Effects of effort and magnitude of reinforcement on the running response in rats

Andrea M. Karkowski

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EFFECTS OF EFFORT AND MAGNITUDE OF REINFORCEMENT
ON THE RUNNING RESPONSE IN RATS

by

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The present experiment was designed to determine whether running in a running wheel under high effort conditions is analogous to running in a runway and to determine the effects that high effort requirements have on running in a running wheel. Sixty-three naive male albino rats were shaped to run 8 trials per day. Each trial consisting of running 240 cm for either a 2 pellet reward or an 8 pellet reward. There was a 1 minute intertrial interval between each trial during which the animal could not run. The amount of tangential force applied to the running wheel was set at one of the following levels: 20 g, 40 g, 60 g, 80 g. After running had stabilized, the rats experienced 12 days of extinction trials. The rats were required to run 240 cm and received no reinforcement during these extinction trials. Running times were calculated for each 30 cm of the required distance. Results indicated that under these conditions running in a running wheel and running in a runway are not analogous behavioral responses. It was also indicated that high effort requirements produced a different response pattern when compared to low effort requirements. Possible explanations for these findings are discussed.
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Effects of Effort and Magnitude of Reinforcement on the Running Response in Rats

While many variables affect learning, the focus of this paper will be on the variables of effort and magnitude of reinforcement. The effects of effort on learning a response will be discussed first. Included in this section will be a review of the literature regarding the ways in which effort influences the acquisition and extinction of a response, the ways in which effort influences the persistence across behaviors, and the ways in which effort influences the behavioral features of a response. The second section will be an examination of the literature regarding the effects of magnitude of reinforcement on responding. This examination will include information on the ways in which magnitude of reinforcement affects acquisition, performance, and extinction of a response. Following this there will be a brief exposition about relevant research that has been conducted using the apparatus which was used in the study to be proposed. It will include further examination of both the effort and magnitude of reinforcement variables.

Effort

Effort has been variably defined as: cost-per-unit-of-time (Solomon, 1948a), distance required in a jumping response (Solomon, 1948b), the amount of force necessary to press a lever (Applezweig, 1951; Capehart,
Viney, & Hulicka, 1958; Keehn, 1981; Maatsch, Adelman, & Denny, 1954; Mowrer & Jones, 1943; Quartermain, 1965; Thompson, 1944; Viney & Jacobson, 1977), the amount of force necessary to swing a door (Aiken, 1957), the amount of force necessary to peck a key (Chung, 1965), the amount of force required to turn a running wheel (Collier, Hirsch, Levitsky, & Leshner, 1973), angle of inclination of a treadmill (Collier et al., 1973; Collier & Levitsky, 1968), the amount of weight that a rat must drag (Lewis, 1964), and distance to a goal box (Larson & Tarte, 1976; Waters, 1937). The amount of effort required to perform a task appears to influence the acquisition, extinction, and behavioral features of the response. The only explanation for this influence can be found in Solomon (1948a) in which it is stated that this influence can be attributed to the cues derived from responding to an effortful task. By this it is meant that when an organism responds to a task, there is physical stimulation for the organism. There is more physical stimulation derived from a more effortful task than there is derived from a less effortful task. According to Solomon, the increased physical stimulation experienced while performing a more effortful task influences the ways in which a more effortful response is learned, performed and extinguished. The ways in which effort influences
acquisition and performance, extinction, persistence, and behavioral features will now be examined.

**Acquisition and Performance**

Solomon (1948a) has asserted that "increasing effort-per-unit-of-time results in slower learning and a depressed asymptote for the acquisition curve" (p.14). The slower learning for more effortful responses has been demonstrated by other researchers (Aiken, 1957; Applezweig, 1951). However, Applezweig (1951) and Lewis (1964) failed to confirm a lower asymptote for more effortful responses.

Applezweig (1951) varied the amount of force required to press a lever for reinforcement and found that the time to learn the response was significantly longer for the animals presented with the levers requiring greater force. Aiken (1957) also found a significant difference in the amount of time it took for the animals to reach the learning criterion. Animals trained on a low effort response required less time to reach asymptotic performance than animals trained on a high effort response. In the Applezweig study significantly fewer animals were able to learn the more effortful responses than the less effortful responses indicating that the more effortful responses are more difficult to learn. There was not a significant difference in the asymptotic performance
between the animals trained for the more effortful responses as compared to the animals trained for the less effortful responses. Applezweig concluded that there is a positive correlation between the amount of effort required to perform a task and the length of time required to learn that task. By this it is meant that for more effortful responses it takes longer to learn the response than for less effortful responses. Applezweig also stated that the responses requiring more effort are more difficult to learn than the responses requiring less effort. However, once the response has been acquired, it is performed as rapidly as the less effortful response.

According to Solomon (1948a), in a distributed practice situation, the "negative drive stimulus traces fade between responses" (p. 12). Thus, effort is less influential on the acquisition of an effortful response in a distributed practice situation. Solomon attributes the increased acquisition time of a more effortful response in a mass practice situation, as was used by Aiken (1957) and Applezweig (1951), to the reduced ability of the response produced effects to fade sufficiently between responses.

However, Lewis (1964) did not find differences in the amount of training that was required for rats to learn to pull an 80 g weight for reinforcement as
compared to rats required to pull a 5 g weight for reinforcement. In addition to this, Lewis found that the animals required to pull the heavier weight actually ran faster than those required to pull the lighter weight. One of the possible explanations for this finding involves differences in the behavioral features of the response. This will be discussed shortly.

**Extinction**

The effects of effort on extinction have been studied more extensively than the effects of effort on acquisition and performance (Aiken, 1957; Applezweig, 1951; Capehart et al., 1958; Maatsch et al., 1954; Mowrer et al., 1943; Quartermain, 1965; Solomon, 1948b; Viney and Jacobson, 1977). The studies in which animals were trained at a given effort level and then extinguished at that same effort level will be examined first. This will be followed by a discussion of the studies in which the animals were trained and extinguished at different effort levels. The final exposition of the effects of effort on extinction will include an examination of the studies in which the animals were trained at all of the effort levels and then extinguished under either low, intermediate, or high effort conditions.

Solomon (1948b) has found that the more effortful
a task, the more rapidly it is extinguished. In this study the animals were trained at the effort level at which they were to be extinguished. The difference in the number of trials to extinction between the low effort and the high effort groups was attributed to fatigue (Solomon, 1948b). This finding has not been confirmed in other studies in which the animals were trained and extinguished at the same effort level (Aiken, 1957; Applezweig, 1951; Maatsch et al., 1954). It has been found that for animals trained and extinguished at the same effort level there is no discernable difference between animals in the low and high effort level groups. The reason for this discrepancy may be that in the Solomon (1948b) study negative reinforcement was used in conjunction with positive reinforcement during acquisition. In the Solomon (1948b) study the animals were trained to jump a distance of either 8 in or 16 in. The training began by submitting the rat to shock until it jumped the required distance. After the rat made the jump it received food. It may be that the rats who were required to jump the farther distance took longer to initiate the response due to fatigue. If the animals in the high effort group took longer to initiate the response during extinction then they would be more likely to learn earlier that shock is no longer being
used as compared to the rats in the low effort group. Negative reinforcement was not used in the other studies. Thus, the use of negative reinforcement in the Solomon (1948b) study could have affected the results.

