSweeney, Roll, & Cannon, 1994, for a more detailed description.)

Figures 5 and 6 also reveal some quantitative differences. In particular, curves for within-session changes in responding were somewhat flatter when food (sweetened condensed milk or Noyes pellets) served as the reinforcer than when water did when subjects responded on schedules that provided high rates of reinforcement. Again, the statistical significance of the differences in the within-session patterns of responding was assessed by applying two-way (Reinforcer  $\times$  Component) mixed-model ANOVAs to the rates of responding by individual subjects on each of the schedules. The interaction terms for key pressing were significant ( $p < .05$ ) for the multiple VI 15-s VI 15-s, the multiple VI 30-s VI 30-s, and the multiple VI 120-s VI 120-s schedules:  $F(11, 88) = 7.703$ ,  $p < .001$ , multiple VI 15 s VI 15 s;  $F(11, 88) = 12.444$ ,  $p < .001$ , multiple VI 30 s VI 30 s;  $F(11, 88) = 1.459$ ,  $p < .162$ , multiple VI 60 s VI 60 s;  $F(11, 88) = 1.977$ ,  $p < .040$ , multiple VI 120 s VI 120 s;  $F(11, 88) = 1.223$ ,  $p < .284$ , multiple VI 240 s VI 240 s. The interaction terms for lever pressing were significant for the multiple VI 15-s VI 15-s, the multiple VI 30-s VI 30-s, and the multiple VI 60-s VI 60-s schedules:  $F(11, 77) = 6.804$ ,  $p < .001$ , multiple VI 15 s VI 15 s;  $F(11, 77) = 2.318$ ,  $p < .016$ , multiple VI 30 s VI 30 s;  $F(11, 77) = 4.395$ ,  $p < .001$ , multiple VI 60 s VI 60 s;  $F(11, 77) = 1.525$ ,  $p$

$< .140$ , multiple VI 120 s VI 120 s;  $F(11, 77) = 0.986$ ,  $p < .466$ , multiple VI 240 s VI 240 s. Therefore, the within-session patterns of responding differed significantly for the two reinforcers when the schedules provided high but not low rates of reinforcement.

Figures 7 (key pressing) and 8 (lever pressing) present the rates of responding during six of the 12 components plotted as a function of the rates of reinforcement obtained from those components. Even-numbered components were arbitrarily selected for presentation. Results have been averaged over all subjects pressing levers. Obtained rates of reinforcement were unavailable when Subject 62 pressed the key, because this subject responded at a rate that was too high for the recording equipment to register the temporal location of all reinforcers within the session. Therefore, results for key pressing have been averaged over all subjects except 62.

Figures 7 and 8 show that, as for food reinforcers (McSweeney, 1992), response rates generally increased monotonically with increases in the obtained rates of reinforcement early in the session. Response rates declined again at higher rates of reinforcement during later components. Unlike the results with food reinforcers, subjects responded very slowly late in the session when the schedules provided high rates of reinforcement (see Figures 1 and 2). These low rates of responding produced low obtained rates of reinforcement even though the schedules provided high programmed rates. Therefore, the range of rates of reinforcement obtained late in the session was limited, even though the schedules continued to provide a wide range of programmed rates of reinforcement.

## DISCUSSION

The present results extend the generality of within-session changes in responding to key and lever pressing for water reinforcers provided in multiple schedules at several different rates of reinforcement. Responding usually increased and then decreased within sessions for both responses and all five rates of reinforcement. The only exception was that lever pressing changed significantly but unsystematically within sessions when subjects responded on the multiple VI 240-s VI 240-s schedule. As described earlier, extending the

