The generality of within-session patterns of responding: Rate of reinforcement and session length

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Rats and pigeons responded for food delivered according to multiple schedules. The session length varied from 10 to 120 min, and the programmed rate of reinforcement varied from 15 to 240 reinforcers per hour. Response rates usually changed systematically within experimental sessions. For both rats and pigeons, responding reached a peak after an approximately constant amount of time since the beginning of the session, regardless of session length. When rats, but not pigeons, served as subjects, the peak rates of responding occurred later in the session and the within-session changes were smaller for lower than for higher rates of reinforcement. The similarities between the results for rats and for pigeons when session length varied suggest that at least one of the factors that produces the within-session changes in responding is shared by the present species, responses, and reinforcers. The differences in results when rate of reinforcement varied are more difficult to interpret.

Rate of responding changes systematically within experimental sessions under some conditions. For example, McSweeney, Hatfield, and Allen (1990) reported that response rates increased to a peak and then decreased within sessions when rats pressed levers or keys on multiple variable-interval (VI) 1-min VI 1-min schedules. These within-session changes deserve further study for several reasons. First, they are as large as, or larger than, those usually studied by operant psychologists. For example, Catania and Reynolds (1968) observed only a doubling of response rate when they changed the programmed rate of reinforcement from 8.4 to 300 reinforcers per hour. The rate of keypressing reported by McSweeney et al. changed by an average of 450% within the session. Second, the changes are orderly. Responding reached a peak at the same time in the session regardless of whether subjects' leverpressing was reinforced by Noyes pellets or whether their keypressing was reinforced by sweetened condensed milk. Finally, as has been discussed elsewhere, within-session changes may have important implications for theory and methodology in operant psychology (see, e.g., McSweeney & Roll, 1993).

The present experiments examined within-session changes in responding as a function of session length and programmed rate of reinforcement. In Experiment 1, rats pressed levers for Noyes pellets and pigeons pecked keys for mixed grain. Session length varied from 10 to 120 min. In Experiment 2, rats pressed keys for sweetened

condensed milk and pigeons pecked keys for mixed grain. The programmed rate of reinforcement varied from 15 to 240 reinforcers per hour. These experiments should add to our knowledge in three ways.

First, the experiments help to establish the generality of within-session changes in responding. If these changes occur only under limited conditions, they are less important than they are if they occur more generally. The behavior of two species making three different responses for three different reinforcers was examined for five rates of reinforcement and five session lengths. If within-session changes were to occur during many of these conditions, the generality of these changes would be more firmly established.

Second, the present functional analysis may help to determine whether the same variables produce the within-session changes under different circumstances. Finding systematic within-session changes in responding when examining the behavior of different species responding for different reinforcers does not establish that similar factors produce these changes. A functional analysis that studies responding at several levels of an independent variable is needed (Bitterman, 1960, 1965). Finding similar results for different species, responses, and reinforcers at each level of the independent variable would strongly suggest that common factors produced all of the results. One similarity might appear by chance, but several similarities are harder to dismiss as an artifact.

Third, the present experiments may help to determine the factors that produce within-session changes in responding. Increases in responding early in the session are often attributed to "warmup" and later decreases to "satiation." However, these terms may mask the action of a variety of factors. For example, previous experiments

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on this topic (e.g., McSweeney, 1992) have confounded the act of responding and the delivery of reinforcers with the passage of time in the session. As time passed in the experimental session, the subjects responded and they received reinforcers. Factors related to any of these variables may have contributed to the within-session changes in responding.

The present experiments were performed in an attempt to clarify the role of factors related to the passage of time, to responding, and to reinforcement in producing within-session changes in responding. If factors related to reinforcement (e.g., "satiation") produce the changes, these changes should be altered by changing the rate of reinforcement. For example, the late-session decreases in responding should be steeper for schedules that provide higher rates of reinforcement if these decreases are produced by satiation. If factors related to responding (e.g., muscular "warmup," "fatigue") produce within-session changes, these changes should occur similarly for schedules that support similar rates of responding and differently for schedules that support different rates. For example, the late-session decreases in responding should be steeper for schedules that support higher rates of responding if these decreases are produced by fatigue. If factors related to the passage of time (e.g., recovery from the handling routine, anticipation of the end of the session) produce within-session changes, these changes should be independent of the rates of reinforcement or rates of responding generated by the schedules when plotted in constant time units.

EXPERIMENT 1

Experiment 1 examined within-session changes in responding when rats pressed levers for Noyes pellets and pigeons pecked keys for mixed grain. Session length varied from 10 to 120 min.

Method

Subjects. The subjects were 5 experimentally naive rats and 3 experimentally experienced pigeons. A 4th pigeon began the experiment but died during it. The data for this subject have not been presented. The rats were bred in the Johnson Tower Vivarium at Washington State University from Sprague-Dawley stock. They were approximately 120 days old at the beginning of the experiment. All subjects were maintained at approximately 85% of their free-feeding weights by postsession feedings.

Apparatus. The apparatus for rats was a standard two-lever experimental enclosure, measuring 20×24.5×24.5 cm. A 5×5.5 cm opening that allowed access to food was centered on the front panel, 0.5 cm above the floor. Two 4×1.5 cm levers appeared 2.5 cm from this opening, one on each side. The levers were 5 cm above the floor and extended 1.5 cm into the enclosure. A 2-cm-diam light appeared 2.5 cm above each lever. A third 2-cm-diam light was centered in the front panel, 4 cm from the ceiling. Another 2-cm-diam light, in the center of the ceiling, served as the houselight.