When animals acquire a response at one effort level and are then shifted to a different effort level there is a positive relationship between the effortfulness of the task performed during acquisition and resistance to extinction (Aiken, 1957; Applezweig, 1951). For animals trained at higher levels of effort the mean number of trials for extinction over all of the effort levels is greater than that for the animals trained at the lower levels of effort. Applezweig (1951) summarized this by claiming that "the more effortful the performance of a task, the better it will be learned" (p. 235). Thus, when a behavior is learned under high effort conditions it will take longer to extinguish under low effort conditions than will a behavior learned under low effort conditions.

Applezweig's study was criticized by Maatsch et al. (1954) because it was assumed that the rats trained under low effort conditions can be made to respond under high effort conditions. In the Maatsch et al. study animals were trained to an intermediate effort level and then given experience at the effort level at which they would be extinguished. No relationship
between the effort required in performing a task and resistance to extinction was found.

Mowrer et al. (1943) found an inverse relationship between the number of responses to extinction and the effort required to press a lever. In the Mowrer et al. study all animals received training at all of the effort levels examined during extinction. However, the amount of training at each effort level was not equal. This criticism will be addressed shortly. After acquisition the animals were divided into three groups and each group was extinguished at either a low, intermediate, or high effort level. The rats who were extinguished at the low effort level made the greatest number of responses during extinction while the rats who were extinguished at the high effort level made the fewest number of responses in extinction. These differences in the rate of extinction were most apparent in the early stages of extinction and disappeared at the end of extinction.

A criticism of the Mowrer et al. study comes from Capehart et al. (1958). According to Capehart et al., the extinction results may have been due to the fact that equal training was not received by all subjects at all effort levels. The animals trained at the lowest effort level received the most training. Therefore, the results of the extinction procedure might not be
due to the effort level, but due to the increased training of the animal. After training all animals equally at each effort level Capehart et al. (1958) extinguished the response. It was indicated that "the number of responses to extinction is a function of the effort required to make the response" (p. 507) such that for the more effortful response there were fewer trials to extinction as compared to the less effortful response. Despite the criticism of the Mowrer and Jones study, Capehart et al. supported their findings.

Using the same procedure as that used by Capehart et al. (1958), Quartermain (1965) failed to confirm the Capehart et al. and Mowrer et al. findings. Quartermain found no differences in the rate of extinction between the different effort level groups. Viney and Jacobson (1977) address this discrepancy by pointing to the difference in the number of total acquisition trials used in both studies. Viney et al. attempted to assess the effects of the amount of training and effort on extinction rates. It was found that while there was an increased resistance to extinction due to an increased number of training trials the increased number of training trials did not explain the contradictory results between the Capehart et al. and Quartermain studies.

To summarize, the literature concerning the
effects of effort on extinction is inconclusive. It appears that for animals who acquire a response at the same effort level used to extinguish the response there is no difference in the rate of extinction between high and low effort groups (Aiken, 1957; Applezweig, 1951; Maatsch et al. 1954). The study which does not support this (Solomon, 1948b) used a different type of reinforcement in training which may have confounded the results. For animals trained and extinguished under different effort levels the trend appears to be a greater resistance to extinction for animals who acquire a high effort response and are extinguished with a low effort response. Once again, training procedures may have affected the results. No explanation is given for the discrepancy in the literature regarding the resistance to extinction for animals trained at each of the effort levels and then extinguished under low, intermediate, or high effort conditions. It can be said that under high effort conditions the behavior is less resistant to extinction only when the behavior was learned under low effort conditions.

**Persistence Across Behaviors**

The general finding in the literature on the effects of effort for persistence across behaviors is that increased effort required to learn one behavior
leads to greater persistence in performing a second behavior (Boyagian & Nation, 1981; Eisenberger & Adornetto, 1986; Eisenberger, Carlson, Guile, & Shapiro, 1979; Eisenberger, Heerdt, Hamdi, Zimet, & Bruckmeir, 1979; Eisenberger, McDermitt, Masterson, Over, 1983; Eisenberger, Mitchell, & Masterson, 1985; Eisenberger, Mitchell, McDermitt, & Masterson, 1984; Eisenberger, Terborg, & Carlson, 1979). This effect has been tested in many different situations. For example, Eisenberger et al. (1979a) have found that requiring more force to bar-press for food reinforcement leads to increased speeds in a shuttle response. Eisenberger et al. (1979b) have also found that psychiatric patients rewarded for a low effort task gave up sooner on a subsequent task than did patients rewarded for a high effort task. Training human subjects with high force requirements in a shuttle task led to quicker responding in the acquisition phase of a subsequent task and a greater resistance to extinction (Boyagian & Nation, 1981). Greater effort required from students in one task led to greater essay length and quality (Eisenberger et al., 1983) and to more accurate drawings and stories (Eisenberger et al., 1984). Children who were paid for a high effort tasks showed greater self control in a copying task as compared to children who were paid for
a low effort task and a no-training control group (Eisenberger et al., 1985). The explanation for these findings comes from Eisenberger et al. (1979a) is that what the subject is learning is to exert more effort and this learning then transfers to other behaviors.

While the transfer of persistence across behaviors appears to be a rather robust phenomenon, it corresponds to only a small part of the effort literature on resistance to extinction. The only studies in which increased effort led to increased resistance to extinction were the ones in which the subjects were trained at a high level of effort and extinguished at a lower level of effort (Aiken, 1957; Applezweig, 1951). Perhaps an alternative explanation of the findings regarding the persistence-across-behaviors phenomenon is that when the subjects are trained on a more effortful task and then switched to a less effortful task, a greater persistence of the second task is obtained due to a contrast effect. In other words, an organism that is trained to respond in an effortful way and is then required to perform a less effortful task may persist in its responding due to the relative easy with which the new task may be performed as compared to the effort conditions under which it was trained. Eisenberger and his colleagues have not assessed whether or not the second task performed by
their subjects was equal in effort to the task at which they were trained. Perhaps by making the effort required to perform both tasks equivalent, the persistence across behavior findings would not be quite so robust.

**Behavioral Features**

Mowrer et al. (1943) have found that during extinction the behavior of animals required to perform a less effortful response was uniform. For animals required to perform a more effortful response the behavior was considerably more variable and more aggressive. The conclusions drawn from this are that when a task is more difficult to perform individual differences in behavior and aggression appear to increase and increased effort is an aversive condition.

However, the behavioral features seen in acquisition may be different than those seen in extinction. Applezweig (1951) indicated that during acquisition the animals required to engage in less effortful responses also tended to "explore" the apparatus. These animals would hold the lever down and lift it and lower it in the down position. In addition, Applezweig found an inverse relationship between the number of holding responses during learning and the amount of effort required to make the response. For the more effortful responses there was a tendency.
for the animal to "short cut" the response during acquisition. In other words, there was a difference in the features of the behavior exhibited during acquisition by the animals as the amount of effort varied. The features of the behavior did not differ once the response was acquired (Applezweig, 1951). Lewis (1964) also attributed the differences in the asymptotic running speeds to the tendency of the animals in the higher effort condition to stay on task while the animals in the lower effort condition did more exploring.

