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The Effects of Differing Response Force Requirements on Response Rate and Post-Reinforcement Pause

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THE EFFECTS OF DIFFERING RESPONSE FORCE REQUIREMENTS ON RESPONSE RATE AND POST-REINFORCEMENT PAUSE

by

Kenneth Lee Alling

A Dissertation
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Doctor of Philosophy
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Western Michigan University
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The present study consisted of three experiments in which rats were exposed to two-component multiple schedules of reinforcement. In the first experiment, fifteen responses were required to produce reinforcement in both components of the multiple schedule. In one component 25 g of downward force was always required to operate the response lever. In the other, the force required varied from 25 g to 200 g across conditions. In the second experiment, fifteen responses were required to produce reinforcement in both components of the multiple schedule. In one component 25 g of downward force was always required to operate the response lever. In the other, the force requirement for five consecutive responses at the beginning, middle, or end of each ratio was varied from 25 g to 200 g. In the third experiment, the number of responses required to produce reinforcement was reduced from 15 to 5, and then to 1. Again the effects of altering the force required to operate the lever were examined. In general, the results of the these experiments indicated that as the amount of force required to operate the lever increased, response rates decreased and post-reinforcement pauses increased.
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The effects of differing response force requirements on response rate and post-reinforcement pause

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Western Michigan University, 1993
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Kenneth Lee Alling
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CHAPTER I
INTRODUCTION

All responses involve some degree of effort and organisms emit responses involving varying amounts of effort or intensity during the course of their daily activities. Further, response effort as a causal variable plays a role in every experiment involving an organism emitting responses. Therefore, examination of the effects of differing response effort would seem to be an important area of research.

A large number of experiments have been performed in which the number of responses required in order to produce a reinforcer were manipulated (e.g., Crossman, Heaps, Nunes, & Alferink, 1974; Felton & Lyon, 1966; Ferster & Skinner, 1957; Kaplan, 1956; Mintz, Mourer, & Gofseyeff, 1967; Pliskoff & Golddiamond, 1966; Powell, 1968; Premack, Schaeffer, & Hundt, 1964; Rilling & McDiarmid, 1965; Thompson, 1954; Winograd, 1965). These experiments have demonstrated that (a) as the number of responses required to produce a reinforcer increases the pause after production of the reinforcer increases (e.g., Felton & Lyon, 1966; Ferster & Skinner, 1957; Kaplan, 1956; Mintz, Mourer, & Gofseyeff, 1967; Powell, 1968; Premack, Schaeffer, & Hundt, 1964; Thompson, 1954; Winograd, 1965), and (b) as the number of responses required to produce a reinforcer increases the time from first to the last response (i.e., work time) increases (e.g., Pliskoff & Golddiamond, 1966; Rilling & McDiarmid, 1965). Some might speculate that increasing the number of responses required to produce a reinforcer is analogous to increasing response effort. However, manipulating the number of responses required to produce a reinforcer is not
necessarily equivalent behaviorally with increasing the amount of effort (i.e., force) required to make each response.

Response force has not, as of this time, received widespread empirical or theoretical attention (Fowler, 1987). Further, much of the research concerned with response force has dealt with it as a dependent variable (e.g., Fowler, 1987; Mintz, 1962; Notterman, 1959; Notterman & Mintz 1965; Skinner, 1938; Trotter, 1956). Relatively little research has been conducted on the effects of force as an independent variable. Realizing the importance of accounting for the influence of response force on behavior, Hull (1943) stated:

It is supposed that each response evocation produces in the organism a certain increment of a fatigue-like substance or condition which constitutes a need for rest. The mean net amount deposited at each response appears to be a positively accelerated increasing function of work or energy expenditure (W) consumed in the execution of the act...It is assumed, further, that this substance or condition has the capacity directly to inhibit the power of S to evoke R (p. 391).