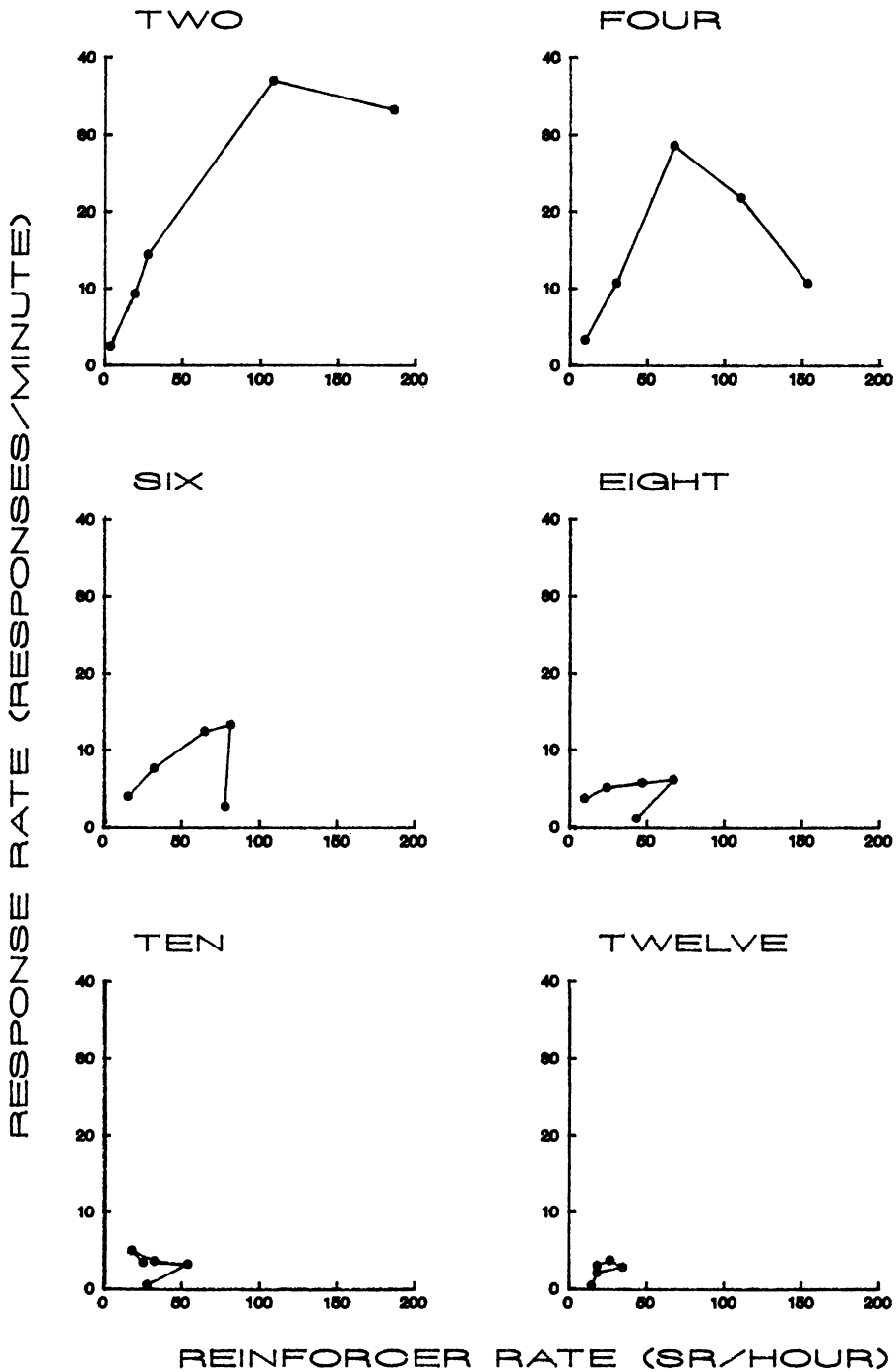


Fig. 7. Rates of key pressing (responses per minute) during even-numbered components as a function of the rates of reinforcement (reinforcers per hour) obtained during those components. Each graph presents the results for a different component within the session. The component number is indicated in block letters at the top. Results have been averaged over all subjects except 62. Points are connected in order of increasing programmed, but not necessarily obtained, rate of reinforcement. For example, during Component 10, subjects obtained more reinforcers from the multiple VI 240-s VI 240-s schedule than from the multiple VI 120-s VI 120-s schedule. Therefore, the first point falls to the right of the second point.