Chung (1965) has found that below a certain force requirement there is not an effect on response rate in pigeons. This has also been demonstrated with rats (Keehn, 1981). Above a critical effort level, however, there are changes in response rate and there are differences in the topography of the behavior as compared with behavior seen in responses requiring lower effort levels. The critical effort level that produced changes in the response rate and topography of the behavior in the Keehn study was 60 g. The behavior that was examined was bar pressing, and Keehn found that at and below 45 g there were no differences in response rates for the different effort levels, however at 60 g the response rate dropped off.

A final note on the effect of effort on behavioral
features comes form Collier et al. (1973) and supports the idea that effort is aversive. Collier et al. (1973) have shown that "the effort required to run is a major determinant of the amount of activity" (p. 94). In the Collier et al. study spontaneous running in a running wheel or on a treadmill decreased as the required effort increased. Since earlier research (Collier & Hirsch, 1971) had shown running to be a reinforcing activity, it was concluded that increasing the required effort makes the response less reinforcing and more aversive.

Not only does it appear that effort influences acquisition and extinction, effort also appears to influence the behavioral features of the response. It is possible that the differences seen in the behavioral features could be confounding the effects of effort on acquisition and extinction.

**Magnitude of Reinforcement**

The effects of magnitude of reinforcement on runway responding are considerably less controversial than the literature regarding effort. Due to the consistency in the magnitude of reinforcement literature regarding the effects that magnitude of reinforcement has on the acquisition, performance, and extinction of a response only brief summaries will be given here. The literature regarding the acquisition
of a response under different levels of reinforcement will be discussed first. This will be followed by a summary of the effects of magnitude of reinforcement on performance in the runway. The section will conclude with a discussion of the way in which extinction is affected by magnitude of reinforcement.

**Acquisition**

In the typical runway situation, there is a positive relationship between the rate at which the running response is learned and the magnitude of reinforcement (Ratliff and Ratliff, 1971; Reynolds 1950). In other words, for the higher magnitudes of reinforcement the animal learns the running response faster than animals receiving lower levels of reinforcement.

**Performance**

Once the response has been acquired, the typical finding in the runway is that the asymptotic speeds are greater for the animals receiving higher levels of reinforcement as compared to animals receiving lower levels of reinforcement (Armus, 1959; Crespi, 1942, 1944; Hill and Wallace, 1967; Metzger, Cotton, & Lewis, 1957; Reynolds and Pavlik, 1960; Wagner, 1961; Zeaman, 1949). There is a positive relationship between the level of reinforcement and performance such that as reinforcement level increases asymptotic running speed
increases.

**Extinction**

It has been shown (Armus, 1959; Ison and Cook, 1964; Metzger et al., 1957; Ratliff and Ratliff, 1971; Reynolds, 1950; Wagner, 1961) that in extinction there is a negative relationship between the magnitude of reinforcement and resistance to extinction. In extinction animals who have received training at higher magnitudes of reinforcement are less resistant to extinction when compared to animals who have received lower magnitudes of reinforcement. This can be clarified by saying that the rate of extinction is faster for animals who receive higher magnitudes of reinforcement in acquisition as compared to animals who receive smaller magnitudes of reinforcement in acquisition.

The effects of magnitude of reinforcement are quite clear. For acquisition and performance there is a positive relationship between the magnitude of reinforcement and the rate of acquisition and level of performance. However, for extinction the relationship between magnitude of reinforcement and resistance to extinction is a negative one.

**Research in the Running Wheel**

The apparatus that was used in the study presented in this paper was a modified running wheel and will be
described shortly. There have been two studies (manuscript in progress) which have used this equipment in a manner that is directly relevant to the study which will be presented in this paper. The first study examined the effort variable and its application to the running wheel. The second study varied the amount of reinforcement received by the rat for running while holding the effort required to respond constant. The focus on this next section will be on the findings of those two studies.

**Effort in the Running Wheel**

In a study in which the effects of effort on the wheel running response in rats was examined, effort was defined as the amount of tangential force required to turn a running wheel. The effort levels employed in the study were 90 g, 110 g, 130 g, and 150 g. The rats were required to run 4.5 m for five 45 mg Noyes pellets. Each rat was shaped to run at the tension level appropriate for its group and then was run in the acquisition phase for eight trials per day for 16 days. After the acquisition phase the rats experienced extinction. Extinction lasted six days.

Effort affected the running response in the following ways. In the first part of acquisition the rats in the 90 g and 110 g groups were running significantly faster than the rats in the higher
tension level groups. However, there was not a significant difference in the running speeds of the 90 g and 110 g groups. In the middle of the acquisition phase the running speeds for the rats in the 110 g group began to decrease. By the end of acquisition the rats in the 90 g group were running significantly faster than the rats in all of the other groups. There were no significant differences in the running speeds of the 110 g, 130 g, and 150 g groups. In extinction, the 90 g group demonstrated a greater resistance to extinction than the other three groups. The rates of extinction for the 110 g, 130 g, and 150 g groups did not differ significantly from each other. From this study it can be concluded that as effort increases asymptotic running and resistance to extinction both decrease.

Magnitude of Reinforcement in the Running Wheel

In the second study, which utilized the same modified running wheel, the level of effort was held constant at 75 g across the two levels of reinforcement. The levels of reinforcement which were used were two 45 mg Noyes pellets and eight 45 mg Noyes pellets. The rats were trained to run 4 trials per day. The distance that was run for each trial was 3 m. Upon completion of the 3 m the rat received reinforcement appropriate for its group. The
acquisition phase lasted 16 days. After acquisition
the rats received extinction trials for 11 days.

The level of reward did not differentially affect
the rate at which the response was acquired nor
extinguished. This is in opposition to the literature
regarding the effects of magnitude of reinforcement in
the runway situation. There may be a functional
difference between responding under high effort as
compared to responding under low effort. Therefor the
discrepancy between the findings in the runway
literature and the findings in the running wheel with
regard to the effects of magnitude of reinforcement on
acquisition and extinction may not be present under low
effort conditions. What does correspond to the
runway literature is that the rats who received the
large reward showed faster asymptotic speeds than those
who received small reward.

Proposal

The present study was an attempt to clarify the
rather murky results found in the effort literature.
This was accomplished by examining the effect that
effort had on the acquisition, performance, and
extinction of the wheel running response. The second
reason for conducting this experiment was to determine
whether or not wheel running, and more specifically
wheel running under high effort conditions, is a
response that is analogous to runway running. Support for the position that wheel running and runway running are analogous behavioral responses would accrue if magnitude effects similar to those obtained in the runway were evident under all effort conditions.