The few studies which have been performed in this area have shown that (a) increasing the amount of force required on an operandum decreases response rate on that operandum (Adair & Wright, 1976; Chung, 1965; Mowrer & Jones, 1943; Skinner, 1972); (b) the rate at which a nonreinforced response extinguishes increases as the amount of force required on that operandum increases (Mowrer & Jones, 1943); and (c) subject's will tend to escape a situation requiring effortful responding (Miller, 1968). These findings are in agreement with and were predicted by Hull's (1943) statement and have led some investigators to suggest that in some respects increasing the force required to obtain reinforcement is similar to adding an aversive consequence for the response (e.g., Blough, 1966; Miller, 1968; & Solomon, 1948).

To date, the research in this area has not provided a comprehensive examination of the effects of differing response force requirements on response rate and post-reinforcement pause. Noticeably absent from the literature is an examination of the
effects of differing response force requirements on responding maintained under ratio schedules. The purpose of the present experiment was to add to the existing body of literature investigating response force (i.e., altering the amount of force required to make a response) as an independent variable. In the present experiment, the effects of differing response force requirements on the response rates and post-reinforcement pausing of rats on ratio schedules were examined.

The present study involved three experiments, each using a multiple fixed-ratio fixed-ratio (MULT FR FR) schedule of food reinforcement. In each experiment the dependent variables examined were response rate and post reinforcement pause time. The ratio requirements in the two components were always equal, but the force requirements differed. In the first experiment a 25 g force requirement was compared with forces from 25 to 200 g across conditions. In the second, the two components had equal force requirements (25 g) except that one component had a 200 g requirement for five consecutive responses at the beginning, middle, or end of the ratio, varying across conditions. The third experiment compared a 25 g and a 200 g force requirement, but with much smaller ratio requirements.
CHAPTER II

EXPERIMENT 1

Experiment 1 was conducted to assess the effects of increasing the force required to make a response on response rate and post-reinforcement pause. Subjects were exposed to a multiple fixed-ratio 15 fixed ratio-15 multiple (MULT FR15 FR15) schedule. That is, every fifteenth lever press produced the reinforcer under both components of the multiple schedule. Under one component, 25 g of downward force was required to depress the lever. In the other, the force required was varied from 25-200 g across conditions. Response rates and post-reinforcement pauses were recorded during each component of the multiple schedule.

Method

Subjects

Eight male Long-Evans strain hooded rats, maintained at 80% of their free-feeding weights, served as subjects. Subjects were approximately 180 days old and experimentally naive at the onset of training. They were individually housed with unlimited access to water in a room with controlled lighting (16-hr/8-hr light-dark cycle), temperature (22-24 degrees C), and humidity (60-70%). The rats were maintained in accordance with the general principles of animal husbandry outlined by the American Psychological Association (1985) and the National Institute of Health (1985). The study was approved by the Institutional Animal Care and Use Committee at Western Michigan University.

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Apparatus

Sessions were conducted in four operant chambers (Lehigh Valley Electronics, Lehigh Valley, PA) measuring 15 cm high, 13 cm wide, and 20 cm long. In each, two response levers 3 cm wide were located on the front wall 9 cm above the chamber floor, 1 cm from the side wall, and 2 cm from a Plexiglass barrier that separated the two levers. The two levers protruded 2.5 cm into the chamber, and the Plexiglass barrier centered on the front wall extended 6 cm into the chamber. Only the left lever was used in the present study. Ambient illumination was provided by 7-W stimulus lights located above each lever. An aperture (3 cm in diameter) horizontally centered on the front wall 4 cm above the chamber floor allowed access to a liquid dipper filled with a 50% sweetened condensed milk, 50% water solution. When the dipper was raised the aperture was illuminated by a 7-W stimulus light located below the dipper. A speaker on the back wall allowed for presentation of auditory stimuli.

The lever mechanisms in each chamber allowed for changes of lever force during experimental sessions. In the resting position, the end of a metal shaft, which was connected to the back of the lever, made contact with an electromagnet. When the lever was depressed until the bottom of the shaft raised approximately 0.2 cm off the electromagnet, a microswitch was operated and a response was recorded. The amount of force required to depress the lever was modulated by the amount of current passed through the electromagnet. When the electromagnet was off, 25 g of force was required to depress the lever.