The apparatus for pigeons was a three-key operant chamber, measuring 30×35.5×27 cm. The response keys were 2.5-cm-diameter Plexiglas panels, located 7 cm apart and 3 cm from the ceiling. The left and right keys were 6.5 cm from the side walls. A 5×4 cm opening, directly below the center key and 8 cm above

the floor, allowed access to the food hopper. A light behind a 4-cm-diameter Plexiglas panel served as a houselight. It appeared 1 cm below the ceiling and 0.5 cm from the right side. A treadle was also located on the floor directly below the right key. The treadle will not be described, because it was not used in this experiment.

Each apparatus was housed in a sound-attenuating chamber. Ventilating fans masked noises from outside the chamber. Experimental events were programmed by SYM microcomputers located in another room.

Procedure. Procedural details were selected to be similar to those used by McSweeney (1992) to allow better comparison of the results of the two studies. The rats were trained to press the right lever by shaping by successive approximations.

The rate of reinforcement was gradually decreased until subjects responded on a VI 60-sec schedule. Then subjects were placed on a multiple VI 60-sec VI 60-sec schedule. Session length was varied by changing the length of the components while delivering 12 components per session. The following session lengths were conducted in the following order: 60 min (300 sec), 30 min (150 sec), 120 min (600 sec), 90 min (450 sec), and 10 min (50 sec). The component duration used to produce each session length appears in parentheses after it. Each session length was conducted for 30 sessions.

In all conditions, the light above the lever was illuminated during the first component, but not during the second. The houselight was illuminated throughout the session. Reinforcers consisted of one 45-mg Noyes pellet delivered according to a 25-interval Fleshler and Hoffman (1962) series. Sessions were conducted five to six times per week.

The procedure for pigeons was identical to that for rats, with minor exceptions. Subjects had pecked keys in prior experiments. Therefore, they were not trained to peck the key. The reinforcer was 5-sec of access to mixed grain, and the components of the multiple schedule were signaled by white and green lights alternating on the center key.

Results and Discussion

Figure 1 presents the proportion of the total session leverpresses during successive components for each rat responding at each session length. Proportions were calculated by dividing the number of responses during a component by the total responses during the session. The proportions have been presented so that differences in the rates at which different subjects responded would not obscure similarities in the patterns of responding within the session. The interested reader may convert these proportions to absolute response rates by using the rates of responding averaged over the session reported in the Appendix for each subject responding at each session length. In Figure 1 and in all of those to follow, each set of axes presents the results for a particular experimental condition. All results have been taken from the last five sessions for which each condition was available.

Table 1 assesses the statistical significance of the within-session changes in responding reported in Figure 1. It presents the results of one-way (component) within-subjects analyses of variance (ANOVAs) applied to the rates of responding by individual subjects during each of the last five sessions for which each session length was available. Tests of significance for the linear and quadratic polynomial contrasts have also been presented to indicate whether the significant ANOVAs were produced by systematic linear changes (significant linear contrasts) or significant bitonic changes (significant quadratic

Figure 1. The proportion of the total session leverpresses during successive components by individual rats in Experiment 1. Proportions were calculated by dividing the number of responses during a component by the total number of responses during the session. Each graph presents the results for a particular session length. Results have been averaged over the last five sessions for which each session length was presented.

contrasts) in responding within the session. These statistical tests, and those that follow, have been applied to absolute rates of responding rather than to the proportions plotted in Figure 1 because proportions are bounded and cannot be assumed to be normally distributed.

Table 1 shows that responding changed significantly within sessions for most subjects. In all except 6 of the 25 cases, the overall ANOVA, the linear contrasts, or the quadratic contrasts were significant at the .05 level. Significant ANOVAs were almost always accompanied by

Table 1
Results of One-Way (Component) Within-Subjects Analyses of Variance (ANOVAs) Applied to the Rates of Leverpressing by Individual Rats During the Last Five Sessions for Which Each Session Length Was Presented, and Results of Linear and Quadratic Polynomial Contrasts

Subject	ANOVAs		Linear Contrasts		Quadratic Contrasts	
	<i>F</i>	<i>p</i>	<i>F</i>	<i>p</i>	<i>F</i>	<i>p</i>
10-Min Sessions						
31	1.56	<.145	7.22	<.055	0.02	<.884
32	2.13	<.038*	5.28	<.083	1.06	<.361
33	4.92	<.001*	6.71	<.061	8.13	<.046*
34	1.46	<.181	2.47	<.191	0.01	<.948
35	4.32	<.001*	8.65	<.042*	32.02	<.005*
30-Min Sessions						
31	1.96	<.057	0.20	<.681	1.76	<.255
32	1.33	<.239	1.10	<.354	9.82	<.035*
33	3.42	<.002*	11.36	<.028*	0.08	<.794
34	4.47	<.001*	15.40	<.017*	33.81	<.004*
35	3.17	<.003*	6.91	<.058	1.44	<.296
60-Min Sessions						
31	0.92	<.529	0.20	<.677	0.65	<.465
32	12.32	<.001*	13.16	<.022*	82.58	<.001*
33	1.87	<.071	1.17	<.340	7.04	<.057
34	4.19	<.001*	1.51	<.286	60.11	<.001*
35	0.93	<.521	0.53	<.508	10.30	<.033*
90-Min Sessions						
31	10.36	<.001*	107.09	<.001*	2.01	<.229
32	1.19	<.324	0.27	<.629	3.01	<.158
33	1.15	<.346	0.06	<.824	10.24	<.033*
34	3.92	<.001*	2.63	<.180	14.97	<.018*
35	9.27	<.001*	61.82	<.001*	0.86	<.407
120-Min Sessions						
31	5.47	<.001*	33.76	<.004*	0.22	<.664
32	3.02	<.004*	2.44	<.194	6.79	<.060
33	1.28	<.265	52.50	<.002*	0.03	<.878
34	5.04	<.001*	79.08	<.001*	3.25	<.146
35	3.13	<.003*	19.18	<.012*	0.38	<.570

