

PARTIAL REINFORCEMENT EXTINCTION EFFECTS
ON RATS IN A RUNWAY AND
OPERANT CHAMBER

by

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ABSTRACT

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The partial reinforcement extinction effect (PREE) is traditionally observed in rats when on a partial reinforcement schedule in a runway, that is, they are more resistant to extinction (persistent) than those on a continuous reinforcement schedule. Behavioral Momentum is observed when, in an operant chamber, rats on the most dense reinforcement schedule show more persistence in responding during extinction (or other response disrupting manipulation). The purpose of this experiment is to combine the runway and operant chamber and discuss the outcome in terms both theories. Subjects were either on a continuous reinforcement schedule (CRF) or a partial reinforcement

schedule (PRF) along with a variable ratio (VR) schedule of 3 or 12. Runtime, latency to bar press, and the number of bar presses emitted in extinction were measured. The VR3 results in a traditional PREE with the PRF/VR3 showing more resistance to extinction (shorter latency to bar press and more bar presses) than the CRF/VR3 group. On the other hand, the VR12 results in an effect consistent with the behavioral momentum prediction; more dense schedules (CRF/VR12) results in greater persistence (shorter latency to bar press and more bar presses) than the less dense schedules (PRF/VR12). The persistence of running was greater for the PRF/VR3 over the CRF/VR3 and also greater for the PRF/VR12 over the CRF/VR12. This is the standard PREE for both PRF and CRF groups, indicating that behavioral momentum does not fit well with the running dependent variable, but does provide an explanation for the latency to bar press and the number of bar presses dependent variables. If supported by future research this finding would resolve the apparent inconsistency of PREE and behavioral momentum approach (Pear, 2001).

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CHAPTER 1

INTRODUCTION

1.1 Background

The partial reinforcement extinction effect (PREE) occurs when there is persistence in responding during extinction trials when prior training was on a partially reinforced schedule compared to training on a continuous reinforcement schedule. In partial reinforcement (PRF), rewards occur sometimes following the response whereas in continuous reinforcement (CRF) reward occurs all the time following the response. CRF groups run slowly down a runway during extinction whereas PRF groups run faster down the runway during extinction (Likely, Little, & Mackintosh, 1971). The change from acquisition to extinction is less drastic for those on a PRF schedule. There are instances during acquisition where reward does not occur so one factor that may result in the PREE is that it becomes harder to discriminate between the end of acquisition and the beginning of extinction whereas it is easier to discriminate the end of acquisition and the beginning of extinction when on a continuous schedule. However, many other factors may influence the PREE. Partial reinforcement extinction effects can occur even when there is as little as one acquisition trial (Goomas, 1982).

There has been extensive research done to evaluate the behavior effects of partial reinforcement versus continuous reinforcement. The majority of research

conducted uses one of two procedures: discrete trial (runway) procedures or free operant procedures. The findings using each procedure are quite different and each are explained using different theories. The results from discrete trials, usually performed in a runway, are described in terms of Capaldi's (1966) Sequential theory. The results obtained from operant trials, performed in an operant chamber or Skinner box, are explained in terms of Behavioral Momentum theory (Nevin, 1988).

1.1.1 Sequential Theory

Sequential theory, developed by Capaldi (1966), states that training on PRF schedules hinders the ability to extinguish behavior. If a rewarded (R) trial is given after a nonrewarded (N) trial, the animal will remember the previous N trials and will be conditioned to respond in the presence of the memory of an N trial on the R trial during acquisition training. The sequential aspects of N and R trials can account for these extinction effects following PRF. The memory of N serves as a cue for responding in extinction for PRF trained subjects, but not for CRF trained subjects.

Jobe, Mellgren, Feinberg, Littlejohn, and Rigby (1977) found that memory of a previous trial is pertinent in obtaining PREE and sequential effects. An N trial followed by an R trial increases resistance to extinction more so than R-N trials or CRF groups (Haddad, Walkenbach, & Goeddel, 1980). Remembering that an N trial is followed by an R trial will cause the animal to continue responding during extinction. Reward expectancy is a factor when determining why animals continue responding (Mellgren, Lombardo, & Wrather, 1973). PRF trials followed by CRF trials results in increased resistance to extinction even more so than groups only receiving PRF. This could be

due to the memory of nonreward during PRF trials followed by the memory of continuous reward during CRF trials. Further support for the memory view and Sequential Theory comes from Capaldi and Miller (2003). They found that NR groups were more resistant to extinction than the RN groups.

1.1.2 Behavioral Momentum Theory

Sequential theory mainly focuses on discrete trial learning. Behavioral momentum theory on the other hand describes how, in an operant situation, rates of responding in extinction are contrary to discrete trial situations. The rate of reinforcement directly affects the persistence in responding, as reinforcement rates increase, resistance to change increases during extinction (Nevin, 1988). The increased resistance to extinction occurs not only with a high rate of reinforcement, but also when the probability of reinforcement is high (Pear, 2001). This is contrary to discrete trial findings. The CRF condition has higher rates of reinforcement compared to the PRF condition, so if the rate of reinforcement were the key to understanding persistence in behavior, one would expect CRF animals to have the greatest resistance to extinction.

Pear (2001) describes behavioral momentum in two ways: “the tendency for behavior that is currently occurring to continue occurring despite various disruptive factors; or the tendency for behavior to occur in the presence of a particular stimulus despite various disruptive factors” (p. 167). Operant trials allow for momentum to be built up and allow for the continuance of responding with little to no disruption depending on the type of experiment being conducted. The presence of a discriminative stimulus in an operant situation may lead to a small disruption of behavior if one

stimulus signals reward and the other does not (Pear, 2001). Discrete trials however have a sometimes much longer disruption of behavior. Once an animal has completed the runway and received reward they are removed from the apparatus and the continuance of behavior has been disrupted for a time. The amount of time can vary depending on the interval between trials. The disruption is much greater in discrete trials because the subject is completely removed from the apparatus whereas those in an operant box are not.

1.1.3 Delay of Reinforcement

Delay of reinforcement causes an increased resistance to extinction. Sgro & Weinstock's 1963 runway experiment revealed that a delay of reinforcement would lead the rats to continue running at higher speeds during extinction compared to the other groups. The group of rats on a 15 second delay of reinforcement was more resistant to extinction than those on the 7.5 second delay and 0 second delay. Capaldi & Spivey (1965) found increased resistance to extinction occurred when delay of reinforcement alternated with immediate reinforcement for rats in a runway compared to the groups that received random partial delay and immediate reinforcement. Dyck and Mellgren (1973) found that groups of rats that received delayed reinforcement were more resistant to extinction than those that received immediate reward.

1.2 Testing PREE Effects

The PREE is usually tested in a runway or an operant box and the data concerning these two methods have been inconsistent (Mellgren & Olson, 1983; Nevin, 1988). As quoted in *The Science of Learning* by Pear (2001), "Perhaps, therefore, a

single definition of behavioral momentum that combines both meanings would resolve the apparent inconsistency between the effects of varying rates or probabilities of reinforcement on subsequent free-operant and discrete-trials extinction” (p. 171).

In an experiment by Mellgren and Olson (1983) a rat ran down the alley into a “patch” of sand that either did or did not contain buried pellets. Their experiment showed no significant differences in running speeds between the CRF and PRF groups during acquisition. The results also showed no significant differences found for the time spent digging regardless of schedule of reinforcement or in the bouts of digging during acquisition. During extinction, the PRF group showed no decline in running speed while the CRF group had a steady decrease in running speeds. During extinction, the PRF groups spent less time digging than the CRF group, but the bouts of digging remained the same when in the patch of sand. Since running is a discrete event and digging is like lever pressing, an operant response, the two different effects of PRF in extinction suggests reconciliation of the apparent discrepancy between the two procedures.

The current experiment examines rats in a runway connected to an operant chamber similar to the methods used by Mellgren & Olson. Like in Mellgren & Olson’s study, a straight runway was be utilized. The operant chamber in their study was a box filled with sand to allow for digging to obtain food pellets, the operant chamber in this experiment was be the classically used operant chamber, or Skinner box, with levers to press to obtain food reward. Both methods require manipulation of the environment to attain a reward.

The rats were placed in a start box at the beginning of the runway and allowed to run into the operant chamber. There were four groups on different schedules of reinforcement: CRF/VR3, CRF/VR12, PRF/VR3, and PRF/VR12. The CRF groups received reward on all four trials per day (RRRR) whereas the PRF groups received reinforcement on a random, counterbalanced schedule of two rewarded and two nonrewarded trials. There was 10 days of acquisition followed by 5 days of extinction.