The operant chambers were individually housed within sound-attenuating boxes. Ventilation was provided by an exhaust fan and masking noise was provided by a Grason-Stadler White Noise Generator through a speaker mounted on the inner wall of the sound-attenuating box. A PDP/8e minicomputer (Digital Equipment
Corporation, Maynard, MA), equipped with SuperSKED® software (State Systems, Inc., Kalamazoo, MI) and electromechanical interfacing, arranged experimental conditions and collected data.

**Procedure**

Subjects were randomly assigned to two groups. For subjects in Group 1 (i.e., Subjects 1, 2, 3, and 4) the two stimulus lights above the levers and a tone remained on during training sessions. For subjects in Group 2 (i.e., Subjects 5, 6, 7, and 8) the two stimulus lights above the levers and the tone came on and went off at 1-s intervals during training sessions. For both groups all stimuli were off during dipper presentation except for the light located below the dipper. Subjects were initially trained to lick the dipper when raised and to press the lever. The dipper was presented for 4-s according to a random-time 60-s schedule. Each response on the left lever resulted in 4-s presentation of the dipper as well. Throughout the experiment responses on the right lever had no effect. Sessions ended following the delivery of 40 reinforcers. Once subjects were pressing the lever and reliably licking the dipper the random-time 60-s schedule of dipper presentation was discontinued and the number of responses on the left lever required to produce the dipper was gradually increased to fifteen. When subjects had completed 5 sessions under the fixed-ratio fifteen (FR 15) schedule, the amount of force required to depress the lever was gradually increased from 25 g to 200 g. Completion of 10 sessions under the FR 15 schedule with a response force requirement of 200 g marked the end of training.

Following completion of training subjects were exposed to a multiple FR 15 FR 15 schedule of reinforcement. In one component (the constant-force component) 25 g of force was required to depress the lever. In the other (the variable-force component) either 25, 50, 100, or 200 g of force was required. The force required to press the
lever in the variable component varied across conditions, not within sessions. Each subject was exposed to four conditions (i.e., multiple FR 15 /25 g FR 15 /25 g; FR 15 /25 g FR 15 /50 g; FR 15 /25 g FR 15 /100 g; FR 15 /25 g FR 15 /200 g) in random order. Conditions were changed after (a) a minimum of 10 sessions, and (b) when there was no visually evident trend in response rate or post-reinforcement pause for 5 consecutive sessions. For subjects in Group 1 the two stimulus lights above the levers and the tone remained on continuously during the constant-force component of the multiple schedule but came on and went off at 1-s intervals during the variable-force component. For subjects in Group 2 the two stimulus lights above the levers and the tone came on and went off at 1-s intervals during the constant-force component but remained on continuously during the variable-force component. For both groups all stimuli were off during dipper presentation except for the light under the dipper.

At the beginning of each multiple-schedule session one of the component schedules was selected at random for each subject. That component was in effect until 5 reinforcers were earned. At that time the other component schedule was arranged. When 5 reinforcers were earned, the component initially arranged was reinstated until 5 reinforcers were earned. This process continued until each component schedule had been in effect 4 times, after which the session ended.

Results

Figures 1 and 2 show mean response rates for the last five sessions under each of the multiple schedules in Experiment 1. Data for Subjects 1-4 are depicted in Figure 1, data for Subjects 5-8 are depicted in Figure 2. As can be seen by examining these figures, as the force required to depress the lever in the varied-force component increased, response rates decreased in that component. In general, response rates during the constant-force component remained the same throughout Experiment 1.
Figure 1. Mean Response Rates During the Last Five Sessions in Each Condition for Subjects 1-4.
Figure 2. Mean Response Rates During the Last Five Sessions in Each Condition for Subjects 5-8.

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However, Subject 3's response rate in the constant-force component increased as the force required to depress the lever in the varied-force component increased and Subjects 6's response rate in the constant-force component decreased as the force required to depress the lever in the varied-force component increased.