For the purpose of the current study effort was defined as the amount of force required to turn a running wheel. Four effort levels were examined. Previous research using the running wheel has indicated that effort levels above 90 g dramatically reduce acquisition. Therefore, the following four effort levels were used: 20 g, 40 g, 60 g, and 80 g. In addition, two magnitudes of reinforcement were used: two 45 mg Noyes pellets (small) and eight 45 mg Noyes pellets (large). These levels of reinforcement correspond to the levels of reinforcement that are typically used in runway studies. Each animal was shaped to run at the effort level appropriate for its group (e.g., the rats in the 80 g groups were trained to run at that level of effort) and received reinforcement for completing the running response appropriate for its group (e.g., the rats in the eight pellet groups received eight pellets for completing the running response throughout training). The training procedure equated the total number of trials run across all groups as well as the number of trials run at the
groups' final tension levels. This minimized the effects of amount of training on extinction, which appears to have confounded earlier investigations of effort. The acquisition phase lasted 24 days and it ended with the rats running at asymptote. Then the rats experienced extinction trials for 12 days.

It was expected that learning would be an inverse relationship between the amount of effort required to complete the running response and the rate at which acquisition occurs: The higher effort groups would take longer to acquire the response than the lower effort groups. It was also expected that asymptotic running performance would be inversely related to the amount of effort required for the response: There would be depressed asymptotic running speeds for the higher effort groups as compared to the lower effort groups. It was expected that effort would not have an effect on the rate of extinction. This means that the different effort level groups should have extinguished at the same rate.

With regard to the magnitude of reinforcement it was expected that the groups receiving large reward would acquire the response faster than the groups receiving small reward at the same effort level. The large reward groups would also have higher asymptotic running speeds than the small reward groups at the same
effort level. It was expected that extinction would be affected by the magnitude of reinforcement in that the groups that receive higher levels of reinforcement should extinguish at a faster rate than the lower level of reinforcement groups. These predictions were derived from the runway literature cited earlier, and assume that the two responses are governed by similar mechanisms.

Method

Subjects
Subjects were 63 naive male albino rats. The rats were 70 days old at the start of the experiment. They were housed individually and had free access to water in their home cages throughout the study. The rats were handled daily and were on ad-lib food until they were 85 days old. At 85 days of age the rats were weighed and then placed on food deprivation. They were maintained at 85% of their ad-lib feeding body weights. The rats were weighed periodically to insure that the appropriate amount of deprivation was maintained. While on deprivation the rats were fed at least one hour after being run each day. At 90 days of age the rats began wheel adaptation and received Noyes pellets in their home cages in addition to their daily food allotment.

Apparatus
effort level. It was expected that extinction would be affected by the magnitude of reinforcement in that the groups that receive higher levels of reinforcement should extinguish at a faster rate than the lower level of reinforcement groups. These predictions were derived from the runway literature cited earlier, and assume that the two responses are governed by similar mechanisms.

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Apparatus
Eight Wahman running wheels were modified as follows: The opening to the wheel was expanded to approximately 8 cm in height at its largest point. The bottom of the opening was cut along a curve which matches the outside rim of the wheel. A plexiglass door approximately 8 x 25 cm and hinged on one side was attached to cover this opening. On the inside of the door and in the approximate middle of the door, a feeder cup made of one half of a 4 cm PVC cap cut lengthwise was attached using sheet metal screws. Colborn Instruments pellet feeders were attached to the frames of the wheel assemblies with the feeder tube extending down to a PVC tube with a ninety degree bend in it which passes through the door and connects to the feeder cup on the inside.

A 7.62 cm aluminum disc approximately 1.3 cm thick was attached to the wheel axle where the original revolution counter had been attached. One end of a metal bar of approximately 20 cm in length was installed on top of the disc and its opposite end was attached to the frame by a bolt. This bolt allowed the bar to "float" on the aluminum disc by permitting it to freely turn on the bolt. Above the bar was a cylinder with a spring and thumbscrew attached to the frame. A shaft protruding from the bottom of the cylinder pressed on the bar and the resulting pressure on the
was controlled by turning the thumbscrew. This permitted the force required to turn the wheel to be adjusted because the bar was being pressed with greater force against the aluminum disc.

The wheel itself was lightened by removing most of its solid metal back and replacing it with screen, thus reducing the weight of the wheel from 1150 g to 700 g. This was done to minimize the inertia of the wheel.

Each wheel was fitted with an electromagnetic braking system controlled by the computer. The system consisted of two solenoids fitted with brake shoes. When activated, the solenoids applied 2.2 kg of force onto two opposite sides of the aluminum disc which stopped the wheel and prevented it from being turned during specific portions of the experimental session.

An 'O' ring was attached to the axle of the wheel and was stretched upward to connect with a 7.62 cm wooden disc. The wooden disc was also attached to the frame of the wheel assembly. The disc freely revolved around an axle. Attached to the axle of the wooden disc was a belt made of heavy fabric which extended upward and was attached to an IBM-compatible mouse mounted to the top of the wheel assembly frame. The purpose of this system was to read wheel movements. It functioned in the following manner: When the running wheel was turned the 'O' ring attached to the axle was
also turned. The 'O' ring then turned the wooden disc which in turn turned the belt. The belt then moved the sectored disc in the mouse and the movement of the sectored disc created a signal that could be read by a computer. In this fashion the wheel movement was monitored by the computer. Further details of the instrumentation can be found in Petree, Haddad, & Berger (1992).

The IBM-compatible computer was programmed using the Turbo-C programming language. The program read rotations of the wheel via the mouse and also functioned as a timing device. Additionally, the computer ran the feeder and braking systems (discussed earlier) and the lighting system (to be discussed shortly) via an A-BUS card system which was connected to the computer. The A-BUS system consisted of a series of relays which operated the feeder, brakes, and lights. The relays switched electricity from a 30 volt and a 12 volt power supply. Each computer could control two running wheels simultaneously.

The running wheels were placed in sound attenuated chambers which were positively vented by a fan system. The air flow was constant throughout the experimental session and the fans served to provide masking noise inside the box.

Two 12 watt house lights were attached to the
ceiling of the chamber. The amount of energy applied to the lights was controlled by the computer. The amount of energy applied to the lights was varied in a regular manner during the experimental session such that at the start of each trial the lights were set to 8.58 w. This was increased to 15.09 w for the middle portion of the trial and increased again to 23.4 w for the final portion of the trial.

Procedure

The rats were divided into eight groups (four tensions x two magnitudes of reinforcement) of eight rats each. One group had only seven rats. The animals were matched for weight. The four tensions that were examined were the following: 20 g, 40 g, 60 g, 80 g. The two levels of reinforcement were two 45 mg Noyes pellets (small) and eight 45 mg Noyes pellets (large) per response. The rats were run in squads of four.

Wheel adaptation.

Each rat was placed in a free running wheel (FRW) for a period of 8 min per day for two days. A FRW is a wheel that required 12.5 g of tangential force in order to turn. The FRW was braked only when the rat was first placed in the wheel -- before the start of the timed session -- and at the end of the running period -- before the rat was removed from the wheel. During the 8 min period the rat was required to move the wheel
at least every 30 sec. If the wheel did not move within 30 sec the wheel was turned by hand one full revolution.