1.3 Hypotheses

According to Nevin's (1988) behavioral momentum theory, the animals in the CRF group should be more resistant to extinction than the PRF animals due to the density of reward. However, when looking at discrete trial behavior, research suggests that the PRF animals should have more resistance to extinction, due to PREE, and continue efforts to gain reinforcement. Research on delay of reinforcement suggests that the larger the delay of reinforcement the more resistance to extinction that will occur. The VR12 schedule results in longer delay than the VR3 schedule and therefore more resistant to extinction. It is of interest to see which direction the results of this experiment turn out and which theories are supported.

The majority of work that analyzes the effects of partial reinforcement is done using either discrete trial or continuous operant methods whereas this experiment combines the two. The two methods alone produce different effects and this experiment examines what behaviors are produced when combining the different methods.

CHAPTER 2

METHOD

2.1 Subjects

This experiment utilized 32 female Sprague-Dawley rats. They were placed on food deprivation, kept at 85% of their ad libitum weight, and allowed free access to water. All subjects were housed according to National Institute of Health rules and regulations for humane treatment of animals.

2.2 Materials, General Procedure, and Data Collection

This experiment utilized a standard operant chamber with levers as well as a straight wooden runway. The operant chamber had grid floor, Plexiglas sides, and measured 8 ¼" (height) x 11 ½" (width) x 9 ½" (depth) with two levers centered 1 ¼" from both sides and 3" above the floor. Attached at the door of the operant chamber was the runway, it measures 5 ft x 6in x 6in. The sides and bottom were solid wood sealed with polyurethane with a top made of hardwire cloth with hinges. Two guillotine doors were in the runway, one located at the start box and the other at the end of the runway to prevent subjects from reentering the runway once inside the chamber. Infrared photocells were located at each guillotine door to measure the runway speed and latency to bar press. The MED-PC program controlled the schedules of reinforcement and the timers (Refer to Appendix A and B for MED-PC programs).

2.2.1 Data Collection

The animals received magazine training using the shaping procedure. They first learned to bar press to obtain a single pellet reinforcer. Once the pretraining was successful, training on an FR1 schedule to establish a consistent bar press response began. After consistency was reached, training on the VR3 and VR12 schedules began. The rats were divided into two groups (VR3 and VR12) and after completing two trials on their appropriate schedules the experiment began.

A 2 (CRF, PRF) x 2 (VR3, VR12) design was used for this experiment. During acquisition, there were four trials per day for 10 days. The rats were split into four groups with eight rats per group: CRF/VR3, CRF/VR12, PRF/VR3, and PRF/VR12. The CRF group received reward on each trial: RRRR. The PRF groups had a random reward/nonreward schedule (See Appendix C for R/N schedule).

2.2.2 Acquisition

During acquisition, there were four trials per day for 10 days. Rats were brought into the experimental room in groups of 4 (one from each condition) in separate cages. Each rat was placed into the enclosed start box for a period of 5 to 10 seconds to acclimate to its surroundings. When the door opened, the rats ran down the alley and into the operant box where it had to make the required number of bar presses for reinforcement. On the rewarded trials, following consumption of a single pellet, the rat was removed from the apparatus and placed back into the holding cage. On the nonrewarded trials, the rat was removed from the apparatus after the appropriate number of bar presses has been made and placed back into the holding cage. The

procedure was repeated for each group until all four trials were completed for all 10 days. The order in which the groups were run each day was chosen randomly.

Runtimes and latency to bar press were measured in this phase of the experiment. A photo beam was broken when the start door opened to begin a timer and the second beam break occurred when the rat stepped into the operant chamber to stop the timer, this recorded runtime. Latency to bar press was recorded by beginning a second timer when the operant chamber beam was broken and stopped upon the first bar press.

2.2.3 Extinction

Following the acquisition phase, extinction began. There were four trials per day per rat for 5 days. No reward was given during this phase of the experiment. The rat was again placed into the enclosed start box and given opportunity to run down the alley into the operant chamber when the start door opened. Once again runtime and latency to bar press were recorded along with the number of bar presses made. The rats were allowed a maximum of 2 minutes in the runway before being placed in the operant chamber. The number of bar presses in 30 seconds was recorded from the time of the first bar press. If no bar presses had been made by two minutes the rat was removed from the chamber and placed in the holding cage. Rats were brought into the experimental room in groups of 4 (one from each condition) in separate cages. The order in which the groups were run each day was chosen randomly. The procedure was repeated for each group until all four trials were completed for all 5 days.

2.3 The Experimental Conditions

2.3.1 Continually Reinforced on a VR3 Schedule (CRF/VR3)

The continually reinforced group on a VR3 schedule (N=8) was rewarded on every trial during acquisition. In order to obtain a pellet they were required to press the bar on average of 3 times.

2.3.2 Partially Reinforced on a VR3 Schedule (PRF/VR3)

The partially reinforced group on a VR3 schedule (N=8) was rewarded on only half of the 4 trials per day. The order in which the reward and nonreward trials were presented was chosen randomly. In order to obtain a pellet or end the session in the operant chamber the bar had to be pressed on average of 3 times.

2.3.3 Continually Reinforced on a VR12 Schedule (CRF/VR12)

The continually reinforced group on a VR12 schedule (N=8) was rewarded on every trial during acquisition. In order to obtain a pellet they were required to press the bar on average of 12 times.

2.3.4 Partially Reinforced on a VR12 Schedule (PRF/VR12)

The partially reinforced group on a VR12 schedule (N=8) was rewarded on only half of the 4 trials per day. The order in which the reward and nonreward trials were presented was chosen randomly. In order to obtain a pellet or end the session in the operant chamber the bar had to be pressed on average of 12 times.

CHAPTER 3

RESULTS

A Multivariate Analysis of Variance (MANOVA) was used to analyze the data. Logarithmic transformations were used on latency and runtime data for analysis and graphing purposes, whereas the actual means were used for the number of bar presses. It was expected that during acquisition runway speeds and latency to bar press would be approximately the same for all four groups. During extinction, however, it was predicted that the behaviors would depend on the factors controlling them. The PREE, the Behavioral Momentum theory, and the effects of delayed reinforcement each predict different outcomes.

3.1 Acquisition

Runtime and bar press latency were measured as a function of the Schedule (CRF and PRF), VR (3 and 12), and Day (days 1-10).

There was a significant interaction effect of VR x Day for the latency variable [$F(9, 280)=2.093, p<.05$]. Over the course of the 10 days of acquisition, each group's latencies decreased with the VR3 group showing the shortest bar press latencies.

There was a significant effect of Schedule for runtime [$F(1, 280)=6.931, p<.05$], and latency [$F(1, 280)=7.131, p<.05$]. The CRF group had shorter runtimes ($MM=1.038$) compared to the PRF group ($MM=1.126$) and shorter latencies

($MM=1.161$) than the PRF group ($MM=1.241$). There was also a significant effect of VR for the runtime variable [$F(1, 280)=39.619, p<.001$]. The VR3 groups had much shorter runtimes ($MM=.977$) than the VR12 groups ($MM=1.187$). A significant effect of the latency measure was also found for Day [$F(9, 280)=11.550, p<.001$]. Overall, as the experiment moved forward, bar press latencies decreased. See figures D.1 and D.2 for latency and runtime means for all four conditions.

When analyzing the last two days of acquisition, it was found that only Schedule and VR yielded main effects. There was a marginally significant effect for runtime [$F(1, 56)=3.949, p=.052$]. The CRF group had shorter runtimes ($MM=.923$) than the PRF group ($MM=1.077$). There was a significant effect of Schedule for latency [$F(1, 56)=5.063, p<.05$]. The CRF group had shorter bar press latencies ($MM=.986$) than the PRF group ($MM=1.135$). The effect of VR was significant for runtime [$F(1, 56)=10.270, p<.01$], and for latency [$F(1, 56)=20.219, p<.001$]. The VR3 groups had shorter runtimes ($MM=.825$) than the VR12 groups ($MM=1.175$). The VR3 groups had shorter bar press latencies ($MM=.955$) than the VR12 groups ($MM=1.66$).

3.2 Extinction

Runtime, bar press latency, and number of presses, were measured as a function of the Schedule (CRF and PRF), VR (3 and 12), and Day (days 1-5). The runtime and latency data were analyzed using a log transformation. To account for the differences observed at the end of acquisition the mean runtime and latency of each subject was calculated for days 9 and 10 of acquisition and subtracted from each subject's runtime

and latency on every extinction trial to obtain a difference score. The number of bar presses was analyzed in its raw form.