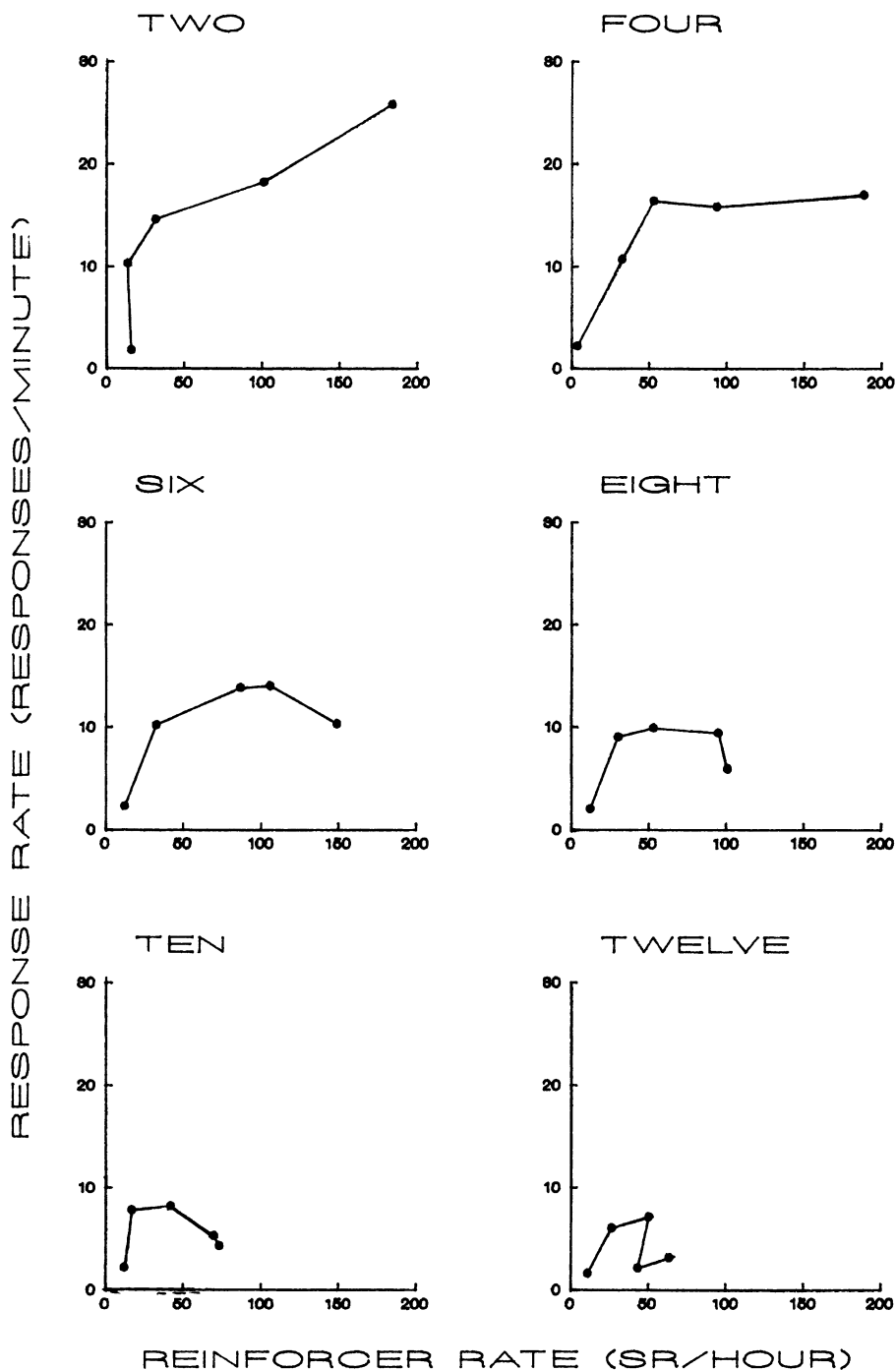


Fig. 8. Rates of lever pressing (responses per minute) during even-numbered components as a function of the rates of reinforcement (reinforcers per hour) obtained during those components. Each graph presents the results for a different component within the session, with the component number indicated in block letters at the top. Results have been averaged over all subjects. Points are connected in order of increasing programmed, but not necessarily obtained, rate of reinforcement.

generality of within-session changes in responding increases their importance because it implies that these changes are not an artifact of a limited set of conditions or procedures.

The present functional analysis indicates that within-session changes in responding share some common characteristics for key and lever pressing and, by comparison with data collected earlier, for responding for food and water. In all cases, the within-session changes peaked later, were smaller, and were more symmetrical around the middle of the session for schedules that provided lower rates of reinforcement than for those that provided higher rates of reinforcement. As with food reinforcers (McSweeney, 1992), within-session changes were also present during the first session of exposure to the experimental procedure. Further experience with the schedule only modified these changes to a form that was appropriate for that schedule. As discussed earlier, the present similarities suggest that basically similar variables produce within-session changes for the two responses and for both reinforcers. Such strong similarities are unlikely to have occurred by chance.

Some quantitative differences between key and lever pressing were also observed. In particular, the within-session changes in group-average rates of responding were smaller for lever pressing than for key pressing when the schedules provided high rates of reinforcement and therefore supported high rates of responding. This suggests that a factor that depends on the choice of the instrumental response contributes to within-session changes at high programmed rates of reinforcement.