**Magazine training.**

A modified magazine training procedure was used. The rats received reinforcement for running. Each rat was placed in the FRW and was required to run eight reinforced trials. A trial was defined as the rat running a criterion distance (CDIST) of 240 cm. The reinforcement the rat received was appropriate for its group, meaning that if the rat was in a high reward group it received eight 45 mg Noyes pellets per trial and if the rat was in a low reward group it received two 45 mg Noyes pellets per trial.

Magazine training lasted 4 days. At that time all of the rats were eating the Noyes pellets in the running wheel. Shaping then began.

**Shaping.**

The tension on the wheels was gradually increased over a period of five days. The increases in the wheel tension were proportional to the final wheel tension at which the rat ran during acquisition and extinction. For example, for a rat who was in an 80 g group the intermediate tension levels were 20 g, 40 g, 40 g, 60 g, and 80 g for days 1 through 5 respectively. For a rat who was in a 60 g group the intermediate tension
levels were 15 g, 30 g, 30 g, 45 g, and 60 g for days 1 through 5 respectively. The rats were required to run eight trials per day. The trials were the same as those described in the magazine phase above. Acquisition then began.

Acquisition.

For days 1, 2, and 3 of acquisition the rats ran 2, 4, and 6 trials respectively. For the remainder of acquisition, the rats ran eight trials per day. At the start of a trial the light in the box housing the wheel had low illumination and the braking mechanism was disengaged. A trial consisted of the rat running the CDIST of 240 cm. As the rat approached the CDIST the intensity of the house light increased to a final high illumination as described in the apparatus section above. When the rat achieved the CDIST it received the reinforcement appropriate for its group, the house light was turned off and the wheel was braked for a one minute inter-trial-interval (ITI). At the completion of the ITI the next trial began. When the rat completed the eighth trial it was removed from the wheel and placed in the transport cage. Acquisition continued until stable running rates (statistically defined) were achieved in each group. This took 24 days. At the end of acquisition the rats received extinction trials.
Extinction.

The procedure for extinction was the same as that used during acquisition with the following modifications. The rats did not receive reinforcement upon completion of the CDIST. The rats were given a maximum time of 5 min to run the CDIST for each trial. The extinction phase continued until the running response was extinguished. The running response was said to be extinguished if the rat's behavior met one of the following three criteria: It did not run in the wheel at all; it failed to complete any of the eight daily trials within the allotted 5 min criterion; running speeds fell below the initial speeds taken during shaping. Extinction lasted 12 days.

During acquisition and extinction the time it took the rat to run the CDIST was measured. There were eight different measurements taken at regular intervals (every 30 cm) of the CDIST.

Results

Acquisition

A 2(magnitude of reinforcement) x 4(effort level) x 5(day) x 8(octile) split plot analysis of variance was conducted on the mean running times for the eight daily trials of the last five days of acquisition. The analysis revealed significant differences for the main
effects of magnitude of reinforcement [F (1, 55) = 25.66, p < .05] indicating that the large reward group was running faster than the small reward group, effort level [F (3, 55) = 3.47, p < .05] indicating that the high effort groups were running faster than the lower effort groups, and octile [F (7, 385) = 126.6, p < .05] indicating that the running times for the first octile and the last two octiles were lower than the running times for the middle octiles. The analysis also revealed three significant 2-way interactions: day x effort level [F (12, 220) = 1.99, p < .05], octile x magnitude of reinforcement [F (7, 385) = 7.02, p < .05], and octile x effort level [F (21, 385) = 2.31, p < .05]. No other interactions were significant (see Table 1). Tukey's HSD multiple comparison test was used to analyze the interactions.

Day x Effort Level. Tukey's HSD post hoc analysis conducted on the day x effort level interaction (see Figure 1) revealed that the 80 g group was running faster at the end of acquisition than the three lower tension groups. It also revealed that the 20 g group was running slower than the three higher tension groups, however this effect was not consistent across all days.

For day 1 the mean running time for the 40 g group was significantly greater than the mean running time
for the 80 g group. All other comparisons for day 1 were not significant. For days 2 and 3 the mean running times for the 20 g group were significantly greater than all other groups, and the mean running times for the 60 g group were significantly greater than the mean running times for the 80 g group. No other comparisons for days 2 and 3 were significant. For day 4 the mean running time for the 80 g group was significantly lower than all other groups and for day 5 the mean running time for the 20 g group was significantly greater than all other groups. No other comparisons for days 4 and 5 were significant.
For the 20 g group the mean running times for days 1 and 4 were significantly lower than the mean running times for days 2, 3, and 5. For the 40 g, 60 g, and 80 g groups there were no differences within each group across days.

**Figure 2** Octile x magnitude interaction in acquisition.

**Octile x Magnitude.** Tukey's HSD post hoc analysis conducted on the octile x magnitude of reinforcement interaction (see Figure 2) indicated that for five of the eight octiles the two-pellet groups were running slower than the eight pellet groups, for the remaining three octiles there were no differences between the groups.
For octiles 1, 5, 6, 7, and 8 the mean running time for the two-pellet group was significantly greater than the mean running time for the eight-pellet group. There was not a significant difference between the two-pellet group and eight-pellet group for octiles 2, 3, and 4.

For the two-pellet group, the mean running times for octiles 1, 7, and 8 were significantly different than each other and all other octiles. The only other significant difference between the octiles for the two-pellet group was between octiles 3 and 6 in which the mean running time for the third octile was significantly lower than the mean running time for the sixth octile.

For the eight-pellet group the mean running time for octile 1 was significantly greater than the mean running time for all other octiles. The mean running time for octile 8 was significantly different than all other octiles except octile 7. The differences here were such that the mean running time for octile 8 was significantly greater than octiles 2, 3, 4, 5, and 6 and the mean running time for octile 8 was significantly lower than the mean running time for octile 1. For the eight-pellet group there were no other significant differences.

Octile x Effort level. Tukey's HSD post hoc
analysis conducted on the octile x effort level interaction (see Figure 3) indicated that the 20 g and 40 g groups completed the first octile before the 60 g and 80 g groups, there were no speed differences between the groups in the second octile, and for octiles 3 through 8, the higher tension groups were running faster than the lower tension groups.

In comparing the 20 g group with the other groups it was found that the only significant difference in the mean running times between the 20 g and 40 g groups occurred in octile 3 where the 20 g group had a mean running time that was higher than the mean running time
of the 40 g group. The mean running time in octile 1 for the 20 g group was significantly lower than the mean running time in octile 1 for the 60 g group while the mean running times in octiles 3, 4, 5, and 6 for the 20 g group were significantly higher than the mean running times in octiles 3, 4, 5, and 6 for the 60 g group. Across all octiles the mean running times for the 20 g group were significantly different than the mean running times for the 80 g group with the mean running time in octile 1 being higher for the 80 g group as compared to the mean running time in octile 1 for the 20 g group and the mean running times for all other octiles being lower for the 80 g group as compared to the mean running times for the 20 g group.

In comparing the 40 g group with the other groups it was found that in octile 1 the mean running time for the 40 g group was significantly lower than the mean running times for the 60 g and 80 g groups. In octiles 5, 6, and 8 the mean running times for the 40 g group were significantly higher than the mean running times for the 80 g group.

