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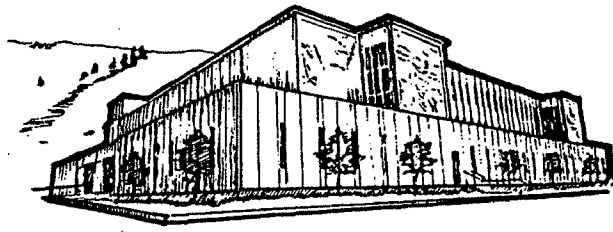
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THE EFFECT OF DIFFERENT FORCE REQUIREMENTS ON THE
PARTIAL REINFORCEMENT EXTINCTION EFFECT:
A RUNNING WHEEL STUDY

By

Robert Foss

B.A., University of Montana, 1988

Presented in partial fulfillment of the
requirements for the degree of

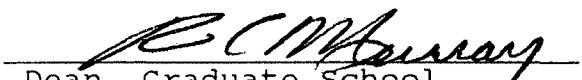
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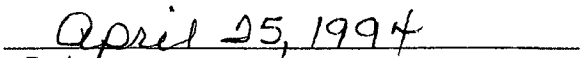
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ABSTRACT

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Experimental Psychology

The Effect of Different Force Requirements on the Partial Reinforcement Extinction Effect: A Running Wheel Study (pp.)

Director: Nabil F. Haddad, Ph.D.

The present experiment was designed to examine the interaction of effort and reward percentage and to determine their effects in an automated running wheel. Sixty male albino rats of the Sprague-Dawley strain were shaped to run 8 trials per day, each trial consisting of running 240 cm under four tension levels (20 g, 40 g, 60 g, 80 g tangential force applied to the rim of the wheel) for either continuous or partial (50% schedule) reinforcement. A computer controlled reinforcement delivery, the house light brightness, and the brakes used to institute 1 minute intertrial intervals. The computer also recorded the time it took the animals to run each octile of the required distance.

The rats were matched by weight before assignment to their respective groups. After 30 days of running, the animals were placed on extinction for 10 days. An examination of the octiles of the running times revealed that the greatest change in performance was found in the first and sometimes the last octile of the distance. There was a significant tension effect in acquisition, but tension played no part in the extinction results. Reward condition played a significant role in both acquisition and extinction results. A very small partial reinforcement effect was found in the extinction results, supporting the robustness of this finding in other studies.

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Introduction

With few exceptions, there has been little research done on the effect of force on the acquisition or extinction of effortful tasks. Particularly lacking is research on how force requirements may affect the partial reinforcement effect (PRE). This paper seeks to address this issue.

Effort has been variously defined as cost per unit of time (Solomon, 1948a), distance run (Larson & Tarte, 1976; Solomon, 1948b; Waters, 1937; Wong & Amsel, 1966), amount of performance per reinforcer, (Eisenberger, Carlson, & Frank, 1979; McCuller, Wong, & Amsel, 1976), amount of force required to press a bar (Applezweig, 1958; Capehart, Viney, & Hulicka, 1958; Kanarek & Collier, 1973; Keehn, 1981; Mowrer & Jones, 1943; Viney & Jacobson, 1977; Young, 1966), force necessary to push a door open (Aiken, 1957), force required to peck a key (Chung, 1965), force required to turn a wheel (Collier, Hirsch, Levitsky, & Leshner, 1973), force required to run in an inclined treadmill (Collier, et al., 1973; Collier & Levitsky, 1968), force required to climb an inclined runway (Johnson & Viney, 1970), degree of difficulty in obtaining food (Eisenberger, Masterson, & Over, 1982).

Each of these definitions uses the concept of energy expenditure in the accomplishment of some task. The greater the effort requirement of a task, the greater the energy expenditure. Energy may be expended in two ways, overcoming

a state of inertia, such as beginning to run in a runway, and by maintenance of a state of inertia once it has been achieved, as in the section of a runway in which running speed is maintained. Force will be defined in this paper as the amount of energy required to produce a change in state or inertia. Thus, in the above example, there will be two times when force is applied; at the beginning of the runway when the animal accelerates to running speed, and at the end of the runway when the animal decelerates as it approaches the goal box.

Effort

One of the earliest studies in which the effect of effort on a task was investigated was done by Mowrer and Jones (1943), who postulated that "the rate at which a rewarded response extinguishes is highly (negatively) correlated with the effortfulness of that response." The assumption was that increased effort requirement increased fatigue in the subject and that this led to lower resistance to extinction. Using a bar-press paradigm, Mowrer and Jones set the force required to press the lever across three groups, the requirement being 5, 42.5, and 80 g. All subjects were trained to reliable responding and then put on extinction. The 5 g group mean response rate per session in extinction was 350; for the 42.5 g group the mean was 248 responses, and for the 80 g group the mean was 111 responses, clearly supporting their hypothesis.

Mowrer and Jones also noticed that the 42.4 and 80 gram groups showed more erratic behavior during extinction, "...excessively vigorous pressing of the bar, gnawing..., jumping and other agitated behavior." It was speculated that this was due to frustration due to no reward.