Many experiments would be needed to specify how the choice of the instrumental response alters within-session patterns of responding. For example, it might be argued that responding decreased late in the session because of "fatigue" and that different responses generate different amounts of fatigue. This argument is consistent with the finding that the differences among the responses are larger for schedules that provide higher rates of reinforcement and therefore generate higher rates of responding (e.g., Catania & Reynolds, 1968). Differences in fatigue among responses should be magnified

when subjects respond more frequently. However, other aspects of the present results are not consistent with a simple interpretation based on fatigue. For example, Figures 1 and 4 show that the within-session decreases in key pressing were steeper for the multiple VI 15-s VI 15-s schedule than for the multiple VI 30-s VI 30-s schedule. If fatigue produced these decreases, they should have been steeper for the multiple VI 30-s VI 30-s schedule. Table 1 shows that subjects responded more quickly, and therefore should have been more fatigued, when responding on the multiple VI 30-s VI 30-s schedule than on the multiple VI 15-s VI 15-s schedule. Further experiments are needed to specify precisely how the choice of the response alters within-session changes in responding.

The results presented in Figures 5 and 6 showed that within-session changes were somewhat smaller for food-reinforced behavior than for water-reinforced responding when schedules provided high rates of reinforcement. This suggests that a variable related to the nature of the reinforcer (e.g., satiation) also influences within-session changes in responding at high rates of reinforcement. This conclusion seems to be justified even though it rests on a comparison of results across studies. The procedural details of these studies were similar. Therefore, it is unlikely that other, unidentified procedural differences between the studies produced the observed differences in behavior. The same apparatus was used in the present experiment and by McSweeney, Roll, and Cannon (1994). The same schedules were studied in the same order in all of the studies. Each schedule was studied for 30 sessions. In all cases, components alternated every 5 min and were signaled by the light above the operandum that was either on or off. All interreinforcer intervals were programmed by Fleshler and Hoffman progressions. Sprague-Dawley rats served as subjects. Finally, the studies were conducted in the same laboratory. Therefore, procedural details such as the handling of the subjects were similar. Finding different results for food and water when such similar procedures were used suggests that a factor related to the nature of the reinforcer contributes to within-session changes when schedules deliver high rates of reinforcement.

Future experiments should specify how the

choice of reinforcer alters within-session patterns of responding. Many of the present results are superficially consistent with an interpretation in terms of satiation. For example, within-session changes should peak earlier and be steeper for higher reinforcement rates than for lower reinforcement rates if satiation contributes to those changes. Schedules that deliver higher rates of reinforcement should produce more and earlier satiation than those that deliver lower rates; this is what was found. However, the present results do not compel an interpretation in terms of satiation. Subjects pressed keys faster for sweetened condensed milk (the mean over all subjects and schedules was 51.7 responses per minute) than for water ( $M = 14.0$  responses per minute). They also pressed levers faster for Noyes pellets ( $M = 34.6$  responses per minute) than for water ( $M = 8.7$  responses per minute). Therefore, the present changes in the content of the reinforcer might have altered within-session changes in responding only indirectly by altering baseline response rates. Future experiments will be required to clarify this matter.

Figures 7 and 8 show that studying within-session patterns of responding may clarify some theoretical issues. The figures show that the relation between rate of responding and rate of reinforcement is different at different times in an experimental session. Responding early in the session increases as a monotonic function of rate of reinforcement, as predicted by some theories (e.g., Herrnstein, 1970). Responding later in the session increases and then decreases with increases in the rate of reinforcement, as predicted by other theories (e.g., Baum, 1981; Staddon, 1979). Similar results were observed when responding was reinforced by food (McSweeney, 1992). Therefore, these findings have some generality.

Figures 7 and 8 also question the use of Herrnstein's (1970) equation to describe absolute rates of responding averaged over the session. Applying Herrnstein's equation to average response rates is appropriate only if the parameters of the equations do not change within sessions. Figures 7 and 8 show that these parameters do change. The asymptotic rate of responding (the size of the  $k$  parameter in Herrnstein's equation) was smaller at the end than at the beginning of the session. Although it is less apparent from the figures,

the size of  $R_0$  (estimate of reinforcers obtained from unprogrammed sources in Herrnstein's formulation) also decreased within the session. Finally, the hyperbolic form of Herrnstein's equation described the data better at the beginning than at the end of the session. Therefore, assumptions required to fit Herrnstein's equation are violated by the present data.