The interaction for Schedule and VR was significant for latency at $F(1, 140)=9.484, p<.05$. The CRF/VR12 group had the shortest bar press latency ($M=1.325$) followed by the PRF/VR12 ($M=1.424$), PRF/VR3 ($M=1.420$), and CRF/VR3 groups ($M=1.581$) (See Figure D.3). The MANOVA also showed a marginally significant interaction for Schedule and VR for the number of bar presses at $F(1,140)=3.747, p=.055$. The PRF/VR3 animals had the highest number of bar presses ($M=6.744$) followed by the CRF/VR12 ($M=6.588$), PRF/VR12 ($M=5.956$), and CRF/VR3 animals ($M=5.538$) (See Figure D.4). The Schedule variable was significant for runtime [$F(1, 140)=6.816, p<.01$]. PRF groups had shorter runtimes ($MM=1.367$) than CRF groups ($MM=1.484$). There was a significant effect of VR for runtime [$F(1, 140)=10.504, p<.01$] and latency [$F(1, 140)=9, p<.01$]. The VR12 groups had shorter runtimes and bar press latencies ($MM=1.353; MM=1.374$) than the VR3 groups ($MM=1.498; MM=1.501$) across the 5 days of extinction (See Figure D.5). The effect of Day was significant for all three variables: runtime – $F(4, 140)=5.052, p<.001$, latency – $F(4, 140)=55.076, p<.001$, and presses – $F(4, 140)=28.018, p<.001$. As the days of extinction progressed, the runtimes and latencies became longer and the number of bar presses decreased (See Figure D.6).

After analysis of the log transformation data for all 5 days of extinction (See Table E.1 for the MANOVA summary table), prior to taking into account the

differences in acquisition, it was observed that extinction effects were at asymptote level once day 4 and 5 were reached.

When taking into account the first 3 days of extinction, the interaction effect of VR and Day remained significant [$F(2, 84)=6.201, p<.01$]. There was also a significant interaction effect for Schedule and VR, but when analyzing the first 3 days of extinction the result is only significant for the number of bar presses [$F(1, 84)=5.883, p<.05$]. The analysis of the first three days yielded a significant effect between VR groups for runtime [$F(1, 84)=4.166, p<.05$]. The VR3 group had shorter runtimes ($MM=1.202$) than the VR12 group ($MM=1.314$). All variables for Day, runtime [$F(2, 84)=12.632, p<.001$], latency [$F(2, 84)=34.496, p<.001$], and presses [$F(2, 84)=11.452, p<.001$] remained significant. Runtimes and latencies increased across the three days and the number presses decreased.

There were no significant interactions in Schedule x Day or Schedule x VR x Day for runtime, latency to bar press, or number bar presses.

CHAPTER 4

DISCUSSION

4.1 Acquisition

During acquisition, the groups with the densest schedule had the shortest runtimes and the shortest bar press latencies. As the days progressed, all groups had shorter bar press latencies. However, as shown by the interaction of VR x Day, the VR3 group had the shortest bar press latencies across the ten days. The main effect of VR revealed a shorter runtime and a shorter latency for the VR3 groups as compared to the VR12 groups. The rats in the CRF group had shorter runtimes (though only marginal significance) and shorter latencies compared to the PRF group. This effect resembles results discussed by Pear (2001). Partial reinforcement hinders the rate of acquisition in some cases. The less dense group, the VR12, and the partially reinforced group both showed a lower level of performance in acquisition.

4.2 Extinction

It was evident when analyzing all five days of extinction, and taking into account the differences observed in acquisition, by subtracting the terminal acquisition data from the extinction data, that behaviors were changing as a result of having no reward present. Runtimes increased, latencies increased, and the number of bar presses decreased over all groups. generally, animals were increasing the amount of time spent

in the runway and the amount of time in the operant box prior to initiating the first bar press, as well as pressing the bar fewer times once the first bar press occurred. This effect was also true for the analysis of the first 3 days of extinction prior to accounting for acquisition differences.

4.2.1 The Runway

There was no interaction for Schedule, VR, and Day for the runtime variable, Schedule and Day, or Schedule and VR when analyzing the first 3 days of extinction and when taking into account differences seen in acquisition. However, the analysis did reveal a significant interaction effect for VR x Day for runtime for the first 3 days of extinction. Runtimes became longer for both the VR3 group and the VR12 group over the course of the 3 days. The significant effect of VR revealed that between the two conditions, the VR3 groups had shorter runtimes, showing more resistance to extinction. This is contrary to the effects of delay of reinforcement. The longer the delay of reinforcement the more resistance to extinction should be observed, but that was not the case. The VR3 rats' continuance of running behavior even when reward was not present as compared to the VR12 rats is inconsistent with that assumption.

Though the data shows that the VR3 group is more persistent during extinction, this may be misleading. During acquisition the VR3 groups had shorter runtimes compared to the VR12 groups. The significant findings may be due to the differences seen in acquisition. This suspicion was confirmed with the final analysis that takes into account these differences. This indicates that the increased delay of reinforcement

effects extinction behavior, as previously found in other studies (Sgro & Weinstock, 1963; Capaldi & Spivey, 1965; Dyck and Mellgren, 1973).

The PRF and CRF groups did not have any differences in runtimes when analyzing the first 3 days of extinction but an effect was found when acquisition differences were accounted for. The continuously reinforced groups took longer in the runway when compared to the partially reinforced groups for both the VR3 and VR12 conditions. The effects here are similar to most runway data in that partial reinforcement results in the rats' greater persistence in running compared to continuous reinforcement.

4.2.2 The Operant Chamber – Latency to Bar Press

The first three days of extinction did not result in any differences between the conditions except for Day as previously discussed. A three way interaction was not observed for the Latency variable or for the VR and Day and Schedule and Day for data accounting for acquisition differences.

There were however, differences between the groups for Schedule and VR. The CRF/VR12 group showed the most resistance to extinction by taking less time to press the bar once inside the operant chamber. The resistance shown by this group is consistent with behavioral momentum theory (Nevin, 1988), as well as results obtained by using delay of reinforcement (Sgro & Weinstock, 1963; Capaldi & Spivey, 1965; Dyck and Mellgren, 1973). The CRF groups have the densest schedules and the VR12 groups have the longest delay of reinforcement.

An effect of schedule was not observed when analyzed alone though an effect of VR was. The VR12 groups, having a much longer delay than the VR3 groups before receiving reinforcement, took less time to initiate a bar press. Again, the effects of delay of reinforcement are observed.

4.2.3 The Operant Chamber – Number of Bar Presses

The PRF/VR3 group showed the most number of bar presses during extinction for both analyses whereas the PRF/VR12 emitted the fewest number of bar presses. The PRF groups on the VR3 schedule demonstrated the most resistance to extinction compared to the other groups.

4.3 Limitations and Future Considerations

A potential problem with this study may be due to the magnitude of reward. Only one pellet was delivered on each trial when reinforcement was given. A single pellet may not have been a large enough reward for the food deprived rats. The motivation of the rats may not have been high enough to detect larger differences in running and bar pressing behaviors between the four conditions during extinction. Future studies should include variations on the magnitude of reward to increase the motivation of the animals on food deprivation.

Another possible limitation is due to the sex of the rats used. Only female rats were used in this experiment. Some of the differences in behavior may have been due to effects of the estrus cycle. The estrus cycle has differing effects on behavior depending on which part of the cycle female rats are in. To remedy this, males as well as females should be tested.

This experiment utilized two VR schedules. More variability should be added to the schedules of reinforcement by utilizing a wider range of VR schedules. A larger sample size would also be a positive change.

4.4 Conclusions

The most interesting finding comes from the interaction of the Schedule of reinforcement and the Variable Ratio schedule. The overall density of reinforcement appears to have an effect on the behavior of animals. The densest and the least dense of the Schedule and VR combination resulted in the longest latencies and the fewest number of bar presses (See Figure D.7). The CRF/VR3, the densest of the schedules, had the fewest number of bar presses and the longest latencies followed by the PRF/VR12, the least dense of the schedules, leaving the PRF/VR3 and CRF/VR12 in the middle.