Figures 3 and 4 show mean post-reinforcement pauses for the last five sessions under each of the multiple schedules in Experiment 1. Data for Subjects 1-4 are depicted in Figure 3, data for Subjects 5-8 are depicted in Figure 4. As can be seen by examining these figures, as the force required to depress the lever in the varied-force component increased, post-reinforcement pauses increased in that component. In general, post-reinforcement pauses during the constant-force component remained the same throughout Experiment 1 for all subjects.

Figures 1-4 show that when the response force requirement was increased the response rate decreased and the post-reinforcement pause increased. It is possible, however, that the reduction in response rate is completely accounted for by the increase in post-reinforcement pause. Figure 5 depicts the mean interresponse time (IRT) averaged across the last five sessions under each of the multiple schedules during Experiment 1 for Subject 1. Note: The first IRT depicted represents post-reinforcement pause. Subject 1 was selected for detailed analysis of IRTs because increases in response force had clear cut effects on response rate and post-reinforcement pause for this subject. As can be seen by examining this figure, as the force required to depress the lever in the varied-force component increased, not only did post-reinforcement pauses increase, but all IRTs in that component increased. That is, increasing the response force requirement also increased the time from the first to the last response (i.e., work time or run rate). In general, the pattern of IRTs during the constant-force component remained the same throughout Experiment 1 for Subject 1. A detailed analysis of IRTs is not provided for all subjects in order to conserve space.
Figure 3. Mean Post-Reinforcement Pauses During the Last Five Sessions in Each Condition for Subjects 1-4.
Figure 4. Mean Post-Reinforcement Pauses During the Last Five Sessions in Each Condition for Subjects 5-8.
Figure 5. Mean Interresponse Time Averaged Across the Last Five Sessions Under Each of the Multiple Schedules Are Shown for Subject 1.
However, increasing the response force requirement had similar effects on IRTs for all other subjects.

Results obtained in Experiment 1 raised three questions. How would the effect of added lever force observed in Experiment 1 have differed if the added force were present for only a portion of the responses making up the FR15? Would the effect differ depending on where in the FR15 the added force was located? Would the effect of added lever force observed in Experiment 1 have differed if an FR smaller than FR15 had been employed? Experiment 2 was an attempt to answer the first two questions; Experiment 3 was an attempt to answer the third.
CHAPTER III

EXPERIMENT 2

Experiment 2 was conducted in an attempt to determine how the effect of added lever force observed in Experiment 1 might have differed if the added force were present for only a portion of the responses making up the FR 15, and whether the effect would differ depending on where in the FR 15 the added force was arranged. Because the greatest differences in response rate and post-reinforcement pause were obtained in Experiment 1 when 25 g and 200 g of force were compared, only those two lever force requirements were used in Experiment 2.

Subjects were again exposed to a multiple FR 15 FR 15 schedule. Under one component (i.e., the constant-force component), 25 g of downward force was required to depress the response lever. In the other component (i.e., the varied-force component), either 25 g or 200 g of force was required, and this value varied within sessions. That is, 25 g of force was typically required to depress the lever in the varied-force component, but the force requirement was increased to 200 g during the first, second, or third 5-responses segment of the FR 15 across conditions. Subjects' response rates and post-reinforcement pauses were recorded during both components.

Method

Subjects

Subjects 2-7 from Experiment 1 served in Experiment 2. Subject 1 died of unknown causes shortly after completing Experiment 1.
Apparatus

The same apparatus used in Experiment 1 was used in Experiment 2.