The only significant difference between the 60 g and 80 g groups occurred in octile 7 in which the mean running time for the 60 g group was higher than the mean running time for the 80 g group.

Within each effort level the mean running time for
octile 1 was significantly higher than all other octiles and the mean running time for octile 8 was significantly higher than the mean running times for octiles 2 through 7. Additional significant differences in the mean running times of the octiles for the 20 g group were between octile 2 and octiles 6 and 7 in which the mean running time for octile 2 was lower than the mean running times for octiles 6 and 7. For the 40 g group it was also found that the mean running time for octiles 2, 3, and 4 were significantly lower than the mean running time for octile 7. The other significant differences for the 60 g group were such that the mean running times for octiles 2 through 6 were significantly lower than the mean running time for octile 7. A similar trend appeared in the 80 g group where the mean running times for octiles 2 through 5 were significantly lower than the mean running time for octile 7.

**Extinction**

Due to the differences between the groups of the terminal acquisition times, the extinction data were converted into proportions of the average terminal acquisition times for the last five days of acquisition. Similar procedures have been used by Roberts (1969) and Wagner (1961). A 2(magnitude of reinforcement) x 4(effort level) x 12(day) x 8(octile)
split plot analysis of variance was conducted on the converted extinction data. The analysis revealed significant differences for the main effects of day \([F (11, 550) = 10.47, p < .05]\) indicating that across days the groups decreased their rates of running, and octile \([F (7, 350) = 50.56, p < .05]\) indicating that relative to their acquisition speeds the groups were running slower for the first few octiles and faster for the last octiles. There was a significant interaction for octile \(x\) magnitude \([F (7, 350) = 2.44, p < .05]\) and a significant interaction for day \(x\) octile \([F (77, 3850) = 1.84, p < .05]\). No other main effects or interactions were significant (see Table 2). Tukey's HSD multiple comparison test was used to analyze the interactions.

Octile \(x\) Magnitude. Tukey's HSD post hoc analysis conducted on the octile \(x\) magnitude of reinforcement interaction (see Figure 4) revealed that the rate of running in extinction for the first five octiles for both groups was at or below the rate of running in acquisition. The rate of running in extinction for the last three octiles was faster than the rate of running in acquisition and the differences between the two-pellet group and the eight-pellet group occurred in the seventh and eighth octiles. The two pellet group was running at a rate that was faster than the eight-pellet
group relative to their acquisition times.

For the two-pellet group the mean proportion of the running time for octile 1 was lower than the mean proportions of the running times for octiles 5, 6, 7, and 8. The mean proportion of the running times for octile 2 was significantly lower than the mean proportions of the running times for octiles 6, 7, and 8. The mean proportions of the running times for 3, 4, 5, and 6 were significantly lower than the mean proportions of the running times for octiles 7 and 8.

For the eight-pellet group the mean proportion of the running times for octile 1 was lower than the mean
proportions of the running times for octiles 5, 6, 7, and 8. The mean proportions of the running times for octiles 2, 3, and 4 were significantly lower than the mean proportions of the running times for octile 7 and 8. The mean proportions of the running times for octiles 5 and 6 were significantly lower than the mean proportion of the running times for octile 8.

Figure 4 illustrates the octile x magnitude of reinforcement interaction obtained in the transformed running times in extinction. It also illuminates the comparison between the running times for acquisition and extinction. Any point below 1.0 on the y-axis indicates that the running time in extinction was higher (slower speed) than the running time in acquisition and any point above 1.0 on the y-axis indicates that the running time in extinction was lower (faster speed) than the running time in acquisition. Further inspection of Figure 4 indicates that for octiles 1 through 4 the two-pellet group's running times in extinction were higher than the running times for the last five days of acquisition, while for octiles 5 through 8 the running times for extinction were at or below the running times in acquisition. The eight-pellet group's running times in extinction for octiles 1 through 5 were higher than the running times in acquisition, while for octiles 6 through 8 the
running times for extinction were at or below the running times in acquisition. In other words, the groups were running slower in extinction for the first half of the response and faster for the second half of the response as compared to the running rate in acquisition.

**Day x Octile.** Tukey's HSD post hoc analysis conducted on the day x octile (see figures 5 & 6) interaction revealed the following: Across days the groups reduced their running speeds, this reduction was more pronounced for the first octiles and virtually

![Graph](image_url)  
**Figure 5** Day x octile interaction in extinction using the acq/ext time ratio.

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nonexistent for the final octiles.

For day 1 the mean proportions of the running times for octiles 1, 2, and 4 were significantly less than the mean proportions of the running times for octiles 7 and 8.

For days 2 and 7 the mean proportions of the running times for octiles 1, 2, 3, 4, 5, and 6 were significantly less than the mean proportions of the running times for octiles 7 and 8, and the mean proportion of the running time for octile 1 was significantly less than the mean proportion of the running time for octile 6.

For day 3 the mean proportion of the running time for octile 1 was significantly less than the mean proportions of the running times for octiles 5, 6, 7, and 8. The mean proportions of the running times for octiles 2 and 3 were significantly less than the mean proportions of the running times for octiles 6, 7, and 8. The mean proportions of the running times for octiles 5 and 6 were significantly less than for octiles 7 and 8.

For day 4 the mean proportion of the running time for octile 1 was significantly less than the mean proportions of the running times for octiles 5, 6, 7, and 8. The mean proportions of the running times for octiles 2, 3, 4, 5, and 6 were significantly different
from the mean proportions of the running times for octiles 7 and 8. A significant difference was also found between the mean proportions of the running times for octiles 7 and 8.

For day 5 the mean proportion of the running time for octile 1 was significantly less than the mean proportions of the running times for octiles 5, 6, 7, and 8. The mean proportions of the running times for octiles 2 and 4 were significantly less than the mean proportions of the running times for octiles 6, 7, and 8. The mean proportions of the running times for octiles 3, 5, and 6 were significantly less than the mean proportions of the running times for octiles 7 and 8.

For day 6 the mean proportions of the running times for octiles 1, 2, and 4 were significantly less than the mean proportions of the running times for octiles 6, 7, and 8. The mean proportions of the running times for octiles 3 and 5 were significantly less than the mean proportions of the running times for octiles 7 and 8. Octile 8 had a mean proportion of the running times that was significantly greater than octiles 6 and 7.

For day 8 the mean proportion of the running times for octile 1 was significantly less than the mean proportions of the running times for octiles 5, 6, 7,
and 8. The mean proportion of the running times of octile 2 was significantly less than the mean proportions of the running times for octiles 6, 7, and 8. The mean proportions of the running times for octiles 3, 4, and 5 were significantly less than the mean proportions of the running times for octiles 7 and 8. There was also a significant difference between the mean proportions of the running times for octiles 6 and 8.

For day 9 the mean proportion of the running times for octile 1 was significantly less than the mean proportions of the running times for octiles 3, 6, 7, and 8. The mean proportion of the running times for octile 2 was significantly less than the mean proportions of the running times for octiles 6, 7, and 8. The mean proportions of the running times for octiles 3, 4, and 5 were significantly less than the mean proportions of the running times for octiles 7 and 8. There was also a significant difference between the mean proportions of the running times for octiles 6 and 8.