Looking at the two VR schedules separately, the VR3 results in a traditional PREE with the PRF/VR3 showing more resistance to extinction (shorter latency to bar press and more bar presses) than the CRF/VR3 group. On the other hand, the VR12 results in an effect consistent with the behavioral momentum prediction; more dense schedules (CRF/VR12) results in greater persistence (shorter latency to bar press and more bar presses) than the less dense schedules (PRF/VR12). When overall density of reinforcement is relatively high, partial reinforcement increases persistence, when density is lower, more frequent reinforcement results in greater persistence, a possibility suggested by Nevin (1988).

The persistence of running was greater for the PRF/VR3 over the CRF/VR3 and also greater for the PRF/VR12 over the CRF/VR12. This is the standard PREE for both PRF and CRF groups, indicating that behavioral momentum does not fit well with the running dependent variable, but does provide an explanation for the latency to bar press and the number of bar presses dependent variables. If supported by future research this finding would resolve the apparent inconsistency of PREE and behavioral momentum approach (Pear, 2001).

APPENDIX A

MED-PC PROGRAMS FOR TRAINING
FR1, VR3, AND VR12

\This is a FR1 schedule of reinforcement

\Filename FR1.mpc

\For use on computer with UTA property number 072500.

\Date September 6, 2007

\This section is for outputs (from the computer)

^Reinf=2

^House=1

\This section is for inputs (to the computer)

^LftLever=1

\This section is for Z pulses

\Z1=Increment Reinforcement (Response) Counter

DIM A=999

DISKCOLUMNS=6.3

\-----

\ Main control logic for "FR"

\-----

S.S.1,

S1,

#START:ON^House --->S2

S2,

#K1!#R^LftLever:ON ^Reinf;Z1--->SX

\-----

\ Reinforcement counter and display

\-----

S.S.2,

S1,

#Z1:ADD R;SHOW 2,REINF,R;--->S2

S2,

.05":OFF^Reinf --->S1

\-----

\ Session Timer

\-----

S.S.3,

S1,

#START:--->S2

S2,

.01":ADD T--->SX

\ This is a VR3 schedule of reinforcement - training
\ Filename VR3train.mpc
\ For use on computer with UTA property number 072500.
\ Date October 18, 2007

\ This section is for outputs (from the computer)

^House = 1

^Reinf = 2

\ This section is for inputs (to the computer)

^LftLever = 1

\ Z pulses

\ Z1 Reinf On

\ DEFINED CONSTANTS

\ Q = # of responses

\ R = Reinf Delivered

\ T = Timer for experiment duration

\ SHOW COMMANDS

\ Show 1 = VR

\ Show 2 = Number of Reinf

\ Show 3 = Number of Resp

DISKCOLUMNS = 1

DISKFORMAT = 6.3

\This is a VR12 schedule of reinforcement - training

\Filename VR12train.mpc

\For use on computer with UTA property number 072500.

\Date October 18, 2007

\This section is for outputs (from the computer)

^House = 1

^Reinf = 2

\This section is for inputs (to the computer)

^LftLever = 1

\Z pulses

\Z1 Reinf On

\DEFINED CONSTANTS

\Q = # of responses

\R = Reinf Delivered

\T = Timer for experiment duration

\SHOW COMMANDS

\Show 1 = VR

\Show 2 = Number of Reinf

\Show 3 = Number of Resp

DISKCOLUMNS = 1

DISKFORMAT = 6.3

LIST D = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23

\-----

\ Main control logic for "VR"

\-----

S.S.1,

S1,

#START: ON ^House ---> S2

S2,

1": SET S = 1 ---> S3

S3,

1": RANDD X = D; SHOW 1,VR =,X ---> S4

S4,

X#R^LftLever: ON ^Reinf; Z1 ---> S3

\-----

\ Reward timer, count, and display

\-----

S.S.2,

S1,

#Z1: ADD R; SHOW 2,REINF,R ---> S2

S2,

0.05": OFF ^Reinf ---> S1

\-----

\ Timer in 0.1 sec int for Experiment

\-----

S.S.3,

APPENDIX B

MED-PC PROGRAMS FOR ACQUISITION
(VR3 AND VR12) AND EXTINCTION

\ This is a VR3 schedule of reinforcement

\ Filename VR3.mpc

\ For use on computer with UTA property number 072500.

\ Date October 18, 2007

\ This section is for outputs (from the computer)

^House = 1

^Reinf = 2

\ This section is for inputs (to the computer)

^LftLever = 1

^1stB = 2 \ Beam 1

^2ndB = 3 \ Beam 2

\ Z pulses

\ Z1 Reinf On

\ DEFINED CONSTANTS

\ A = Array recording run time from 1stB to 2ndB

\ B = Array recording latency from 2ndB to bar press

\ I = Cell entry in array A

\ J = Cell entry in array B

\ Q = # of responses

\ R = Reinf Delivered

\ S = Max Reward

\ T = Timer for experiment duration

\ SHOW COMMANDS

\ Show 1 = VR

\ Show 2 = Number of Reinf

\ Show 3 = Number of Resp

\ Show 4 = Time in Array A

\ Show 5 = Time in Array B

DIM A = 999

DIM B = 999

DISKOLUMNS = 1

DISKFORMAT = 6.3

LIST D = 1, 2, 3, 4, 5

\-----
\ Main control logic for "VR"
\-----

S.S.1,

S1,

#START: ON ^House ---> S2

S2,

1": SET S = 1 ---> S3

S3,

1": RANDD X = D; SHOW 1,VR =,X ---> S4

S4,

X#R^LftLever: ON ^Reinf; Z1 ---> S3

\-----
\ Reward timer, count, and display
\-----

S.S.2,

S1,

 #Z1: ADD R; SHOW 2,REINF,R ---> S2

S2,

 0.05": OFF ^Reinf ---> S1

\-----
\ Timer in 0.1 sec int for Experiment
\-----

S.S.3,

S1,

 #START: ---> S2

S2,

 0.1": SET T = T + 0.1 ---> SX

\-----
\ Record Run Time in 0.01 sec int 1stB to 2ndB -- array A
\-----

S.S.4,

S1,

 #START: SET A(I) = -987.987 ---> S2

S2, \ Wait for 1stB Break and update array

 #R^1stB: SET A(I) = 0, A(I+1) = -987.987 ---> S3

S3, \ 1st Statement - start run time timer

\ 2nd statement - wait for 2ndB

#R^2ndB: ADD I; SHOW 3,Beam 1,I ---> S4

0.01": SET A(I) = A(I) + 0.01 ---> SX

S4,

#Z1: ---> S2

\-----

\ Record latency from 2ndB to bar press in 0.01 sec int -- array B

\-----

S.S.5,

S1,

#START: SET B(J) = -987.987 ---> S2

S2, \ Wait for 2ndB break and update array

#R^2ndB: SET B(J) = 0, B(J+1) = -987.987 ---> S3

S3, \ 1st Statement - start latency timer

\ 2nd statement - wait for bar press

#R^LftLever: ADD J; SHOW 4,Beam 2,J ---> S4

0.01": SET B(J) = B(J) + 0.01 ---> SX

S4,

#Z1: ---> S2

\-----

\ Record number of responses

\-----

S.S.6,

\ This is a VR12 schedule of reinforcement
\ Filename VR12.mpc
\ For use on computer with UTA property number 072500.

\ Date October 18, 2007

\ This section is for outputs (from the computer)

^House = 1

^Reinf = 2

\ This section is for inputs (to the computer)

^LftLever = 1

^1stB = 2 \ Beam 1

^2ndB = 3 \ Beam 2

\ Z pulses

\ Z1 Reinf On

\ DEFINED CONSTANTS

\ A = Array recording run time from 1stB to 2ndB

\ B = Array recording latency from 2ndB to bar press

\ I = Cell entry in array A

\ J = Cell entry in array B

\ Q = # of responses

\ R = Reinf Delivered

\ S = Max Reward

\ T = Timer for experiment duration

\-----
\ Reward timer, count, and display
\-----

S.S.2,

S1,

#Z1: ADD R; SHOW 2,REINF,R ---> S2

S2,

0.05": OFF ^Reinf ---> S1

\-----
\ Timer in 0.1 sec int for Experiment
\-----

S.S.3,

S1,

#START: ---> S2

S2,

0.1": SET T = T + 0.1 ---> SX

\-----
\ Record Run Time in 0.01 sec int stB to 2ndB -- array A
\-----

S.S.4,

S1,

#START: SET A(I) = -987.987 ---> S2

S2, \ Wait for 1stB Break and update array

#R^1stB: SET A(I) = 0, A(I+1) = -987.987 ---> S3

S3, \ 1st Statement - start run time timer

\ 2nd statement - wait for 2ndB

#R^2ndB: ADD I; SHOW 3,Beam 1,I ---> S4

0.01": SET A(I) = A(I) + 0.01 ---> SX

S4,

#Z1: ---> S2

\-----

\ Record latency from 2ndB to bar press in 0.01 sec int -- array B

\-----

S.S.5,

S1,

#START: SET B(J) = -987.987 ---> S2

S2, \ Wait for 2ndB break and update array

#R^2ndB: SET B(J) = 0, B(J+1) = -987.987 ---> S3

S3, \ 1st Statement - start latency timer

\ 2nd statement - wait for bar press

#R^LftLever: ADD J; SHOW 4,Beam 2,J ---> S4

0.01": SET B(J) = B(J) + 0.01 ---> SX

S4,

#Z1: ---> S2

\-----

\ Record number of responses

\-----

S.S.6,

\ This is an Extinction Program
\ Filename Ext.mpc
\ For use on computer with UTA property number 072500.