Note—*df* = 11,44 for ANOVAs and 1,4 for polynomial contrasts.
 **p* < .05.

significant linear and/or quadratic polynomial contrasts. The ANOVA was significant but neither contrast was significant in only three cases (Subject 32, the 10-min sessions; Subject 35, the 30-min sessions; Subject 32, the 120-min sessions). Because the failures to obtain significance occurred for different subjects and for different session lengths, they do not represent a systematic violation of the conclusion that responding usually changes within experimental sessions. In particular, responding usually increased or increased and then decreased slightly within the session when components and sessions were short (10 and 30 min). Responding usually decreased or increased and then decreased within sessions when components and sessions were long (60, 90, and 120 min).

Figure 2 presents the proportion of the total-session keypecks by individual pigeons during successive components. Proportions were calculated and presented as in Figure 1. Again, they may be converted to absolute response rates by using the average rates of responding reported in the Appendix. Table 2 presents the results of

one-way (component) within-subject ANOVAs applied to the rates of keypecking by individual pigeons during the last five sessions in which each session length was conducted. Tests of significance are also presented for the linear and quadratic polynomial contrasts.

The changes in responding reported in Figure 2 were statistically significant for all subjects and session lengths, except for Subject 22's responding during the 120-min sessions. The significant ANOVAs were almost always accompanied by significant linear or quadratic (bitonic) trends. Both of the polynomial contrasts failed to reach significance only for Subject 2 in the 30-min sessions, and for Subjects 19 and 22 in the 90- and 120-min sessions. Responding generally increased or increased and then decreased within sessions for the shorter components and sessions (10 and 30 min). Responding generally decreased or increased and then decreased within sessions for the longer components and sessions (60, 90, and 120 min).

Increases in responding early in the session are not readily apparent in Figure 2 for the longer sessions (60, 90, and 120 min). These increases may have been obscured by averaging the data over relatively long components for these sessions (5, 7.5, and 10 min for the 60-, 90-, and 120-min sessions, respectively). Figure 3 confirms this. It presents the proportion of responses during the first 15 min of the session as a function of successive minutes for the 30-, 60-, 90-, and 120-min sessions. Proportions were calculated by dividing the number of responses during a minute by the total number of responses during the first 15 min. Again, proportions were calculated to reduce the influence of differences in absolute response rates. All results are those for the mean of all subjects. Figure 3 shows that responding increased during the early part of all sessions when the data are plotted in smaller units of time.

Figure 4 presents the proportion of the total session responses during successive components for leverpressing for Noyes pellets (circles, data taken from Figure 1), keypecking for mixed grain (triangles, data taken from Figure 2), and keypressing for sweetened condensed milk (inverted triangles, data taken from McSweeney, 1992). Proportions have been calculated and presented as for Figure 1. The data have been averaged over all subjects. No data appear for the 10- and 120-min sessions for rats pressing keys because McSweeney (1992) did not conduct these session lengths.

Figure 4 shows that responding changed similarly within sessions for these different species, responses, and reinforcers when session length was varied. To begin with, the changes in responding were smaller for the intermediate session (component) lengths than for either longer or shorter sessions (components). McSweeney (1992) reported that the changes in responding were smaller for 60- and 90-min sessions than for 30-min sessions when rats pressed keys. Figure 4 presents similar results for leverpressing and keypecking. The smallest changes from the component containing the lowest to the component containing the highest propor-

Figure 2. The proportion of the total session keypecks during successive components by individual pigeons in Experiment 1. Proportions were calculated as in Figure 1. Each graph presents the results for a particular session length. Results have been averaged over the last five sessions for which each session length was presented.

tion of leverpresses (.04 and .05) were reported for the 60- and 90-min sessions, respectively. Larger changes (.07) were reported for both the shortest (10-min) and the longest (120-min) sessions. The smallest changes from the component containing the lowest to the component containing the highest proportion of keypecks (.03 and .05) were reported for the 60- and 90-min ses-

sions, respectively. Again, larger changes (.07 and .06) were reported for the 10- and 120-min sessions, respectively.

The peak rate of responding was reached after an absolute amount of time had passed in the session, not after a time that was relative to session length, for both species and all responses and reinforcers. This peak oc-

Table 2
Results of One-Way (Component) Within-Subjects Analyses of Variance (ANOVAs) Applied to the Rates of Keypecking by Individual Subjects During the Last Five Sessions for Which Each Session Length Was Available, and Results of Linear and Quadratic Polynomial Contrasts