For day 10 there was a significant difference between the mean proportions of the running times for octile 1 when compared with octiles 3, 4, 5, 6, 7, and 8. Octile 2 had a mean proportion of the running times that was significantly different than octiles 5, 7, and
8. The mean proportions of the running times for octiles 3 and 4 were significantly less than the mean proportions of the running times for octiles 7 and 8. There was also a significant difference between the mean proportions of the running times for octiles 5 and 6 when compared with 8.

For day 11 the mean proportion of the running times for octile 1 was significantly less than the mean proportion of the running times for octiles 5, 6, 7, and 8. The mean proportions of the running times for octiles 2 and 3 were significantly less than the mean proportions of the running times for octiles 7 and 8. There was also a significant difference between the mean proportions of the running times for octiles 4, 5 and 6 when compared with octile 8.

For the last day of extinction, the mean proportion of the running times for octile 1 was significantly lower than the mean proportions of the running times for octiles 3, 4, 5, 6, 7, and 8. The mean proportions of the running times for octiles 2, 3, and 4 were significantly less than the mean proportions of the running times for octiles 7 and 8. There was also a significant difference between the mean proportions of the running times for octiles 5, 6 and 7 when compared with octile 8.

For octile 1 there were significant differences
between the mean proportions of the running times when comparing day 1 with days 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12, and when comparing day 2 with day 6, 10, 11, and 12. For octiles 2 and 3 there were significant differences between the mean proportions of the running times when comparing day 1 with days 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12, and when comparing day 2 with day 11. For octile 4 there were significant differences between the mean proportions of the running times when comparing day 1 with days 4, 5, 6, 7, 11, and 12, and when comparing day 2 with day 11. For octile 5 there were significant differences between the mean proportions of the running times when comparing day 1 with days 4, 6, 7, 8, 9, 10, 11, and 12, and when comparing day 2 with days 6 and 11. For octile 6 there were significant differences between the mean proportions of the running times when comparing day 1 with days 4, 5, 6, 7, 8, 9, 10, 11, and 12, and when comparing day 11 with days 3, 5, 6, and 9. The differences in the mean proportions of the running times for octile 7 occurred between days 1 and 2 when compared to days 10, 11, and 12, and day 11 when compared with days 3, 4, 5, 6, 8, and 9. For octile 8 there were significant differences between the mean proportions of the running times when comparing day 8 with days 4 and 6, and when comparing day 11 with days
Discussion

Aiken (1957), Applezweig (1951), and Solomon (1948a) have found that the more effort it takes to perform a response, the longer it takes to acquire the response and therefore it was predicted that this would occur in the present study. As Figure 6 depicts, the acquisition of the response was not delayed for the high effort groups in this study. One possible explanation for the lack of delayed learning for the higher effort groups in this study is that wheel running is an activity that is reinforcing for the rats (Collier and Hirsch, 1971). In the studies that found differences in acquisition rates between the various effort levels, the response that was required -- bar pressing and jumping -- was one in which the rats will not engage spontaneously and the animal must be shaped to perform it. Rats will engage in running in a running wheel spontaneously; during the wheel adaptation phase of the present experiment, the rats ran on average 35 m per session. The shaping used in this equipment was necessary in order to insure running under increased effort. It is possible that the differences in the types of the response that the subjects were required to perform have led to the discrepancy in the findings between this study and the
Figure 6a Total times; 20 g

Figure 6b Total times; 40 g

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**Figure 6c** Total times; 60 g

**Figure 6d** Total times; 80 g
previous research (Aiken, 1957; Applezweig, 1951; Solomon, 1948).

This study failed to replicate the finding that there is slower acquisition of a response due to higher effort requirements and it was in direct opposition to Applezweig's (1951) finding that significantly fewer animals were able to learn to bar press under higher effort conditions. In the present study, there were more problems associated with training the animals in the lowest effort group as compared to the higher effort groups. During the magazine training and shaping procedures, a few of the rats in the 20 g groups would not run for several of the trials, whereas all of the rats in the higher effort groups were successfully completing the trials. This aberrant behavior of those few rats was even apparent in the first few days of acquisition as is shown in Figure 5. In fact, this group's slow acquisition rate was the main contributor to the day x effort level interaction obtained in acquisition. Lewis (1964) had a similar finding. In his study the rats that were required to pull an 80 g weight down a runway acquired the running response faster for food reinforcement than rats that were required to pull a 5 g weight. Lewis's explanation for this is that the rats who were required to pull the heavier weight did less exploring in the
runway and therefore learned to complete the required distance sooner that the rats who were required to pull the lighter weights.

The differences obtained in the behavioral features across the effort levels can also be used to explain the lack of support for the prediction that effort would be inversely related to asymptotic running speeds. While there was a significant main effect for effort, it was not in support of Solomon's (1948a) findings that increased effort led to depressed asymptotic performance. In the current study it was found that the asymptotic running speeds of the rats in the 80 g group were significantly faster than the asymptotic running speeds of the rats in the 20 g group. Lewis (1964) also found that rats required to perform a more effortful task had higher asymptotic running speeds than rats required to perform a less effortful task. Lewis proposed that his low-effort animals, "... acquired responses which were inconsistent with the behavior of moving forward to the goal area..." (p. 372).

The discrepancy between the findings of the Solomon (1948a) study and the Lewis (1964) study and the current study can be resolved when one examines the types of responses and the measurement of the responses used in each of the studies. Solomon had his rats jump
to escape shock; this type of response requires a very brief burst of energy that need not be sustained for any appreciable length of time. The measurement that Solomon used was the latency to onset of the jumping response. The responses examined by Lewis (1964) and the current study were running responses which last for several seconds. The measurements used in these two studies were running times. The differences in response features and measurement techniques may not allow for a direct comparison of the studies. However, if one examines a portion of the response of the current study that is analogous to the required response in the Solomon study, then the results of these two studies do not conflict with each other. By examining the first octile -- the first 30 cm -- of the response in the running wheel (see Figure 2) it is apparent that the lower effort groups completed this portion of the criterion distance faster than the high effort groups. This difference between the groups, in fact, reached statistical significance as was discussed earlier. Thus, it is only when the response must be sustained that the findings of these studies become inconsistent.

The fact that the running speeds observed in the first potion of the response are different than those observed on the middle and last portion of the response
indicates that there is a non-linear behavioral profile for the response. This profile, as seen in acquisition, resembles a backward "J" (e.g. figures 2 and 3). Similar behavioral profiles have been found in other research conducted in the running wheel and in longer runways. Crespi (1942) found a comparable behavioral profile using a 20 ft runway. The interpretation of this is that for more effortful running responses (increased tension on a running wheel or longer distances in a runway) there is some behavioral inertia during the first portion of the response and an anticipation of the end of the response. In the running wheel, the increased latency to complete the first octile is indicative of the behavioral inertia. Anticipation of the end of the response manifests itself in the increased time required to complete the last two octiles. This behavioral profile develops and stabilizes during acquisition and changes in extinction. These changes in extinction will be discussed shortly.