\ Date October 18, 2007

\ This section is for outputs (from the computer)

^House = 1

^Reinf = 2

\ This section is for inputs (to the computer)

^LftLever = 1

^1stB = 2 \ Beam 1

^2ndB = 3 \ Beam 2

\ Z pulses

\ DEFINED CONSTANTS

\ A = Array recording run time from 1stB to 2ndB

\ B = Array recording latency from 2ndB to bar press

\ C = Array for 30 second timer on lever press

\ I = Cell entry in array A

\ J = Cell entry in array B

\ K = Cell entry in array C

\ Q = # of responses

\ S = Max Time

\ T = Timer for experiment duration

\ SHOW COMMANDS

\ Show 1 = Number of Resp

\ Show 2 = Time in Array A

\ Show 3 = Time in Array B

DIM A = 999

DIM B = 999

DIM C = 999

DISKCOLUMNS = 1

DISKFORMAT = 6.3

\-----

\ House Light and Left Lever On

\-----

S.S.1,

S1,

 #START: ON ^House ---> S2

S2,

 X#R^LftLever: Z1 ---> SX

\-----

\ Timer in 0.1 sec int for Experiment

\-----

S.S.3,

S1,

 #START: ---> S2

S2,

0.1": SET T = T + 0.1 ---> SX

\-----
\ Record Run Time in 0.01 sec int 1stB to 2ndB -- array A
\-----

S.S.4,

S1,

#START: SET A(I) = -987.987 ---> S2

S2, \ Wait for 1stB Break and update array

#R^1stB: SET A(I) = 0, A(I+1) = -987.987 ---> S3

S3, \ 1st Statement - start run time timer

 \ 2nd statement - wait for 2ndB

#R^2ndB: ADD I; SHOW 2,Beam 1,I ---> S4

0.01": SET A(I) = A(I) + 0.01 ---> SX

S4,

#Z1: ---> S2

\-----
\ Record latency from 2ndB to bar press in 0.01 sec int -- array B
\-----

S.S.5,

S1,

#START: SET B(J) = -987.987 ---> S2

S2, \ Wait for 2ndB break and update array

#R^2ndB: SET B(J) = 0, B(J+1) = -987.987 ---> S3

S3, \ 1st Statement - start latency timer

APPENDIX C

SCHEDULE OF REINFORCEMENT ACROSS SUBJECTS, DAYS,
AND TRIALS FOR THE PARTIALLY REINFORCED GROUP

Subject	Day 1 trial				Day 2 trial				Day 3 trial				Day 4 trial				Day 5 trial			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	R	N	R	N	N	R	R	N	N	R	R	N	R	N	R	N	N	R	R	
2	N	R	N	R	R	N	N	R	N	R	R	N	R	N	N	R	N	R	N	R
3	N	R	N	R	R	N	N	R	N	R	N	R	R	N	N	R	N	R	R	N
4	N	R	R	N	N	R	N	R	R	N	N	R	N	R	R	N	N	R	R	N
5	N	R	R	N	R	N	R	N	N	R	N	R	R	N	N	R	R	N	N	R
6	R	N	R	N	N	R	R	N	R	N	N	R	N	R	N	R	N	R	R	N
7	N	R	N	R	R	N	N	R	R	N	R	N	N	R	R	N	R	N	R	N
8	R	N	N	R	R	N	N	R	N	R	N	R	N	R	N	R	N	R	R	N
9	N	R	R	N	R	N	R	N	N	R	R	N	N	R	N	R	R	N	R	N
10	N	R	R	N	N	R	N	R	R	N	N	R	N	R	R	N	R	N	N	R
11	N	R	R	N	N	R	N	R	R	N	N	R	R	N	R	N	N	R	R	N
12	R	N	N	R	N	R	R	N	N	R	R	N	N	R	N	R	N	R	R	N
13	R	N	R	N	R	N	R	N	R	N	N	R	N	R	N	R	N	R	N	R
14	R	N	R	N	R	N	N	R	N	R	R	N	N	R	R	N	R	N	N	R
15	N	R	R	N	R	N	N	R	N	R	N	R	N	R	N	R	N	R	R	N
16	R	N	N	R	R	N	R	N	N	R	R	N	N	R	R	N	N	R	N	R
Subject	Day 6 trial				Day 7 trial				Day 8 trial				Day 9 trial				Day 10 trial			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	R	N	N	R	N	R	R	N	N	R	N	R	R	N	N	R	R	N	N	R
2	R	N	N	R	N	R	R	N	R	N	R	N	R	N	R	N	N	R	R	N
3	R	N	R	N	N	R	R	N	R	N	N	R	R	N	R	N	N	R	R	N
4	R	N	R	N	N	R	N	R	R	N	N	R	R	N	N	R	R	N	R	N
5	N	R	R	N	N	R	R	N	R	N	N	R	N	R	N	R	R	N	R	N
6	R	N	N	R	R	N	R	N	R	N	N	R	N	R	R	N	N	R	N	R
7	N	R	R	N	R	N	N	R	R	N	N	R	N	R	R	N	N	R	N	R
8	R	N	R	N	N	R	R	N	N	R	R	N	R	N	R	N	R	N	N	R
9	R	N	N	R	R	N	N	R	R	N	N	R	N	R	R	N	N	R	N	R
10	R	N	N	R	R	N	R	N	N	R	R	N	R	N	R	N	N	R	N	R
11	R	N	N	R	R	N	N	R	N	R	N	R	N	R	R	N	R	N	R	N
12	R	N	N	R	N	R	N	R	N	R	N	R	R	N	R	N	R	N	N	R
13	N	R	R	N	R	N	N	R	R	N	N	R	N	R	R	N	N	R	R	N
14	N	R	R	N	R	N	N	R	R	N	N	R	R	N	R	N	N	R	N	R
15	R	N	N	R	R	N	R	N	R	N	R	N	R	N	N	R	R	N	R	N
16	R	N	N	R	N	R	N	R	N	R	N	R	R	N	N	R	R	N	R	N

APPENDIX D

FIGURES

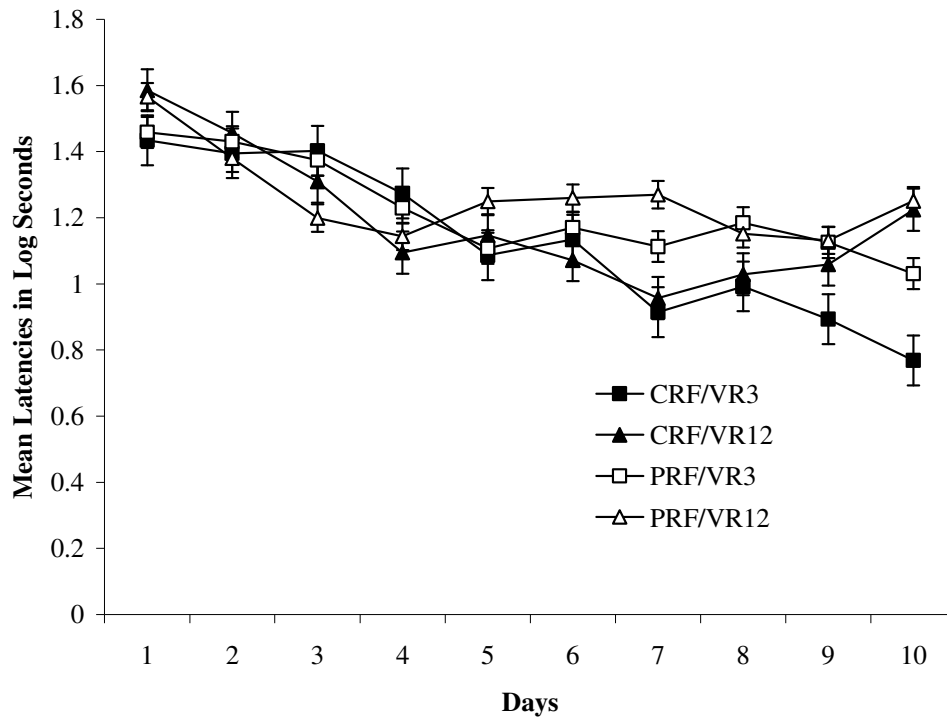


Figure D.1. Mean bar press latencies (+/- S.E.M.) for animals in all conditions in acquisition.