Procedure

Following completion of Experiment 1 subjects were exposed to another multiple FR 15 FR 15 schedule of reinforcement. In one component (the constant-force component) 25 g of force was required to depress the lever. In the other component (the variable-force component) either 25 g or 200 g of force was required. The force required in the variable-force component varied within sessions. In one condition, 200 g of force was required for the first 5 responses, and 25 g of force was required for the remaining 10 responses of the FR15. In another condition, 25 g of force was required to depress the lever for the first 5 responses, 200 g of force was required for the 6th through 10th response, and 25 g of force for the remaining 5 responses. In another condition, 25 g of force was required for the first 10 responses, and 200 g of force was required for the remaining 5 responses. In a final condition, 25 g of force was required to depress the lever for all 15 responses. In both components every fifteenth response produced access to the dipper. Each subject was exposed to each of the four conditions (i.e., multiple 25 g/200 g in 1st five; 25 g/200 g in 2nd five; 25 g/200 g in 3rd five; or 25 g/200 g in none) in random order. Conditions were changed after (a) a minimum of 10 sessions and (b) when there was no visually evident trend in response rate or post-reinforcement pause for 5 consecutive sessions. For subjects in Group 1 (i.e., Subjects 2, 3, and 4) the two stimulus lights above the levers and a tone remained on continuously during the constant-force component of the multiple schedule but came on and went off at 1-s intervals during the variable-force component. For subjects in Group 2 (i.e., Subjects 5, 6, 7, and 8) the two stimulus
lights above the levers and the tone came on and went off at 1-s intervals during the constant-force component but remained on continuously during the variable-force component. For both groups all stimuli were off during dipper presentation except for the light under the dipper.

At the beginning of each multiple-schedule session one of the component schedules was selected at random for each subject. That component was in effect until 5 reinforcers were earned. At that time the other component schedule was arranged. When 5 reinforcers were earned, the component initially arranged was reinstated until 5 reinforcers were earned. This process continued until each component schedule had been in effect 4 times, after which the session ended.

Results

Figures 6 and 7 show mean response rates for the last five sessions under each of the multiple schedules in Experiment 2. Data for subjects in Group 1 are depicted in Figure 6, data for subjects in Group 2 are depicted in Figure 7. As can be seen by examining these figures, response rates in the varied-force components were roughly the same regardless of where in the FR 15 the additional force was placed. However, when additional lever force was not added to the FR 15 in the varied force component (i.e., 25 g of force was required to operate the lever throughout the FR 15) response rates increased and were comparable to those in the constant-force component. In general, response rates during the constant force component remained the same throughout Experiment 2. However, Subject 6's response rate in the constant-force component dropped when additional lever force was not added to the FR 15 in the varied-force component.

Figures 8 and 9 show mean post-reinforcement pauses for the last five sessions under each of the multiple schedules in Experiment 2. Data for subjects in Group 1 are
Figure 6. Mean Response Rates During the Last Five Sessions in Each Condition for Subjects 2-4.
Figure 7. Mean Response Rates During the Last Five Sessions in Each Condition for Subjects 5-8.
depicted in Figure 8, data for subjects in Group 2 are depicted in Figure 9. As can be seen by examining these figures, post-reinforcement pauses in the varied-force component increased when the additional force was added in the first third of the FR15, but were relatively unaffected when additional force was located elsewhere in the FR15. In general, post-reinforcement pauses during the constant-force component remained the same throughout Experiment 2.

As with the data of Experiment 1, the independence of response rate and post-reinforcement pause becomes of interest. Figure 10 depicts the mean interresponse time (IRT) averaged across the last five sessions under each of the multiple schedules during Experiment 2 for Subject 4. Note: The first IRT depicted represents post-reinforcement pause. Subject 4 was selected for detailed analysis of IRTs because increases in response force had clear cut effects on response rate and post-reinforcement pause for this subject. As can be seen by examining this figure, when the force required to depress the lever in the varied-force component increased the corresponding IRTs in that component increased. Also evident is that the subject paused longer before making the first response requiring 200 g force than for all other responses requiring 200 g of force. However, the later in the FR the force was increased to 200 g the smaller the pause prior to the first response requiring 200 g of force became. In general, the pattern of IRTs during the constant-force component remained the same throughout Experiment 1 for Subject 4. A detailed analysis of IRTs is not provided for all subjects in order to conserve space. However, increasing the response force requirement had similar effects on the other subjects' IRTs.
Figure 8. Mean Post-Reinforcement Pauses During the Last Five Sessions in Each Condition for Subjects 2-4.
Figure 9. Mean Post-Reinforcement Pauses During the Last Five Sessions in Each Condition for Subjects 5-8.
Figure 10. Mean Interresponse Time Averaged Across the Last Five Sessions Under Each of the Multiple Schedules Are Shown for Subject 4.
CHAPTER IV