Subjects	ANOVAs		Linear Contrasts		Quadratic Contrasts	
	<i>F</i>	<i>p</i>	<i>F</i>	<i>p</i>	<i>F</i>	<i>p</i>
10-Min Sessions						
2	24.14	<.001*	57.67	<.002*	45.35	<.003*
19	4.35	<.001*	6.64	<.062	18.07	<.013*
22	25.31	<.001*	0.61	<.477	9.13	<.039*
30-Min Sessions						
2	10.93	<.001*	6.90	<.058	0.05	<.839
19	18.33	<.001*	36.91	<.004*	4.80	<.094
22	11.82	<.001*	17.59	<.014*	125.08	<.001*
60-Min Sessions						
2	5.84	<.001*	9.88	<.035*	0.08	<.792
19	11.47	<.001*	26.64	<.007*	12.37	<.025*
22	8.47	<.001*	8.57	<.043*	5.35	<.082
90-Min Sessions						
2	4.10	<.001*	11.59	<.027*	0.21	<.668
19	2.66	<.011*	0.43	<.549	6.67	<.061
22	3.20	<.003*	5.92	<.072	3.04	<.156
120-Min Sessions						
2	5.94	<.001*	8.21	<.046*	25.31	<.007*
19	3.26	<.003*	0.02	<.910	4.12	<.112
22	1.16	<.344	0.71	<.448	1.74	<.258

Note—*df* = 11,44 for ANOVAs and 1,4 for polynomial contrasts.
**p* < .05.

occurred slightly earlier for pigeons than for rats. McSweeney (1992) reported that the peak rate of responding was reached just after 20 min into the session when rats pressed keys for sweetened condensed milk. Figure 4 presents similar results for rats pressing levers for Noyes pellets. Peak responding occurred during the 7th, 10th, 5th, 5th, and 3rd components for the 10-, 30-, 60-, 90-, and 120-min sessions, respectively. Because the components were of different lengths for different session durations, these peaks occurred at approximately the same number of minutes after the beginning of the session. That is, the peak occurred between 22.5 and 25 min for the 30-min sessions, between 20 and 25 min for the 60-min sessions, between 22.5 and 30 min for the 90-min sessions and between 20 and 30 min for the 120-min sessions. The only exception occurred for the 10-min sessions. Responding could not peak after 20 min because of the short session duration.

In contrast, the peak rate of keypecking occurred during the first component for the 120-min sessions, during the third component for the 60- and 90-min sessions, and during the fifth component for the 30-min sessions. A clear peak was not apparent for the 10-min sessions. This means that the peak rate of keypecking occurred in the first 10 min of the session for the 120-min sessions. It occurred between 10 and 12.5, and 10 and 15 min, for the 30- and 60-min sessions, respectively. Only the peak for the 90-min sessions (between 15 and 22.5 min) occurred somewhat later.

The finding that within sessions response rate reaches its peak after an absolute, not a relative, period of time distinguishes it from many other findings in the conditioning literature. Responding on many conditioning procedures is governed by relative time (e.g., Balsam, 1984). For example, the length of the postreinforcement pause on fixed interval schedules is proportional to the time between successive reinforcers (Schneider, 1969).

EXPERIMENT 2

Experiment 2 examined within-session changes in responding when rats pressed keys for sweetened condensed milk and pigeons pecked keys for mixed grain. The programmed rate of reinforcement varied from 15 to 240 reinforcers per hour.

Method

Subjects. Five experimentally naive rats and 4 experimentally experienced pigeons served as subjects. The rats were bred in the Johnson Tower Vivarium at Washington State University from Sprague-Dawley stock. They were approximately 120 days old at the beginning of the experiment. The pigeons were not the same subjects that served in Experiment 1. All subjects were maintained at approximately 85% of their free-feeding weights by postsession feedings.

Apparatus. The apparatus for rats was a 21×21.5×24 cm experimental enclosure. A 2-cm-diameter Plexiglas panel, covering a 5-W light, appeared 3 cm from each side of the panel and 5.5 cm from the top. The Plexiglas that covered the left light was clear; that covering the right light was opaque. A 2.5-cm-diameter response key was located 2 cm below the left light. A 3.5-cm lever, which extended 2 cm into the chamber, was located 3 cm below

Figure 3. The proportion of the total early-session keypecks during successive minutes for pigeons responding during the 30-, 60-, 90-, and 120-min sessions in Experiment 1. The results are those for the mean of all subjects responding during the last five sessions for which each session duration was presented. Proportions were calculated by dividing the number of responses during a minute by the total number of responses during the first 15 min of that session.

Figure 4. The proportion of the total session leverpresses (circles), keypecks (triangles), and keypresses (inverted triangles) during successive components for each session length. Each graph presents the results for one session length. The results for keypressing have been taken from McSweeney (1992); those for leverpressing and keypecking, from Experiment 1. All results have been averaged over all subjects and over the last five sessions for which each session length was presented.

the right light. A 6-cm-diameter opening, centered in the panel and 4 cm above the floor, allowed access to a 0.25-ml dipper.

The apparatus for pigeons was a two-key two-treadle experimental enclosure, measuring 39×33×31 cm. Two 2.5-cm-diam response keys appeared 22 cm above the floor and 12 cm apart. The left key was 11.5 cm from the left wall; the right key was 10.5 cm from the right wall. A 6×5 cm opening allowed access to a magazine containing mixed grain. It appeared 5.5 cm above the floor and 17 cm from the right wall. A 3-cm-diameter houselight was located 3.5 cm from the ceiling and 3.5 cm from the right wall. A floor treadle appeared directly below each of the response keys. The treadles will not be described because they were not used in this experiment.

Each experimental apparatus was located in a sound-attenuating chamber. A ventilating fan masked noises from outside the apparatus, and SYM microcomputers, located in another room, presented the experimental events.

Procedure. The rats were trained to press the key with their snouts by shaping by successive approximations. The rate of reinforcement was gradually decreased until subjects responded on a VI 30-sec schedule. The experimental procedure then began. All procedural details were selected to be similar to those used by McSweeney (1992), so that the results of the two studies could be compared.