Solomon (1948) followed Mowrer and Jones with a confirmation of their findings but used a different preparation in which rats were required to jump across a gap of either 8" or 16". The 16" group extinguished much faster than the 8" group" with the 8" group failing to extinguish at all in the first set of extinction trials.

Applezweig (1951) used a preparation in which five groups of twenty rats each were all trained at five levels of bar-press effort (10 g, 20 g, 30 g, 40 g, & 50 g) for water reinforcement. After fifty continuously reinforced (CR) trials, some of the rats were randomly divided into five groups of four each and placed on extinction at one of the effort levels. The results showed that performance was dependent on the level of effort required during training as well as the effort level in extinction. The group most resistant to extinction was the one group trained with 40 g and then extinguished with 10 g. However, another finding was that, if effort was the same for both acquisition and extinction, performance in extinction was negatively related to the effort requirement.

There was criticism of the study of Mowrer and Jones on methodological grounds. Maatsch, Adelman and Denny (1954) pointed out that the 5 g group had received a much higher number of reinforcements during training than subjects in the other two effort groups and this could have resulted in the higher response rates during extinction. When the number of reinforcements was controlled, the differences in extinction disappeared. However, careful examination of the preparation used by Maatsch, et al., (1954) reveals that the 5 g and the 40 g groups had far more experience at their respective levels of effort than did the 80 g group. This confounding was addressed by Aiken (1957), who also criticized Applezweig's (1951) replication of the earlier Mowrer and Jones (1943) findings. Applezweig (1951) had eliminated a large number of subjects from his analyses for their failure to acquire the response. When Aiken (1957) controlled for the number of training trials and for subject selection, all differences in extinction performance became nonsignificant.

These findings were not supported by Capehart, Viney, and Hulicka (1958). In their preparation, subjects were trained with thirty trials at all levels of bar-press effort and then divided into three equated groups of 5 g, 40 g, and 70 g. The groups were then placed on extinction. Results showed significant differences between groups across the two days of extinction trials based on thirty minutes of free

responding to the lever, with the high effort group extinguishing sooner.

These and other early investigations, although replete with procedural problems, seemed to agree on three findings. Each will be examined in turn and more current findings will be added.

1. Responses requiring more effort take longer to learn (Mowrer & Jones, 1943; Applezweig, 1951; Maatsch, et al., 1954; Aiken, 1957). Mowrer and Jones (1943) found that the average time it took for subjects to make the required number of bar-press responses to obtain 20 reinforcements (continuously reinforced) at each force level was 5.18 min for the 5 g group, 7.24 min for the 30 g group, 8.28 min for the 55 g group, and 19.07 min for the 80 g group.

Solomon (1948a) also found that increased effort in acquisition results in slower learning of the response and lower asymptotic performance levels than those of animals trained under lower effort requirements. This finding was supported by Aiken (1957), who found that rats required to overcome a force of 55 g to open a door for food access took longer to acquire the response than rats which had to overcome a 5 g force. Applezweig (1951) found that learning took longer under higher effort conditions, but was able to obtain identical asymptotic performance for both low and higher effort requirements. The identical asymptotic performance has been replicated in only one other

experiment. Lewis (1964) found rats trained under higher effort requirements actually outperformed rats trained under a low effort requirement at asymptote. This finding is confounded with magnitude of reward, however.

2. Higher effort responses will result in more erratic behavior and may result in failure to acquire the behavior. Mowrer and Jones (1943) noted that, in extinction, subjects in the higher effort groups were more erratic in responding and engaged in "excessively vigorous pressing of the bar, gnawing at the guards and other parts of the apparatus, jumping and other agitated behavior." Applezweig (1951) found that the number of partial level presses (not sufficient to activate the mechanism) increased with increased force requirements, and that the overall behavior was very different when force requirements were low. Applezweig (1951) additionally dropped 33 animals from his study for failure to acquire the response. The force requirements were 10 g, 20 g, 30 g, 40 g, 50 g, and the number of animals were eliminated for each force requirement were 1, 2, 3, 10, 17, respectively. Thus, at a 50 g force requirement, 46% of the animals failed to acquire the response.

3. If everything else is held constant, the higher response effort requirements in acquisition and/or extinction will lead to earlier extinction than lower response effort requirements (Applezweig, 1951; Solomon,

1948b).

Johnson and Viney (1970) examined the role that effortful responding during acquisition plays in extinction performance. They cited several studies which showed that animals trained on a certain effort level and then extinguished on a different effort level tend to be less resistant to extinction than animals trained and extinguished on the same effort level. They hypothesized that a) resistance to extinction is inversely related to effort requirements in acquisition and extinction; b) animals trained with heavy effort requirements and then extinguished under light effort requirements will be more resistant to extinction than animals trained with light effort requirements and extinguished under heavy effort requirements; c) animals working under heavy effort in both acquisition and extinction will be less resistant to extinction than animals working under light effort requirements in both acquisition and extinction.