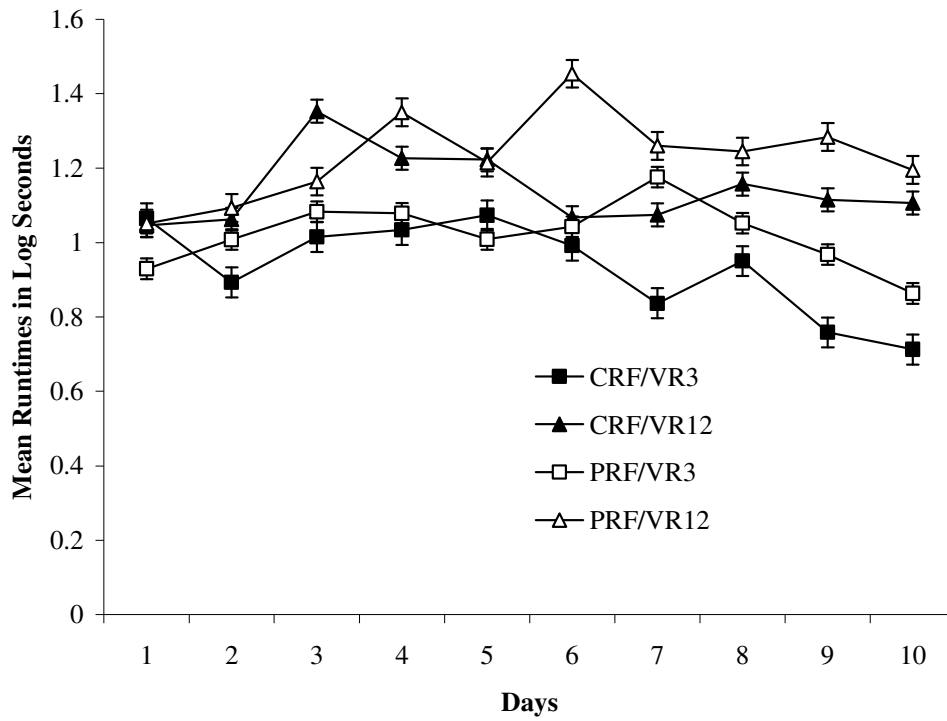


Figure D.2. Mean runtimes (+/- S.E.M.) for all conditions during acquisition.

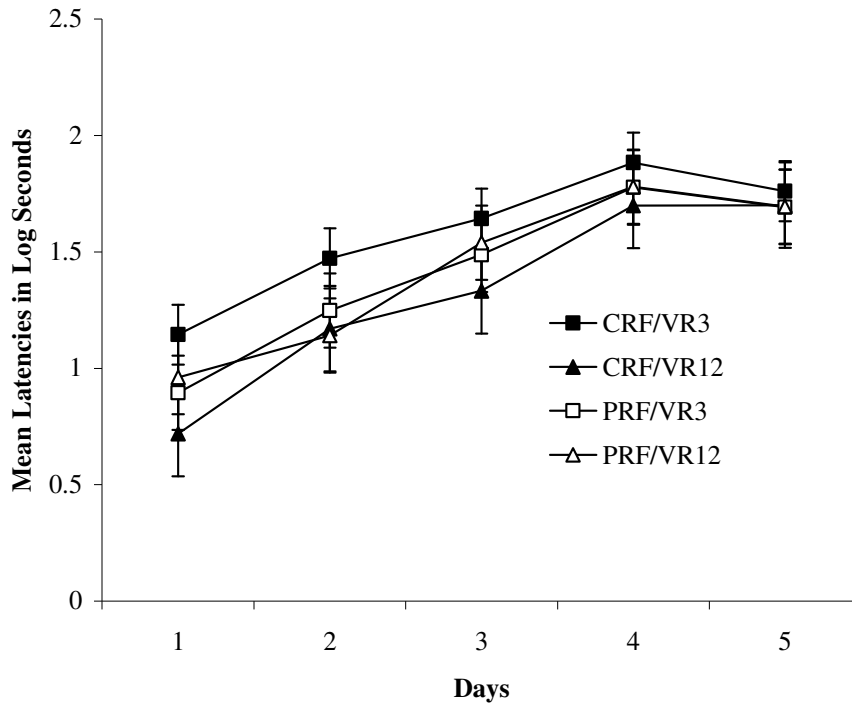


Figure D.3. Mean bar press latencies (+/- S.E.M.) for all conditions in extinction.

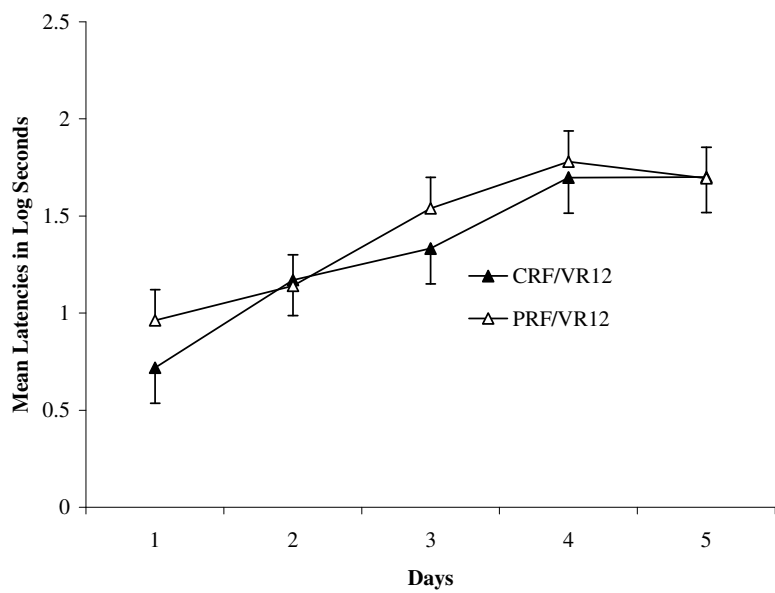
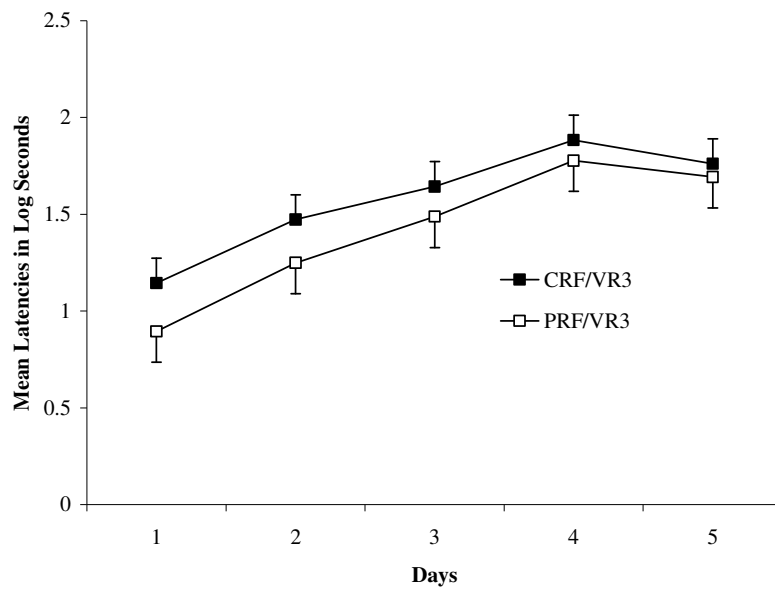


Figure D.4. Mean bar press latencies (+/- S.E.M.) for VR3 and VR12 conditions in extinction.