EXPERIMENT 3

Experiment 3 was conducted in an attempt to determine whether decreasing the number of responses required to produce the dipper would influence the effects of altering the amount of force required to operate the lever under conditions similar to Experiment 1. Because the differences in response rate and post-reinforcement pause were most obvious when 25 g and 200 g of force were compared in Experiment 1, only those two lever force requirements were used in Experiment 3.

Subjects were once again exposed to a two-component multiple schedule, and the experiment involved four conditions. In two of the conditions every fifth lever press was followed by reinforcement under both components of the multiple schedule (i.e., MULT FR 5 FR 5). In the other two conditions, every lever press was followed by reinforcement under both components of the multiple schedule (i.e., MULT FR 1 FR 1). Under one component, 25 g of downward force was required to depress the response lever. In the other component, either 25 g or 200 g of downward force was required to depress the response lever, depending on the condition. Subjects' response rates and post-reinforcement pauses were recorded during both components.

Method

Subjects

Subjects 3, 4, 5, 7, and 8 from Experiments 1 and 2 served in Experiment 3. Subjects 2 and 6 died of unknown causes shortly after completing Experiment 2.
Apparatus

The same apparatus used in Experiments 1 and 2 was used in Experiment 3.

Procedure

Following completion of Experiment 2, subjects were exposed to another multiple schedule. In the constant-force component 25 g of force was always required to depress the lever. In the variable-force component either 25 or 200 g of force was required. The force required in the variable-force component varied across conditions, not within sessions. In both components of the multiple schedule the same number of responses produced access to the dipper. In the first two of the conditions, 5 responses produce access to the dipper (i.e., FR 5). In one of these conditions 25 g of force was required to depress the lever in the variable force component; in the other, 200 g of force was required in the variable-force component. In the other two conditions each response produced access to the dipper (i.e., FR 1). In one of these conditions 25 g of force was required in the variable-force component; in the other, 200 g of force was required. Each subject was exposed to the two FR5 conditions in random order first and the two FR 1 conditions in random order second.

Conditions were changed after (a) a minimum of 10 sessions and (b) when there was no visually evident trend in response rate or post-reinforcement pause for 5 consecutive sessions. For the subjects remaining in Group 1 (i.e., Subject 3 and 4) the two stimulus lights above the levers and a tone remained on continuously during the constant force component of the multiple schedule but came on and went off at 1 sec intervals during the variable force component. For the subjects remaining in Group 2 (i.e., Subjects 5, 7, and 8) the two stimulus lights above the levers and the tone came on and went off at 1-s intervals during the constant force component but remained on
continuously during the variable force component. For both groups all stimuli were off during dipper presentation except for the light under the dipper.

At the beginning of each multiple-schedule session one of the component schedules was selected at random for each rat. That component was in effect until 5 reinforcers were earned. At that time the other component schedule was arranged. When 5 reinforcers were earned, the component initially arranged was reinstated until 5 reinforcers were earned. This process continued until each component schedule had been in effect 4 times, after which the session ended.

Results

Figures 11 and 12 show mean response rates for the last five sessions under each of the multiple schedules in Experiment 3. Data for subjects in Group 1 are depicted in Figure 11, data for subjects in Group 2 are depicted in Figure 12. Relevant data (i.e., 25/25 and 25/200) from Experiment 1 are also depicted in this figure to aid in comparison of results across experiments. Subject 3 died shortly after completing the first two conditions of Experiment 3.