During the experiment, rats responded on a multiple schedule in which components alternated every 5 min. The light above the key was illuminated during the first component, but not during the second. Reinforcers consisted of 5 sec of access to a 0.25-ml dipper that contained sweetened condensed milk mixed one to one with water. Their delivery was scheduled according to a 25-interval Fleshler and Hoffman (1962) series. Sessions ended when 12 components had been presented (60 min). Sessions were conducted daily, five to six times per week. The houselight was illuminated throughout the session.

During the first condition, rats responded on a multiple VI 30-sec VI 30-sec schedule. Then they were placed on a multiple VI 120-sec VI 120-sec, a multiple VI 240-sec VI 240-sec, a multiple VI 15-sec VI 15-sec, and a multiple VI 60-sec VI 60-sec schedule. The subjects responded on each schedule for 30 sessions.

The procedure for pigeons was identical to that used for rats with minor exceptions. Keypecking was not shaped, because subjects had pecked in prior experiments. The reinforcer was 5 sec of access to mixed grain. Finally, the components of the multiple schedule were signaled by white and green lights appearing on the left key. The right key was dark throughout the session.

Results and Discussion

Figure 5 presents the proportion of the total session keypresses by individual rats during successive components for each of the five schedules. Proportions were calculated and reported as in Figure 1. Again, they may be converted to absolute response rates by using the average rates of responding reported in the Appendix. Table 3 presents the results of one-way (component) within-subjects ANOVAs applied to the rates of responding by individual subjects during the last five sessions for which each schedule was available. The results of significance tests for the linear and quadratic polynomial contrasts are also reported.

Figure 5 and Table 3 show that large and systematic changes in responding occurred within sessions. These within-session changes were significant for each subject responding on each schedule, except for Subject 65 on the multiple VI 60-sec VI 60-sec schedule. Significant linear or quadratic (bitonic) trends were also reported in all cases except for Subject 62 on the multiple VI 15-sec

VI 15-sec schedule, Subjects 61, 63, and 65 on the multiple VI 60-sec VI 60-sec schedule, and Subject 63 on the multiple VI 120-sec VI 120-sec schedule. In general, responding decreased, or increased and then decreased, within the session.

Figure 6 presents the proportion of the total session keypecks by individual pigeons during successive components for each schedule of reinforcement. Proportions were calculated and presented as in Figure 1. They can be converted to absolute rates of responding by using the average response rates reported in the Appendix. Table 4 presents the results of one-way (component) within-subject ANOVAs applied to the rates of responding by individual subjects during the last five sessions for which each schedule was available. The results of significance tests for the linear and quadratic polynomial contrast are also presented.

Table 4 shows that responding changed systematically within sessions only for the multiple VI 60-sec VI 60-sec schedule. Responding changed significantly for many subjects responding on the other schedules. However, these significant changes were rarely accompanied by significant polynomial contrasts, indicating that the significant changes were not usually systematic.

It is not known why responding failed to change systematically within sessions in this case. These results may indicate that the factors that control the within-session changes in responding are different for pigeons and rats. Apparently, whatever these factors are, they were not present or they were not strong enough to produce systematic changes for pigeons under the present circumstances. Alternatively, the failures may be a procedural artifact. For example, the present experiment used experimentally experienced pigeons but experimentally naive rats. Figure 6 shows that the changing of the component resulted in large changes in the rates of keypecking. A "sawtooth" pattern of responding is especially apparent for the multiple VI 30-sec VI 30-sec and multiple VI 120-sec VI 120-sec schedules. Because this effect is most apparent for the two schedules that were conducted first, it may have been produced by the subjects' experimental history. That is, past experience may have added variance to the data for the present pigeons that obscured systematic changes in responding within the session.

The present results suggest that experimentally naive pigeons would show systematic changes in responding within sessions. A tendency for responding to increase and then decrease within the session is apparent in Figure 6 for all schedules. This becomes more apparent when results are summed over two components to reduce the variance added by the changing of the components. The proportions of the total session responses during successive sixths of the session for the mean of all subjects were 0.14, 0.22, 0.23, 0.21, 0.13, and 0.08 for the multiple VI 15-sec VI 15-sec schedule; 0.14, 0.21, 0.21, 0.17, 0.15, and 0.15 for the multiple VI 30-sec VI 30-sec schedule; 0.19, 0.31, 0.23, 0.13, 0.07, and 0.05 for the multiple VI 60-sec VI 60-sec schedule; 0.17,

Figure 5. The proportion of the total session keypresses during successive components by individual rats in Experiment 2. Proportions were calculated as in Figure 1. Each graph presents the results for a particular schedule. Results have been averaged over the last five sessions for which each schedule was presented.

0.21, 0.19, 0.15, 0.14, and 0.13 for the multiple VI 120-sec VI 120-sec schedule; and 0.15, 0.22, 0.17, 0.18, 0.14, and 0.14 for the multiple VI 240-sec VI 240-sec schedule.