It might be objected that the data presented in Figures 7 and 8 were obtained using multiple VI VI schedules, but that Herrnstein's equation is usually fit to results obtained during simple VI schedules. This is true, and the present results need to be confirmed with simple VI schedules before Herrnstein's equation is rejected. Nevertheless, the present results suggest that researchers should determine the constancy of the parameters within sessions before applying Herrnstein's equation to the rate of responding averaged over the session.

Finding large and systematic changes in response rates within a session raises problems for research in many areas. For example, studies in behavioral pharmacology often evaluate the effect of a drug relative to a constant baseline rate of responding. The present results imply that rate of responding may not be constant within a session when subjects respond for water reinforcers, especially when the schedules provide high rates of reinforcement. Researchers in this area may want to provide relatively low rates of reinforcement and to examine their baseline rates of responding carefully before proceeding.

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APPENDIX

Mean number of responses per component and the standard error of the mean (*SEM*) for each subject responding during the last five sessions for which each schedule was available. Responding during the first six components is presented in the upper two rows for each subject and that for the second six components is presented in the lower two rows.

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Key pressing								
Multiple VI 15 s VI 15 s								
Subject 61	<i>M</i>	260.8	303.6	102.8	60.8	28.2	11.8	
	<i>SEM</i>	27.4	11.2	7.4	16.5	5.3	1.9	
Subject 61	<i>M</i>	3.4	1.2	0.0	0.0	0.0	0.0	
	<i>SEM</i>	1.6	1.0	0.0	0.0	0.0	0.0	
	<i>M</i>	327.0	491.2	268.4	260.0	102.2	176.2	
	<i>SEM</i>	41.0	72.0	27.7	64.0	35.7	52.1	
Subject 62	<i>M</i>	79.2	45.4	26.8	50.2	21.4	28.6	
	<i>SEM</i>	44.0	16.8	10.8	27.9	6.3	13.5	
	<i>M</i>	87.6	139.2	108.8	61.8	29.2	18.6	
	<i>SEM</i>	16.6	21.9	16.2	14.2	2.7	5.0	
Subject 63	<i>M</i>	18.6	11.2	15.8	8.2	13.4	5.0	
	<i>SEM</i>	3.8	2.9	2.8	3.1	4.2	1.5	
	<i>M</i>	35.0	53.2	37.6	34.8	15.6	8.8	
	<i>SEM</i>	5.4	6.6	5.2	6.5	2.2	2.0	
Subject 64	<i>M</i>	8.8	5.6	4.6	0.4	1.8	0.0	
	<i>SEM</i>	3.1	3.1	2.1	0.4	1.6	0.0	
	<i>M</i>	217.6	168.8	94.4	55.2	20.2	14.6	
	<i>SEM</i>	12.0	13.0	21.2	12.4	5.1	8.1	
Subject 65	<i>M</i>	12.4	4.4	1.2	2.2	5.2	2.8	
	<i>SEM</i>	4.3	2.1	0.5	1.5	3.2	2.6	
	Multiple VI 30 s VI 30 s							
	Subject 61	<i>M</i>	189.6	271.8	193.8	105.4	57.6	32.6
<i>SEM</i>		17.2	14.9	12.2	14.0	5.5	4.6	
<i>M</i>		14.0	8.8	4.2	7.4	6.6	1.2	
<i>SEM</i>		3.6	2.4	1.2	1.6	2.2	0.6	
Subject 62	<i>M</i>	270.8	442.0	466.4	459.4	394.4	325.0	
	<i>SEM</i>	22.5	24.9	36.3	15.2	37.6	44.6	
	<i>M</i>	375.0	317.0	222.8	155.2	142.4	98.0	
	<i>SEM</i>	39.0	44.0	60.5	59.2	33.6	31.4	
Subject 63	<i>M</i>	140.8	197.4	176.4	148.6	131.4	111.0	
	<i>SEM</i>	19.0	29.3	40.9	31.5	23.4	25.6	
	<i>M</i>	107.2	67.0	52.8	35.4	40.0	31.6	
	<i>SEM</i>	25.8	9.3	15.7	10.2	11.2	10.2	
Subject 64	<i>M</i>	64.8	121.6	121.8	103.8	67.2	69.8	
	<i>SEM</i>	6.4	29.8	22.8	35.3	20.5	28.6	
	<i>M</i>	35.4	20.4	15.0	9.6	5.4	3.4	
	<i>SEM</i>	13.1	10.4	6.3	4.0	2.1	2.7	
Subject 65	<i>M</i>	136.8	148.8	113.8	78.6	58.8	51.6	
	<i>SEM</i>	12.6	13.7	10.1	9.3	12.8	11.3	
	<i>M</i>	29.2	25.2	19.8	11.8	9.2	6.6	
	<i>SEM</i>	9.7	9.0	9.8	5.0	3.7	4.5	
Multiple VI 60 s VI 60 s								
Subject 61	<i>M</i>	31.2	84.0	147.4	268.2	149.8	70.4	
	<i>SEM</i>	6.0	17.7	31.6	24.6	33.6	27.7	
	<i>M</i>	27.8	22.0	17.4	10.4	7.4	4.2	
	<i>SEM</i>	3.2	3.4	3.5	1.9	2.9	1.2	
Subject 62	<i>M</i>	64.4	296.8	314.8	315.0	308.4	228.4	
	<i>SEM</i>	17.9	20.8	20.4	26.5	47.7	23.0	
	<i>M</i>	166.0	148.8	112.8	100.2	82.4	66.4	
	<i>SEM</i>	49.0	24.1	33.0	21.1	24.7	19.2	