As can be seen by examining Figures 11 and 12, as the force required to depress the lever in the varied-force component increased response rates decreased regardless of how many responses were required to produce access to the dipper. However, the size of the decrease was affected by the number of responses required to produce access to the dipper. Generally, the size of the decrease that resulted from increasing the response force requirement decreased as the FR requirement decreased. Response rates during the constant-force were also affected by the number of responses required to produce access to the dipper. It appears that subjects' response rates in the constant-force component went down as the number of responses required to produce reinforcement in that component went down.
Figure 11. Mean Response Rates During the Last Five Sessions in Each Condition for Subjects 3 and 4. Relevant Data (i.e., 25/25 and 25/200) From Experiment 1 Are Also Show in This Figure for the Sake of Comparison.
Figure 12. Mean Response Rates During the Last Five Sessions in Each Condition for Subjects 5, 7, and 8. Relevant Data (i.e., 25/25 and 25/200) From Experiment 1 Are Also Shown in This Figure for the Sake of Comparison.
Figures 13 and 14 show mean post-reinforcement pauses for the last five sessions under each of the multiple schedules in Experiment 3. Data for subjects in Group 1 are depicted in Figure 13, data for subjects in Group 2 are depicted in Figure 14. Again, relevant data (i.e., 25/25 and 25/200) from Experiment 1 are reproduced in this figure to aid in comparison of results across experiments. Subject 3 died shortly after completing the first two conditions of Experiment 3.

As can be seen by examining Figures 13 and 14, as the force required to depress the lever in the varied-force component increased, post-reinforcement pauses increased regardless of how many responses were required to produce access to the dipper. However, the size of the increase was affected by the number of responses required to produce access to the dipper. Generally, the size of the increase which resulted from increasing the response force requirement decreased as the FR requirement decreased. Post-reinforcement pauses during the constant-force component were relatively constant regardless of the number of responses required to produce access to the dipper.

As with the other two experiments it is necessary to examine the independence of response rate and post-reinforcement pause. Figure 15 depicts the mean interresponse time (IRT) averaged across the last five sessions under each of the FR5 FR5 multiple schedules during Experiment 3 for Subject 4. Relevant data (i.e., 25/25 and 25/200) from Experiment 1 are also show in this figure for the sake of comparison. Note: The first IRT depicted represents post-reinforcement pause. Subject 4 was selected for detailed analysis of IRTs because increases in response force had clear cut effects on response rate and post-reinforcement pause for this subject. As can be seen by examining this figure, as the force required to depress the lever in the varied-force component increased, not only did post-reinforcement pause increase, but all IRTs in that component increased regardless of the number of responses required to produce
Figure 13. Mean Post-Reinforcement Pauses During the Last Five Sessions in Each Condition for Subjects 3 and 4. Relevant Data (i.e., 25/25 and 25/200) From Experiment 1 Are Also Shown in This Figure for the Sake of Comparison.
Figure 14. Mean Post-Reinforcement Pauses During the Last Five Sessions in Each Condition for Subjects 5, 7, and 8. Relevant Data (i.e., 25/25 and 25/200) From Experiment 1 Are Also Show in This Figure for the Sake of Comparison.
Figure 15. Mean Interresponse Time Averaged Across the Last Five Sessions Under Each of the FR5 FR5 Multiple Schedules Are Shown for Subject 4. Relevant Data (i.e., 25/25 and 25/200) From Experiment 1 Are Also Show in This Figure for the Sake of Comparison.
access to the dipper. That is, increasing the response force requirement also increased the time from the first to the last response (i.e., work time or run rate). In general, the pattern of IRTs during the constant-force component were roughly the same for Subject 4 regardless of the number of responses required to produce access to the dipper. A detailed analysis of IRTs is not provided for all subjects in order to conserve space. However, increasing the response force requirement had similar effects on the other subjects IRTs.
CHAPTER V