Figure 7 summarizes the changes in the within-session patterns of responding with changes in the programmed rates of reinforcement for different species, responses, and reinforcers. It presents the proportion of the total

Table 3
Results of One-Way (Component) Within-Subjects Analyses
of Variance (ANOVAs) Applied to the Rates of Keypressing
by Individual Rats During the Last Five Sessions
for Which Each Schedule Was Available, and Results
of Linear and Quadratic Polynomial Contrasts

Subject	ANOVAs		Linear Contrasts		Quadratic Contrasts	
	<i>F</i>	<i>p</i>	<i>F</i>	<i>p</i>	<i>F</i>	<i>p</i>
Multiple VI 15-sec VI 15-sec Schedule						
61	13.14	<.001*	14.44	<.019*	21.65	<.010*
62	6.10	<.001*	6.80	<.060	0.85	<.410
63	7.41	<.001*	15.32	<.017*	1.26	<.324
64	8.74	<.001*	21.82	<.010*	9.07	<.039*
65	5.76	<.001*	11.64	<.027*	2.26	<.208
Multiple VI 30-sec VI 30-sec Schedule						
61	10.67	<.001*	17.68	<.014*	5.79	<.074
62	11.67	<.001*	34.27	<.004*	1.99	<.232
63	22.20	<.001*	205.27	<.001*	0.00	<.984
64	6.51	<.001*	9.63	<.036*	7.09	<.056
65	13.84	<.001*	30.30	<.005*	0.05	<.829
Multiple VI 60-sec VI 60-sec Schedule						
61	4.58	<.001*	0.07	<.806	4.96	<.090
62	4.56	<.001*	8.83	<.041*	2.76	<.172
63	2.47	<.017*	1.64	<.270	6.10	<.069
64	2.30	<.025*	0.14	<.727	8.55	<.043*
65	0.70	<.726	0.17	<.700	1.38	<.305
Multiple VI 120-sec VI 120-sec Schedule						
61	12.73	<.001*	35.43	<.004*	28.60	<.006*
62	5.65	<.001*	6.48	<.064	14.90	<.018*
63	4.78	<.001*	0.62	<.475	0.39	<.569
64	6.70	<.001*	0.27	<.632	13.82	<.021*
65	5.52	<.001*	1.08	<.357	8.16	<.046*
Multiple VI 240-sec VI 240-sec Schedule						
61	8.22	<.001*	1.78	<.253	16.59	<.015*
62	27.83	<.001*	9.59	<.036*	39.17	<.003*
63	6.54	<.001*	8.72	<.042*	0.18	<.692
64	7.16	<.001*	9.27	<.038*	19.04	<.012*
65	6.49	<.001*	6.70	<.061	14.70	<.019*

Note—*df* = 11,44 for ANOVAs and 1,4 for polynomial contrasts.
 **p* < .05.

session responses during successive components for rats pressing levers for Noyes pellets (circles, data taken from McSweeney, 1992), for pigeons pecking keys for mixed grain (triangles, data taken from Figure 6), and for rats pressing keys for sweetened condensed milk (inverted triangles, data taken from Figure 5). Each graph presents the results for a single schedule of reinforcement. All results have been taken from the last five sessions for which a schedule was available, and they have been averaged over all subjects.

The results presented in Figure 7 for pigeons will not be discussed because responding did not usually change systematically for these subjects. The results reported when rats pressed keys for sweetened condensed milk (inverted triangles) resembled those reported when rats pressed levers for Noyes pellets (circles). In both cases, the peak rate of responding appeared later in the session as the programmed rate of reinforcement decreased. For both responses, the peak rate of responding occurred during the second component of the multiple VI 15-sec VI 15-sec schedule, the third component of the multiple VI 30-sec VI 30-sec schedule, the fourth component of

the multiple VI 60-sec VI 60-sec and multiple VI 120-sec VI 120-sec schedules, and the sixth component of the multiple VI 240-sec VI 240-sec schedule. A Friedman ANOVA by ranks applied to the number of the component in which the peak response rate occurred for individual subjects showed that the location of the peak changed significantly with the schedule of reinforcement for the present keypressing (Friedman test statistic = 13.400, *df* = 4, *p* < .009). A nonparametric test was used to avoid assuming that the locations of peak response rates were normally distributed.

The size of the within-session changes in responding decreased with decreases in the programmed rate of reinforcement. McSweeney (1992) reported that the within-session changes in leverpressing became smaller as the programmed rate of reinforcement decreased. This is not readily apparent in the results for keypressing when results are reported in terms of proportion of total session responses (Figure 5). However, the trend does appear when absolute response rates are considered. The differences between the highest and the lowest rates of keypressing during the session were 97.8, 102.6, 38.4, 42.2, and 28.0 responses per minute for the multiple VI 15-sec VI 15-sec, multiple VI 30-sec VI 30-sec, multiple VI 60-sec VI 60-sec, multiple VI 120-sec VI 120-sec, and multiple VI 240-sec VI 240-sec schedules, respectively. A Friedman ANOVA by ranks applied to the differences between the high and low response rates for individual subjects showed that the size of the change in keypressing changed significantly with the schedule of reinforcement (Friedman test statistic = 14.240, *df* = 4, *p* < .007). Again a nonparametric test was used, because the differences in response rates cannot be assumed to be normally distributed.

GENERAL DISCUSSION

Generality

The present results greatly increase the generality of within-session changes in responding. When session (component) length varied, responding usually changed significantly and systematically within sessions for both species, all responses, and all reinforcers. The only exceptions occurred for some individual rats and for 1 pigeon pecking during the 120-min sessions. When programmed rates of reinforcement varied, responding also changed significantly and systematically within sessions for rats pressing keys for sweetened condensed milk for all five schedules. Responding changed significantly for pigeons pecking keys for mixed grain during several schedules, but these changes were systematic only for the multiple VI 60-sec VI 60-sec schedule. The reason for these failures to find systematic changes for pigeons are unknown, but, as argued earlier, the failures may be a procedural artifact.