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## APPENDIX

*(Continued)*

Subject 63	<i>M</i>	24.2	74.0	101.6	128.0	106.0	80.6
	<i>SEM</i>	4.4	17.3	22.0	19.3	31.5	22.9
	<i>M</i>	63.4	45.4	43.8	38.8	42.2	29.0
	<i>SEM</i>	10.5	11.3	6.1	4.5	10.6	8.1
Subject 64	<i>M</i>	12.8	43.2	71.2	83.4	55.2	34.6
	<i>SEM</i>	2.7	2.5	8.3	9.7	9.6	4.6
	<i>M</i>	25.0	17.4	13.6	5.6	6.8	5.2
	<i>SEM</i>	4.9	5.1	4.0	2.1	3.5	3.4
Subject 65	<i>M</i>	63.8	87.6	74.2	92.6	76.2	62.2
	<i>SEM</i>	9.7	9.1	12.2	26.6	14.1	3.8
	<i>M</i>	55.2	29.2	22.4	16.6	10.8	17.8
	<i>SEM</i>	3.3	4.7	4.4	4.6	3.5	3.5
Multiple VI 120 s VI 120 s							
Subject 61	<i>M</i>	18.8	54.2	96.0	88.4	69.4	39.0
	<i>SEM</i>	3.7	16.4	23.7	13.2	5.1	2.8
	<i>M</i>	20.2	20.8	20.8	11.6	11.6	12.2
	<i>SEM</i>	1.6	1.8	1.4	2.0	1.5	2.4
Subject 62	<i>M</i>	46.6	130.0	202.0	223.8	164.6	253.4
	<i>SEM</i>	7.1	16.7	11.8	27.0	26.4	13.1
	<i>M</i>	251.8	248.6	219.6	225.4	216.2	144.4
	<i>SEM</i>	17.7	24.0	12.6	15.5	18.9	38.1
Subject 63	<i>M</i>	29.4	37.2	41.4	32.6	25.6	27.2
	<i>SEM</i>	1.8	2.9	7.6	2.4	3.8	3.8
	<i>M</i>	25.0	19.0	25.0	26.8	27.0	20.6
	<i>SEM</i>	3.3	4.4	1.9	3.0	3.6	1.7
Subject 64	<i>M</i>	13.0	33.8	48.0	42.6	44.8	34.2
	<i>SEM</i>	1.8	4.5	11.3	5.0	4.0	6.6
	<i>M</i>	34.4	31.2	19.2	22.6	16.4	12.8
	<i>SEM</i>	4.7	4.8	3.7	6.7	4.2	3.1
Subject 65	<i>M</i>	45.2	61.6	61.8	51.0	49.4	52.4
	<i>SEM</i>	2.2	7.5	6.5	6.0	4.6	6.8
	<i>M</i>	46.2	31.2	41.2	38.0	38.6	27.6
	<i>SEM</i>	5.2	3.6	6.6	3.1	4.6	4.4
Multiple VI 240 s VI 240 s							
Subject 61	<i>M</i>	1.2	6.2	11.6	20.4	30.6	23.2
	<i>SEM</i>	1.2	2.5	3.6	4.2	4.3	2.6
	<i>M</i>	26.2	19.4	16.4	13.0	10.4	7.6
	<i>SEM</i>	4.1	2.7	2.8	1.3	1.9	0.7
Subject 62	<i>M</i>	2.2	3.4	13.6	6.2	40.6	69.2
	<i>SEM</i>	0.6	0.7	6.2	2.2	19.4	30.3
	<i>M</i>	58.4	31.4	6.6	3.2	0.4	2.0
	<i>SEM</i>	4.5	16.5	1.5	0.9	0.2	0.7
Subject 63	<i>M</i>	1.6	3.8	2.2	4.4	5.0	3.8
	<i>SEM</i>	0.8	1.5	0.7	1.5	1.5	0.7
	<i>M</i>	7.8	10.4	14.6	16.4	14.0	13.4
	<i>SEM</i>	2.6	1.2	0.2	1.8	1.3	2.2
Subject 64	<i>M</i>	3.8	11.8	11.6	9.0	14.4	12.8
	<i>SEM</i>	0.5	1.9	2.8	2.0	3.0	3.7
	<i>M</i>	15.0	14.0	15.8	17.2	19.8	9.6
	<i>SEM</i>	3.6	2.7	2.3	3.7	4.0	1.4
Subject 65	<i>M</i>	17.8	28.0	23.6	31.4	38.8	40.0
	<i>SEM</i>	2.7	5.2	3.7	3.5	6.7	4.1
	<i>M</i>	41.0	29.2	24.2	22.0	30.0	28.8
	<i>SEM</i>	8.3	5.5	5.2	3.7	6.6	5.5