With regard to the effects of magnitude of reinforcement on the performance of a response in acquisition it was expected that the asymptotic running speeds would be a product of the amount of reward such that animals receiving high reward magnitude would have higher asymptotic running speeds than those receiving
low reward magnitude. This prediction was derived from
the literature regarding magnitude of reinforcement
(Armus, 1959; Crespi, 1942, 1944; Hill and Wallace,
1967; Metzger, Cotton, & Lewis, 1957; Reynolds, 1950;
Reynolds and Pavlik, 1960; Wagner, 1961; Zeaman, 1949)
and from previous research that has been done in the
running wheel. The results of the present study
support this prediction. As was mentioned earlier,
there was a significant main effect for magnitude of
reinforcement in acquisition indicating that animals
receiving larger reinforcement had lower running times
than those of the animals receiving small reinforcement
(see Figure 7). Theories relating to drive and
incentive motivation have been used to explain this
effect (e.g. Amsel, 1967; Crespi, 1942).

In extinction, it was expected that effort level
would not have an effect on the rate of extinction and
in fact it did not affect extinction. This finding
supports the findings of Aiken (1957), Applezweig
(1951) and Maatsch et al. (1954) with regard to animals
who have been extinguished at the same level of effort
at which they had been trained.

Three important findings arose from the effect
that magnitude of reinforcement in acquisition had on
extinction. These findings will be discussed in this
order: First, the typical runway finding was not
supported. Second, there was an interaction between magnitude of reinforcement and octile. Finally, it appears that only part of the running response was extinguished.

There is an inverse relationship between magnitude of reinforcement and resistance to extinction in a runway situation (Armus, 1959; Ison and Cook, 1964; Metzger et al., 1957; Ratliff and Ratliff, 1971; Reynolds, 1950; Wagner, 1961) and it was predicted that this relationship would be prevalent in the running wheel. This prediction was not supported; there was no difference in the rate of extinction for the different magnitudes of reinforcement. This indicates that the running wheel response, taken as a whole, is not analogous to a runway situation.

There was, however, an octile x magnitude of reinforcement interaction in extinction. The occurrence of this interaction indicates that the rats redistributed their running response relative to their acquisition responding as a function of the amount of reinforcement they had received in acquisition. Figure 4 depicts the profile of the response for the two magnitude of reinforcement groups relative to their acquisition responding. It can be seen that for octiles 1 through 5 the running times for extinction were at or below the running times in acquisition, and
there are no differences between the groups. In octiles 7 and 8, however, the groups diverge: The amount of difference between the relative running rates reached statistical significance as was discussed in the results section. The support for this divergence in the last two octiles can be found in Wagner (1961). Wagner indicated that for the final quartile of the runway -- the goal box portion -- rats receiving small reward were more resistant to extinction than were rats receiving large reward. The seventh and eighth octiles -- the final quartile -- in the running wheel are analogous to the goal portion of Wagner's runway. The findings in the running wheel with regard to this portion of the criterion distance in extinction also indicate that the small reward group was more resistant to extinction. The two-pellet group increased their rates of running relative to their acquisition rates more than the eight-pellet group increased their rates of running relative to their acquisition rates. It is possible that the cues that are available at the time (in Wagner's experiment the cues would include the goal box itself, and in the present experiment, the cues would include the intensity of the light) produce a greater frustration in the rats receiving large reward because relatively more is being withheld from them as compared to the rats receiving the small reward.
It is rather peculiar, though, that rats in the running wheel would actually be running faster at the end of the response in extinction than they had been running in acquisition. It is as though only the beginning of the response had been extinguished (this can be clearly seen in Figure 5 and Figure 6). In order to resolve this, a detailed examination of what happens during an extinction trial may be helpful. The ITI from the previous trial ends and the rat is faced with the beginning of a new trial. The trial is signaled by the light coming on and the brake releasing. However, the rat's responding is inhibited because it had just experienced non-reward on the previous trial, which may cause the animal to delay responding. However, the rat eventually starts moving and with enough movement, the wheel begins to turn. Once the turning motion has started the rat experiences the reinforcing properties of running and completes the trial.

But why does the rate of running, at the end of the response, increase so dramatically -- above and beyond the rate of running in acquisition? As the rat nears the end of the criterion distance, it receives the cues that it is almost finished with the trial. The reinforcing properties that wheel running has may be interacting with the frustration of non-reward and the
result could be that the rat runs at a faster rate just to finish the trial at which point there is a cessation of the competing motivations. In other words, there may be a conflict occurring due to the pleasure associated with wheel running and the aversiveness associated with non-reward. The only way for the conflict to be resolved is for the rat to finish the trial. This analysis is consistent with predictions made by Amsel's (1967) frustration theory.

Trapold, Miller, and Coons (1960) studied similar approach-avoidance conflicts in rats' running behavior. They trained their animals to run down a 100 ft runway for food reward. When stable running was achieved, the rats then experienced shock in the goal box. They found that under conditions of low motivation (relatively few hours of food deprivation) the rats would not complete the run. Under conditions of high motivation (up to 24 hours of deprivation) all of the animals finished the trials. This suggests that the there is a point at which approach will outweigh avoidance. It appears that for the behavior of running in the running wheel, under the conditions examined in the present study, the reinforcing properties of running are stronger than the frustration of non-reward.

The findings of the current study pose many
questions. The first question to be contemplated is whether or not the running wheel can be used as an analogue to the runway situation. While the findings in the running wheel in acquisition may mimic runway findings, those in extinction do not. One possible reason for this involves the nature of the responses. A rat running in a runway can attain speeds over 120 cm/sec; the behavior is a burst of movement. In the running wheel under the conditions used in the present study, the asymptotic running speeds reached are roughly 40 cm/sec; the behavior is a loping response. It is possible that the nature of the response in the running wheel is too disparate from the response seen in the runway. A second possible reason for the discrepancy between the findings in the runway and in the running wheel involves the amounts of reinforcement used. While two pellets and eight pellets are sufficient to produce a magnitude of reinforcement effect in the runway, these specific magnitudes may not be sufficient to produce the same effects in the running wheel. In order to determine whether or not runway running and wheel running are analogous behavioral responses, further research should be conducted in the running wheel. Shorter distances, no tension on the wheel, and larger magnitudes of reinforcement may be necessary to demonstrate that
wheel running and runway running can be comparable responses.

It is recognized that the current experiment is not a parametric study with regard to the effects of effort, therefore only limited conclusions can be drawn. The amount of effort does influence responding. This influence emerged in acquisition as faster running speeds for animals running under increased effort and as a differential response pattern across the effort level. Effort did not appear to influence extinction responding. Subsequent research on the effects of effort should compare effort levels above and below those used in the present study and examine the possible interactions that may occur between effort and distance.
References


rate. Journal of the Experimental Analysis of Behavior, 8(1), 1-7.


Table 1

ANOVA for the average daily octile running times in acquisition.

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Table 2

ANOVA for the converted extinction data.

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