Functional Analysis

Two findings suggest that at least one common factor contributes to the within-session changes in responding

Figure 6. The proportion of the total session keypecks during successive components by individual pigeons in Experiment 2. Proportions were calculated as in Figure 1. Each graph presents the results for a particular schedule. Results have been averaged over the last five sessions for which each schedule was presented.

Table 4
Results of One-Way (Component) Within-Subjects Analyses
of Variance (ANOVAs) Applied to the Rates of Keypecking
by Individual Pigeons During the Last Five Sessions
for Which Each Schedule Was Available, and Results
of Linear and Quadratic Polynomial Contrasts

Subject	ANOVAs		Linear Contrasts		Quadratic Contrasts	
	<i>F</i>	<i>p</i>	<i>F</i>	<i>p</i>	<i>F</i>	<i>p</i>
Multiple VI 15-sec VI 15-sec Schedule						
25	1.24	<.292	0.94	<.388	3.05	<.156
72	6.43	<.001*	7.86	<.049*	10.95	<.030*
42	1.99	<.053	1.75	<.257	3.36	<.141
41	2.33	<.043*	4.32	<.106	0.59	<.486
Multiple VI 30-sec VI 30-sec Schedule						
25	1.44	<.188	0.24	<.650	1.52	<.286
72	5.16	<.001*	1.51	<.287	11.03	<.029*
42	1.32	<.247	1.60	<.275	2.20	<.212
41	2.46	<.017*	1.05	<.364	2.03	<.228
Multiple VI 60-sec VI 60-sec Schedule						
25	3.31	<.002*	2.62	<.181	25.11	<.007*
72	10.68	<.001*	19.08	<.012*	87.22	<.001*
42	9.42	<.001*	36.31	<.004*	0.00	<.998
41	3.26	<.002*	11.58	<.027*	0.03	<.864
Multiple VI 120-sec VI 120-sec Schedule						
25	5.96	<.001*	8.30	<.045*	0.25	<.643
72	6.13	<.001*	4.46	<.102	0.99	<.376
42	3.27	<.002*	3.24	<.146	0.03	<.868
41	1.19	<.321	1.99	<.231	1.26	<.325
Multiple VI 240-sec VI 240-sec Schedule						
25	9.03	<.001*	10.87	<.030*	18.03	<.013*
72	1.55	<.150	0.04	<.847	0.50	<.520
42	3.02	<.004*	0.46	<.537	3.76	<.125
41	2.14	<.037*	5.14	<.086	2.28	<.205

Note—*df* = 1,44 for all ANOVAs except that for Subject 41, multiple VI 15-sec VI 15-sec schedule. This subject did not respond during the last 15 min of the session. Therefore, the ANOVA was applied only to the first 9 components (*df* = 8,32). *df* = 1,4 for the polynomial contrasts. **p* < .05.

for these different species, responses, and reinforcers. First, the within-session patterns of responding changed similarly in all cases when session length or component duration varied (Figure 4). The functions were flatter for intermediate session durations than they were for either longer (Experiment 1) or shorter (Experiment 1; McSweeney, 1992) sessions. The peak rate of responding was also controlled by absolute, not relative, time. That is, peak responding was reached a constant number of minutes after the beginning of the session regardless of session length, not after a constant proportion of the session had passed. Second, within-session patterns of responding changed similarly with changes in the programmed rates of reinforcement when rats pressed levers (McSweeney, 1992) and keys (Experiment 2). The peaks of the functions appeared later as the programmed rates of reinforcement decreased and the changes in absolute response rates were smaller for lower than for higher rates of reinforcement.

Finding functional similarities is important. Procedural differences inevitably arise when one is studying different species making different responses for differ-

ent reinforcers. For example, even if both rats and pigeons are deprived to 85% of their free-feeding body weights, it cannot be assumed that they are equally "hungry." These procedural differences should produce different behavioral results. The finding of similar results in spite of these procedural differences strongly implies that the behaviors of these different species are controlled by relatively powerful variables that are shared in common by these species, responses, and reinforcers.

There were also some differences between the results for rats and those for pigeons. The peak rate of responding occurred earlier for pigeons (just after 10 min) than for rats (just after 20 min). Responding also changed systematically for rats responding on all of the schedules of reinforcement in Experiment 2, but for pigeons responding only on the multiple VI 60-sec VI 60-sec schedule.

The theoretical implications of these differences are not clear. The differences in the time at which responding reached a peak may represent a quantitative, not a qualitative, difference between the species, responses, and reinforcers. As argued earlier, future experiments will also be needed in order to isolate the variables that contributed to the failure of responding to change systematically for pigeons in Experiment 2. This failure may indicate that at least some factors that contribute to within-session changes differ for rats and pigeons. Alternatively, it may be a procedural artifact.

Theoretical Analysis

The present results help to clarify the factors that produce within-session changes in responding. To begin with, the finding that changes in the programmed rates of reinforcement alter the within-session patterns questions the idea that factors related to the passage of time are solely responsible for these changes. If they were, then similar within-session changes should have been reported for all schedules, but they were not. Instead, events that occurred within the session contributed to the within-session changes.

The results presented in Figures 4 and 7 question whether factors related to responding (e.g., "fatigue") contribute strongly to the within-session changes. Figure 4 shows that the changes are similar for all three types of responses that have been studied when session (component) length varies. Figure 7 shows that the changes are similar for rats pressing keys (inverted triangles) and levers (circles) when the programmed rate of reinforcement varies. It seems unlikely that "fatigue" would occur at the same rate for rats pressing levers or keys and for pigeons pecking keys.