APPENDIX

(Continued)

Lever pressing							
Multiple VI 15 s VI 15 s							
Subject 161	<i>M</i>	107.2	144.0	100.4	73.2	39.2	22.4
	<i>SEM</i>	8.6	8.4	7.0	3.7	6.6	6.6
	<i>M</i>	10.6	2.4	1.2	0.6	6.2	2.6
	<i>SEM</i>	3.1	1.9	1.2	0.6	6.2	1.6
Subject 162	<i>M</i>	84.2	110.8	110.0	102.2	72.4	49.4
	<i>SEM</i>	11.5	4.7	4.8	9.2	6.1	7.0
	<i>M</i>	32.0	36.0	22.6	24.8	16.0	22.2
	<i>SEM</i>	7.4	5.9	4.3	5.2	4.0	9.0
Subject 163	<i>M</i>	143.4	170.0	138.2	121.6	118.6	112.2
	<i>SEM</i>	12.4	23.2	32.4	31.5	23.5	14.7
	<i>M</i>	87.2	71.4	67.8	54.0	42.2	35.8
	<i>SEM</i>	17.8	10.6	20.8	18.5	17.3	11.7
Subject 164	<i>M</i>	85.6	89.6	62.8	43.2	39.4	20.8
	<i>SEM</i>	9.8	10.6	8.0	6.8	6.1	5.4
	<i>M</i>	15.6	7.6	6.4	7.0	7.6	2.0
	<i>SEM</i>	5.6	2.5	3.3	3.3	3.6	1.3
Multiple VI 30 s VI 30 s							
Subject 161	<i>M</i>	71.2	100.6	99.2	85.6	53.6	64.2
	<i>SEM</i>	12.2	4.8	3.5	6.0	7.1	10.5
	<i>M</i>	47.0	40.0	24.8	18.2	14.6	5.6
	<i>SEM</i>	8.1	13.6	7.4	6.2	7.7	4.6
Subject 162	<i>M</i>	40.8	69.4	70.4	62.4	63.8	61.8
	<i>SEM</i>	4.4	9.9	7.4	2.5	8.1	5.6
	<i>M</i>	45.2	37.2	31.4	33.2	10.2	0.0
	<i>SEM</i>	4.2	4.7	4.0	4.8	3.1	0.0
Subject 163	<i>M</i>	95.2	115.6	100.6	87.6	85.6	89.2
	<i>SEM</i>	8.7	7.2	7.5	5.3	5.7	6.3
	<i>M</i>	71.8	68.4	57.2	49.6	39.6	36.2
	<i>SEM</i>	5.1	8.6	4.2	3.1	6.4	9.0
Subject 164	<i>M</i>	45.6	77.4	67.8	80.0	74.2	64.2
	<i>SEM</i>	5.5	8.9	6.1	6.1	9.1	13.9
	<i>M</i>	42.8	41.8	24.0	6.2	0.2	0.4
	<i>SEM</i>	7.1	8.8	4.1	4.5	0.2	0.4
Multiple VI 60 s VI 60 s							
Subject 161	<i>M</i>	36.6	76.8	86.0	105.0	76.2	79.0
	<i>SEM</i>	6.6	7.5	15.1	6.3	13.5	9.2
	<i>M</i>	67.0	55.4	37.4	26.8	28.6	27.4
	<i>SEM</i>	9.2	7.0	7.7	10.9	12.1	12.3
Subject 162	<i>M</i>	31.0	57.6	44.8	46.2	46.0	48.6
	<i>SEM</i>	5.4	12.4	5.5	7.7	7.0	6.9
	<i>M</i>	33.0	37.0	26.0	35.0	27.6	38.2
	<i>SEM</i>	3.3	3.9	3.1	3.9	2.1	6.1
Subject 163	<i>M</i>	49.0	104.0	84.4	83.6	77.6	80.0
	<i>SEM</i>	8.7	17.8	9.8	6.9	12.1	7.4
	<i>M</i>	68.6	64.6	57.6	71.2	55.6	53.2
	<i>SEM</i>	7.4	9.0	7.1	9.6	7.8	5.8
Subject 164	<i>M</i>	26.2	54.2	87.0	92.8	88.4	68.2
	<i>SEM</i>	9.0	13.8	17.5	19.3	11.8	13.6
	<i>M</i>	42.8	40.6	33.0	30.8	25.0	22.6
	<i>SEM</i>	6.7	6.5	7.8	9.7	5.3	5.7
Multiple VI 120 s VI 120 s							
Subject 161	<i>M</i>	16.4	59.4	64.6	53.0	59.2	31.4
	<i>SEM</i>	3.1	11.7	9.7	7.5	4.3	3.4
	<i>M</i>	12.8	21.6	13.6	18.2	13.8	10.0
	<i>SEM</i>	2.3	4.6	3.3	2.5	4.7	2.4