DISCUSSION

Altering the amount of force required to depress the lever in the present experiment had significant effects on both response rate and post-reinforcement pause. Further, these effects were consistent across subjects. The results of Experiment 1 indicated that increasing the amount of force required to make a response decreased the rate of responding, increased the post-reinforcement-pause, and increased all IRTs. The results of Experiment 3 indicated that this relationship held regardless of whether 1, 5, or 15 responses were required to produce the reinforcer. The results of Experiment 2 indicated that if force is added to only a portion of the responses required to produce reinforcement, (a) the effects on response rate were the same regardless of where in the FR the added force was located, (b) the added force had the greatest effect on post-reinforcement pause when it was added to the first responses of the FR, (c) the corresponding IRTs increased, and (d) pauses were longer before making the first response requiring 200 g of force than for all other responses requiring 200 g of force, however, when the force was increased to 200 g latter in the FR the pause prior to the first response requiring 200 g of force was smaller.

The results of the present study are in agreement with Hull's (1943) prediction that subjects would emit fewer responses in time as the effort required to make the response increased. These results are also in agreement with those obtained by previous investigators (Adair & Wright, 1976; Chung, 1965; Mowrer & Jones, 1943; Skinner, 1972), who found that increasing the amount of force required on an operandum, decreased response rate on that operandum. The results of the present
study add to those of previous investigations by providing information regarding the effects of increasing lever force requirements on post-reinforcement pause.

The results of the present experiment parallel the results of studies examining the effects of manipulating the number of responses required to produce a reinforcer. Those experiments demonstrated that: (a) as the number of responses required to produce a reinforcer increased the pause after production of the reinforcer increased (e.g., Felton & Lyon, 1966; Ferster & Skinner, 1957; Kaplan, 1956; Mintz, Mourer, & Gofseyyeff, 1967; Powell, 1968; Premack, Schaeffer, & Hundt, 1964; Thompson, 1964; Winograd, 1965), and (b) as the number of responses required to produce a reinforcer increased the time from first to the last response (i.e., work time) increased (e.g., Pliskoff & Goldiamond, 1966; Rilling & McDiarmid, 1965). These results, compared with those in the present experiment, indicate that increasing response force and increasing the number of responses required to produce a reinforcer have similar effects on behavior. Therefore, manipulating the number of responses required to produce a reinforcer and manipulating the amount of force required to make a response might both be viewed as effective ways of manipulating response effort.

Some investigators have suggested that in some respects increasing the force required on an operandum is similar to adding an aversive consequence for the response (e.g., Blough, 1966; Miller, 1968; & Solomon, 1948). The results of the present study also support this argument. Azrin (1959) found that punishment of responding maintained by fixed-ratio reinforcement decreased overall response rate and increased post-reinforcement pause. The greater the intensity of the punishment, the lower the response rate and the longer the post-reinforcement pause. Increasing the amount of force required to operate the lever in the present experiment produced effects similar to those of punishment (Azrin, 1959).
The results of the present study have implications for between-subject differences obtained in some experiments where subjects are exposed to the same experimental conditions (e.g., schedule of reinforcement). Based on the results of the present experiment, one would expect to obtain different response rates from subjects tested in the different chambers, irrespective of differences between subjects, if the operandi in those chambers require different amounts of force to operate. Hopefully, knowledge of the relationships between required response force required and the corresponding response rate and post-reinforcement pause will aid investigators in the prediction and control of behavior.
INVESTIGATOR CERTIFICATION

Title of Project: Effects of Lever Force on Response Rate and Post-Reinforcement Pause in Rats

If any of the above procedures are changed, I will submit a new protocol.

I understand that any failure to comply with the Animal Welfare Act, the provisions of the DPHS Guide for the Care and Use of Laboratory Animals and requirements set down by the IACUC may result in the suspension of my animal studies.

Signature: Principal Investigator

Department

Date 6-18-91

REVIEW BY THE INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE

| Disapproved | Approved | Approved with the provisions listed below |

Provisions

or

Explanation:

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Leonard E. Miller

IACUC Chairperson

Aug 4, 1991

Researcher's Acceptance of Provisions:

Aug 20, 1991

Signature: Principal Investigator

IACUC Chairperson Final Approval

Approved IACUC Number

Revised February 12, 1991

A-6

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