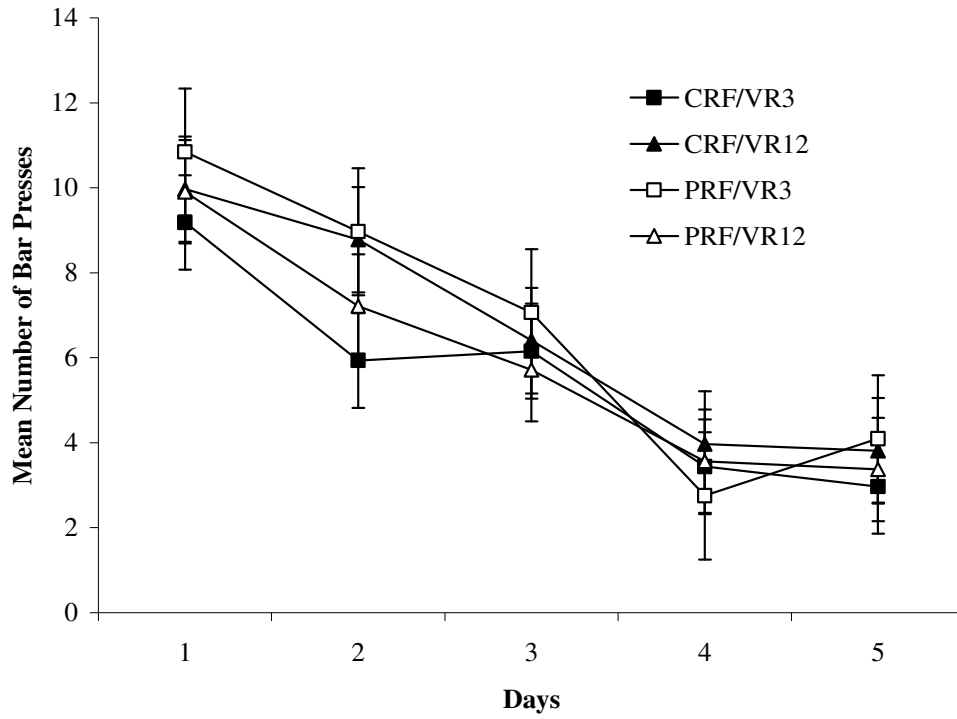


Figure D.5. Mean number of bar presses (+/- S.E.M.) across all groups in extinction.

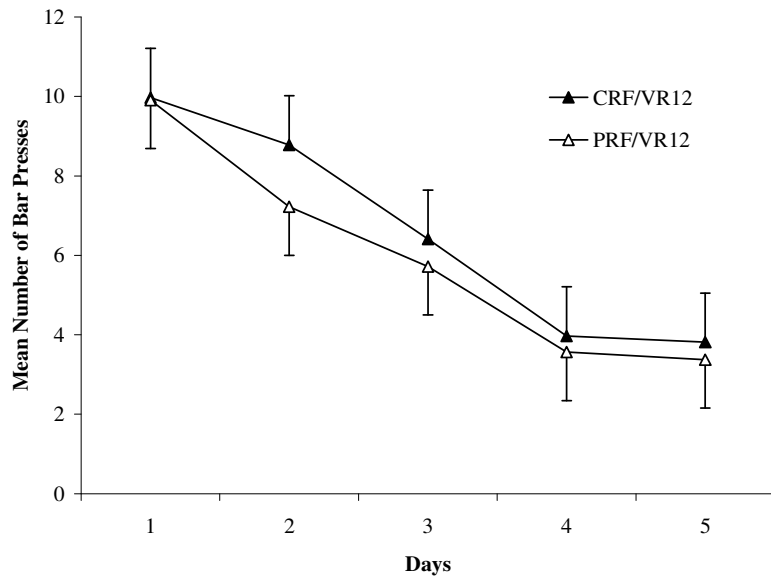
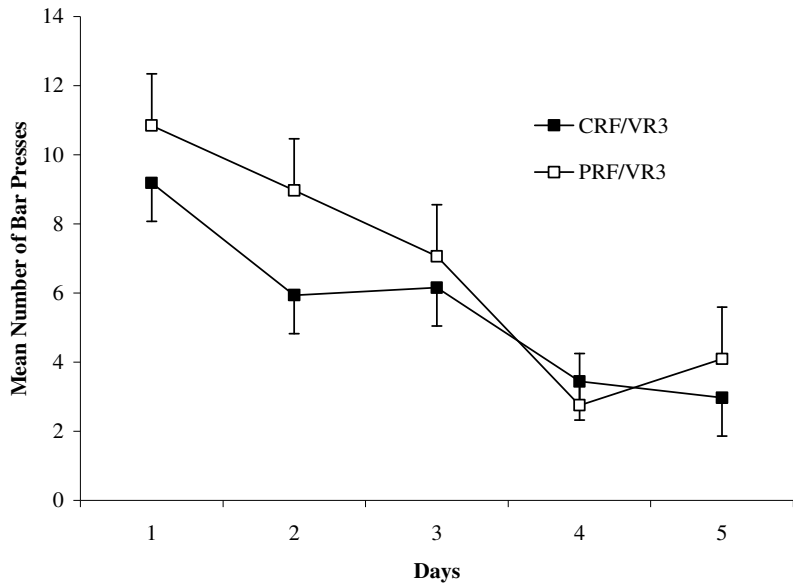


Figure D.6. Mean number of bar presses (+/- S.E.M.) for VR3 and VR12 conditions in extinction.

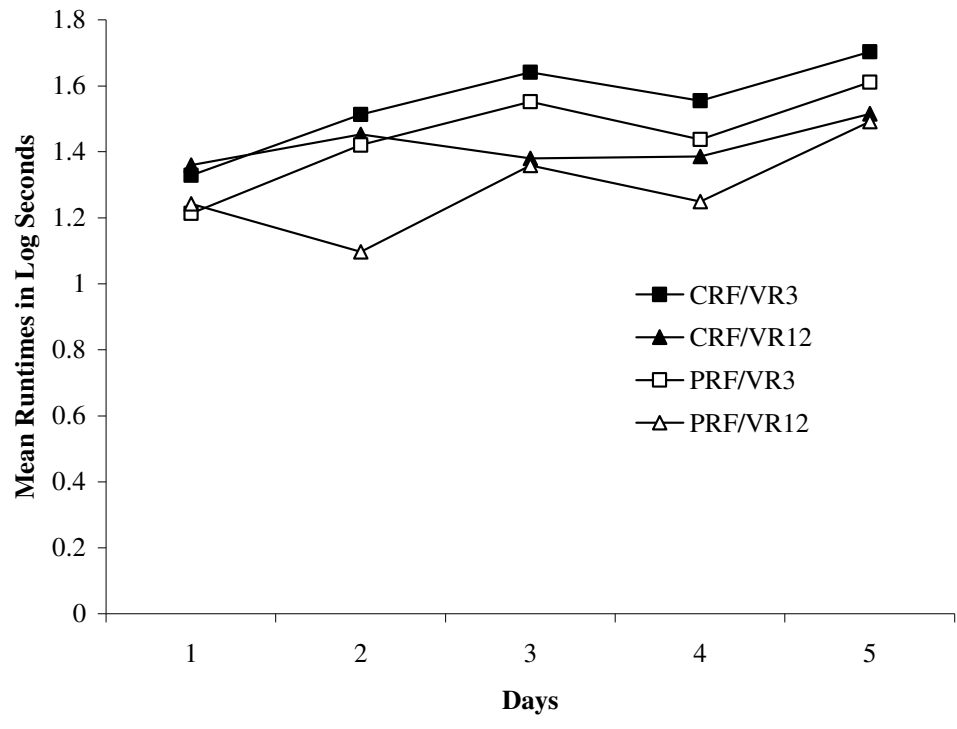


Figure D.7. Mean runtimes (+/- S.E.M.) for all conditions in extinction.