## APPENDIX

(Continued)

Subject 162	<i>M</i>	15.8	28.0	22.8	28.6	24.6	26.8
	<i>SEM</i>	3.9	5.9	2.4	1.3	2.7	3.7
	<i>M</i>	24.8	27.6	22.4	22.4	20.2	9.0
	<i>SEM</i>	2.6	2.9	1.7	1.8	1.9	5.9
Subject 163	<i>M</i>	35.2	84.8	88.2	89.6	77.2	80.8
	<i>SEM</i>	3.6	6.5	8.5	8.3	5.7	6.2
	<i>M</i>	61.4	77.4	57.8	62.8	47.6	53.8
	<i>SEM</i>	8.7	9.4	4.3	8.9	5.8	9.9
Subject 164	<i>M</i>	12.8	33.2	44.2	58.6	61.2	63.8
	<i>SEM</i>	1.0	3.2	9.8	4.0	3.8	6.1
	<i>M</i>	67.4	53.4	52.4	51.4	54.2	46.0
	<i>SEM</i>	7.1	6.9	5.8	5.0	8.3	6.3
Multiple VI 240 s VI 240 s							
Subject 161	<i>M</i>	1.0	6.2	7.4	17.0	13.0	16.8
	<i>SEM</i>	0.4	1.2	1.7	3.6	2.0	3.5
	<i>M</i>	11.4	12.6	9.4	9.2	4.6	6.2
	<i>SEM</i>	2.4	1.3	0.6	2.0	0.7	1.1
Subject 162	<i>M</i>	6.8	10.6	3.0	5.2	1.6	8.2
	<i>SEM</i>	1.9	1.7	1.4	3.1	1.2	4.9
	<i>M</i>	12.4	10.2	5.4	2.6	3.0	1.2
	<i>SEM</i>	3.7	6.3	2.7	1.3	1.3	0.8
Subject 163	<i>M</i>	0.8	3.0	3.0	8.8	3.2	4.0
	<i>SEM</i>	0.5	0.9	1.3	3.3	1.6	1.3
	<i>M</i>	3.0	3.2	6.0	13.8	15.2	12.0
	<i>SEM</i>	2.3	1.3	2.4	6.6	6.7	5.1
Subject 164	<i>M</i>	4.0	15.6	12.6	13.4	10.2	16.0
	<i>SEM</i>	2.0	4.3	1.8	4.0	4.3	4.4
	<i>M</i>	12.2	14.0	10.2	18.2	17.0	12.6
	<i>SEM</i>	5.1	4.6	0.8	3.3	4.1	2.5