Even more challenging is that the similarities among the responses are particularly strong in Figure 4 for the longer sessions and in Figure 7 for the higher programmed rates of reinforcement (multiple VI 15-sec VI 15-sec and multiple VI 30-sec VI 30-sec schedules). More "fatigue" should occur for longer sessions, because more responding occurs. More "fatigue" should also occur for higher rates of reinforcement, because these schedules support

Figure 7. The proportion of the total session responses during successive components for rats pressing levers for Noyes pellets (circles), pigeons pecking keys for mixed grain (triangles), and rats pressing keys for sweetened condensed milk (inverted triangles). Results for leverpressing have been taken from McSweeney (1992); those for keypecking and keypressing, from Experiment 2. All results are those for the mean of all subjects and have been averaged over the last five sessions for which that schedule was available. Each set of axes presents the results for a particular schedule of reinforcement. Proportions have been calculated by dividing the number of responses during a component by the total number of responses during the session.

higher rates of responding (see the Appendix). Any differences in "fatigue" that occur among the responses should be magnified, not reduced, when more responding occurs. Therefore, if "fatigue" produces the within-session changes in responding, these changes should be more different, not more similar, for different responses when longer sessions and higher rates of reinforcement are used.

The finding of earlier peaks for higher rates of reinforcement when rats press keys (Experiment 2) or levers (McSweeney, 1992) supports the idea that a factor related to reinforcement (e.g., "satiation") plays a role in producing the within-session changes. If a factor related to reinforcement contributes, these functions should peak earlier and decline more steeply when reinforcers are delivered at a higher rate. This is what occurred (Figures 5 and 7).

Future experiments should specify the nature of this reinforcement-related factor more precisely. It is unlikely that the present decreases in responding were produced by "satiation," interpreted simply. To begin with, the decreases in responding were similar for Noyes pellets, sweetened condensed milk, and mixed grain when session length varied (Figure 4). The decreases in responding were also similar for sweetened condensed milk and Noyes pellets when the programmed rate of reinforcement varied (Figure 7). It seems unlikely that "satiation" would occur at a similar rate for all of these reinforcers, given that they differ in calories, stomach loading, sweetness, and so forth. More convincing is that the results for the different reinforcers presented in Figure 4 are more similar for longer than for shorter sessions. Responding for Noyes pellets is also more similar to responding for sweetened condensed milk for schedules that deliver higher, not lower, rates of reinforcement (Figure 7). Again, any differences in rates of "satiation" among the reinforcers should be magnified when more reinforcers are presented (longer sessions) or

when reinforcers are presented at higher rates. Therefore, the similarities among the responses should be stronger for shorter, not longer, sessions and for lower, not higher, rates of reinforcement if they were produced by a simple interpretation of "satiation."

The present results strongly argue that future experiments should examine dynamic changes in responding within sessions. Not only do such changes occur, but they are large and systematic, and they occur in many situations. In addition, the present results suggest that at least one of the variables that produces these changes may be shared by at least two different species, making different responses for different reinforcers.

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APPENDIX

Table A1
Mean Rates of Leverpressing for Noyes Pellets
(Responses per Minute) by Each Rat Responding
at Each Session Duration Over the Last Five Sessions
for Which That Duration Was Available in Experiment 1

Subject	Session Duration				
	10 min	30 min	60 min	90 min	120 min
31	10.6	6.5	12.7	13.7	12.3
32	2.6	16.5	28.9	13.6	6.7
33	16.3	6.2	7.2	20.4	11.1
34	6.5	16.8	19.1	9.0	7.2
35	16.2	6.1	3.9	17.7	15.3
<i>M</i>	10.4	10.4	14.4	14.9	10.5

Table A2
Mean Rates of Keypecking for Mixed Grain
(Responses per Minute) by Each Subject Responding
at Each Session Duration Over the Last Five Sessions
for Which That Duration Was Available in Experiment 1

Subject	Session Duration				
	10 min	30 min	60 min	90 min	120 min
2	107.1	89.1	80.8	56.0	48.0
19	62.1	60.0	58.2	66.7	46.0
22	67.7	66.5	67.1	29.1	34.5
<i>M</i>	79.0	71.9	68.7	50.6	42.8

Table A3
Mean Rates of Keypressing for Sweetened Condensed Milk
(Responses Per Minute) by Each Subject Responding on
Each Schedule Over the Last Five Sessions for Which
the Schedule Was Available in Experiment 2

Subject	Schedule				
	VI 15	VI 30	VI 60	VI 120	VI 240
61	96.6	128.3	54.0	19.6	10.6
62	75.8	64.3	49.7	52.8	18.0
63	61.6	53.5	41.4	42.6	10.7
64	115.3	58.2	39.6	67.9	28.1
65	68.6	51.9	34.4	35.1	12.8
<i>M</i>	83.6	71.2	43.8	43.6	16.0

Note—VI 15, variable-interval 15-sec schedule, etc.

Table A4
Mean Rates of Keypecking for Mixed Grain
(Responses per Minute) by Each Subject Responding
on Each Schedule Over the Last Five Sessions for
Which the Schedule Was Available in Experiment 2

Subject	Schedule				
	VI 15	VI 30	VI 60	VI 120	VI 240
25	24.9	20.3	18.7	21.5	7.6
72	35.2	62.5	59.8	56.9	32.9
41	6.5	46.6	40.2	38.6	13.5
42	36.3	54.2	47.3	49.9	38.1
<i>M</i>	25.7	45.9	41.5	41.7	23.1

Note—VI 15, variable-interval 15-sec schedule, etc.