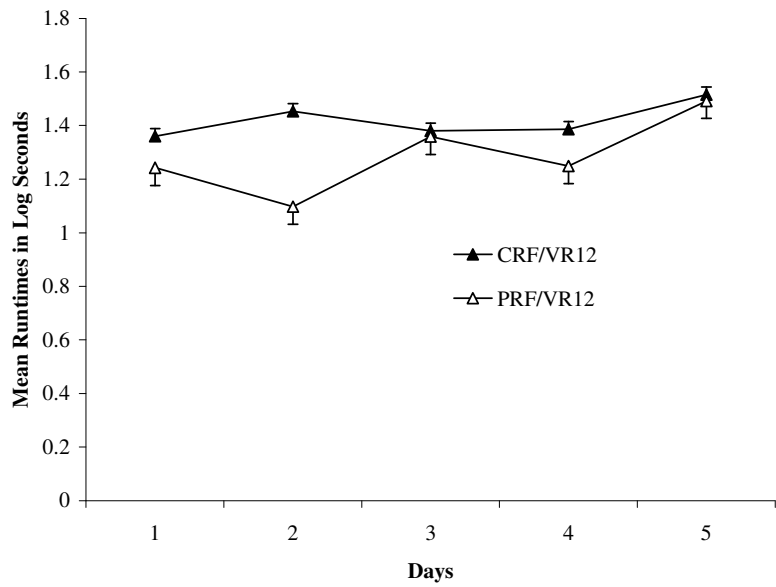
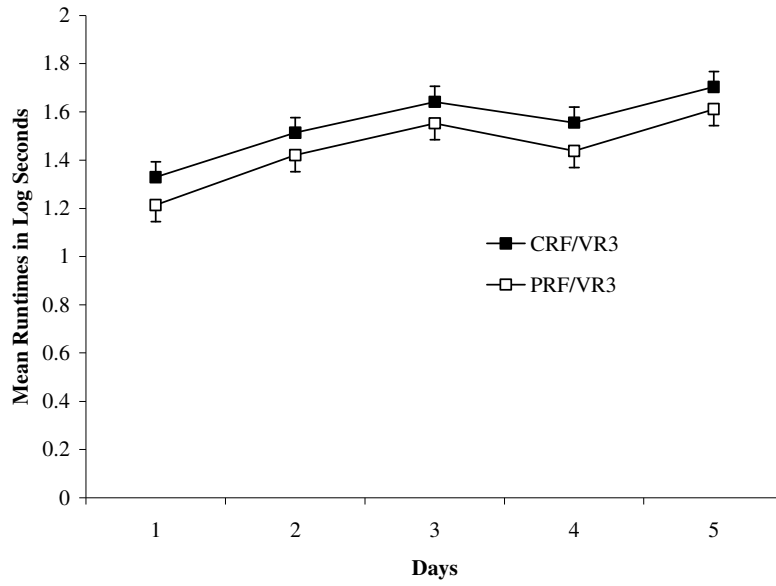


Figure D.8. Mean runtimes (+/- S.E.M.) for VR3 and VR12 conditions in extinction.

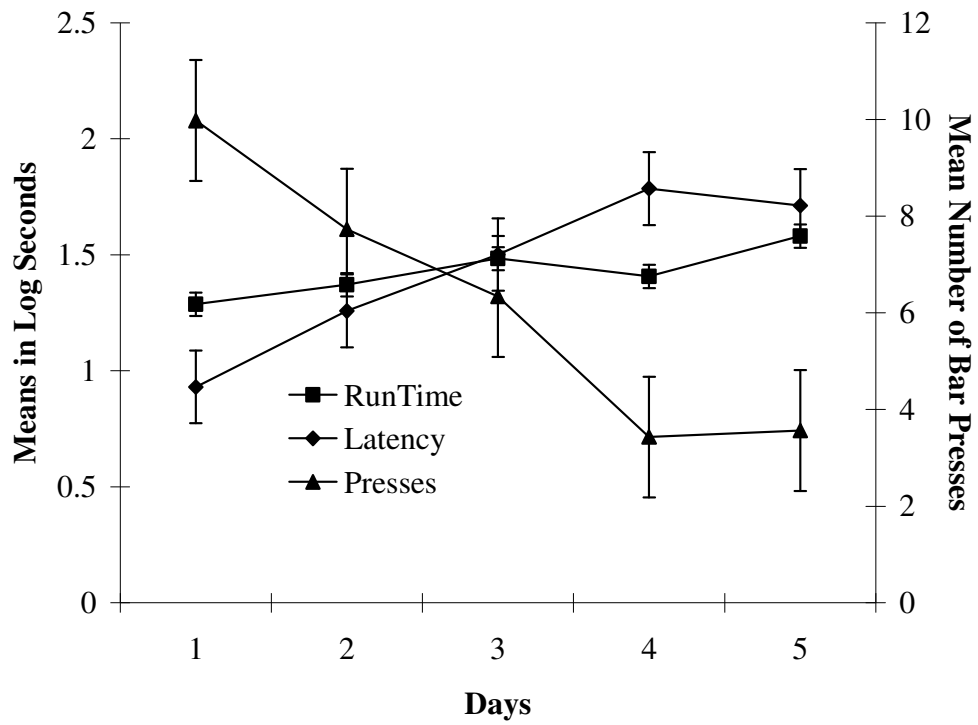


Figure D.9. Mean runtimes, latencies and bar presses (+/- S.E.M.) for all conditions.

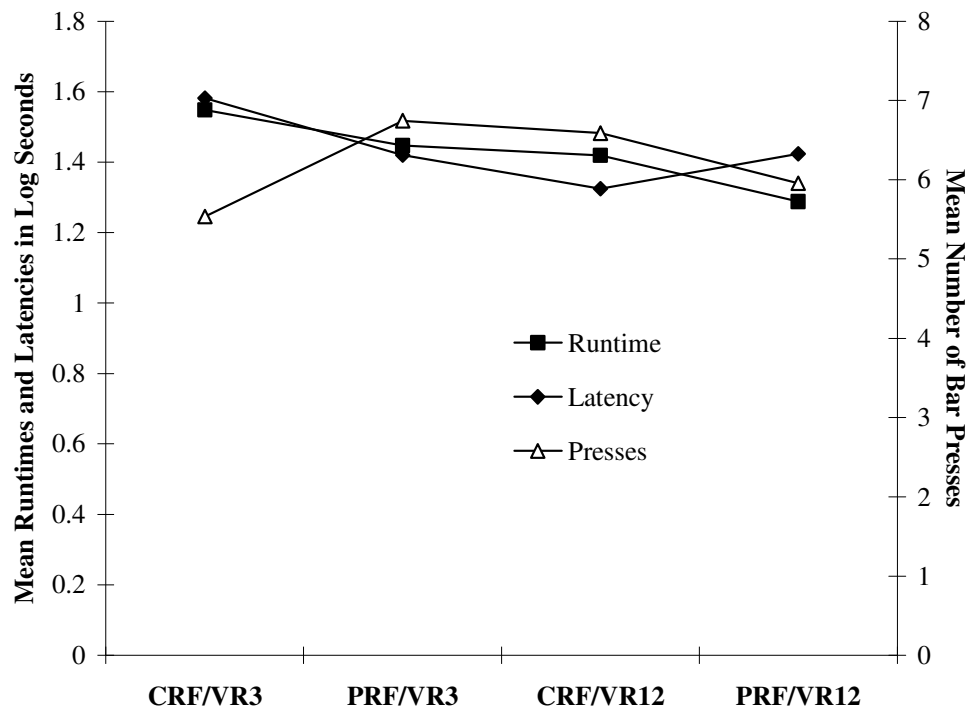


Figure D.10. Mean runtimes, latencies, and bar presses (+/- S.E.M.) as a function of schedule density.

APPENDIX E

TABLES

Table E.1. ANOVA Summary Table for Extinction Log Data

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Schedule	RunTime	.068	1	.068	.886	.348
	Latency	.016	1	.016	.356	.552
	Presses	3.306	1	3.306	.367	.546
VR	RunTime	.255	1	.255	3.308	.071
	Latency	.001	1	.001	.013	.909
	Presses	.689	1	.689	.076	.783
Day	RunTime	3.457	4	.864	11.204	.000
	Latency	11.766	4	2.942	66.786	.000
	Presses	999.748	4	249.937	27.737	.000
Schedule * VR	RunTime	.014	1	.014	.182	.670
	Latency	.220	1	.220	5.005	.027
	Presses	33.764	1	33.764	3.747	.055
Schedule * Day	RunTime	.220	4	.055	.715	.583
	Latency	.072	4	.018	.406	.804
	Presses	9.522	4	2.380	.264	.901
VR * Day	RunTime	.998	4	.249	3.234	.014
	Latency	.240	4	.060	1.360	.251
	Presses	7.787	4	1.947	.216	.929
Schedule * VR * Day	RunTime	.207	4	.052	.672	.613
	Latency	.053	4	.013	.299	.878
	Presses	24.470	4	6.118	.679	.608
Error	RunTime	10.799	140	.077		
	Latency	6.166	140	.044		
	Presses	1261.531	140	9.011		
Total	RunTime	16.019	159			
	Latency	18.533	159			
	Presses	2340.819	159			

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BIOGRAPHICAL INFORMATION

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