To test these predictions, rats were trained in a runway preparation where the runway was either horizontal (0 deg.) or inclined to an angle of 40 degrees. Four of the groups used were trained and extinguished under the following effort (defined as inclination angle of the runway) conditions: 0-0, 0-40, 40-0, 40-40. The results showed that the 0-0 group was most resistant to extinction with a mean of 40.4 responses in extinction, and that the

4040 group was the least resistant to extinction of all of the groups with a mean response of 14.6 in extinction.

This study also examined differences between animals experiencing all effort levels in training (e.g., Mowrer & Jones, 1943) and animals experiencing only one effort level in training (e.g., Applezweig, 1951). Two groups of subjects were trained on both 0 and 40 degree inclinations and then one group was extinguished at 0 degrees and the other at 40 degrees. The animals extinguished at 0 degrees were far more resistant than the 40-degree animals.

This may not be a robust finding, however. Aiken (1957) used a preparation in which rats were required to push a door open to obtain food. He used two force levels by weighting the door with either five (L) or fifty (H) grams. Aiken found that animals trained and extinguished at the same effort level (L-L; H-H) performed about the same in extinction. Animals trained on low effort and switched to high effort in extinction (L-H) were least resistant; animals trained under high effort and placed on low effort in extinction (H-L) were superior in resistance to extinction to all other groups.

It is difficult to assess the reasons for these different results since the preparations were so different (nose press effort vs. runway inclination). It could be hypothesized that the differences could result from the

different force requirements, different preparations, or different response systems used in these studies. Furthermore, the original hypothesis (Applezweig, 1951) that higher response effort requirements in acquisition and extinction lead to less resistance in extinction may be modulated by other variables such as force requirements or magnitude of reinforcement. Clearly, further research in this area is warranted.

Solomon (1948a) found that tasks requiring higher effort are less resistant to extinction. This finding was supported by Viney and Jacobson (1977), who used either 30 or 90 training trials and trained rats to run in either a level or 40 degree inclined runway. After training the four original groups (0-30, 0-90, 40-30, 40-90) were divided and given 20 extinction trials at one of the inclination angles (0-30-0, 0-30-40, 0-90-0, 0-90-40, 40-30-0, 40-30-40, 40-90-0, 40-90-40). Results indicated an inverse relationship between resistance to extinction and effort requirements in extinction. No information concerning the relationship between acquisition effort and extinction resistance was reported.

Studies in which animals experience all levels of force in acquisition are equivocal. Johnson & Viney (1970) used two groups which were trained on both runway inclination angles (0, 40 degrees) and then extinguished at either 0 degrees or 40 degrees. The (0-40)-0 group was equally

resistant to extinction as the group experiencing only 0 degrees, and the (0-40)-40 groups was similar to the group experiencing only 40 degrees.

Capehart, et al., (1958) trained all animals to bar-press at all levels of bar force (5 g, 40 g, 70 g) and then placed them on extinction at one of the force levels. The number of responses observed in extinction was significantly lower for the 70 g group on both of the days that extinction trials were run. On the other hand, Maatsch, et al., (1954) found no differences in extinction resistance in rats trained at three different levels in a bar-press paradigm.

Evidence in this area seems to suggest that higher effort requirements in acquisition and/or extinction result in less resistance to extinction. Most of the studies have not specifically addressed this question, and as far as can be determined, none have addressed the question in preparations involving very high force requirements.

Research on Persistence

Applezweig (1951) found that animals trained under higher levels of effort tend to be more persistent in extinction at all levels of effort than animals trained under low effort requirements. Most early research does not support this finding (e.g., Maatsch, et al., 1954; Aiken, 1957). However, there is a significant amount of recent research that lends support to this claim.

In examining effort requirements across topologically divergent classes of behavior, McCuller, Wong, and Amsel (1976) found that, as the required number of lever presses for food increased, subsequent extinction performance of reinforced running in a runway increased. Eisenberger, Terborg, and Carlson (1979) found that rats required to make five runway shuttles per reinforcement later bar-pressed at a greater rate than rats reinforced after every shuttle response. The continuously reinforced group was in turn superior to a group that had received free food in the shuttle after magazine training. Eisenberge, Carlson, and Frank (1979) found that rats required to bar-press for reinforcement made more round trips in a runway than rats receiving free food. The second experiment in this study found that rats required to press a bar with high force requirements performed better in a shuttle situation than rats not required to press a bar.

Similar findings have been obtained using human subjects. Eisenberger, Heerdt, Hamdi, Zimet, and Bruckmeir (1979) used three groups of depressed psychiatric patients: High effort, low effort, and a control group. High effort patients received praise once from a ward attendant for completion of several cleaning and maintenance tasks in their ward. Low effort patients received praise after completion of each task. Control patients were not required to perform any task. High effort patients subsequently

persisted longer at a card-sorting task than either the low effort or control patients. Similar findings have been found by Eisenberger, Carlson, Guile, and Shapiro (1979), Eisenberger, Mitchell, McDermitt, and Masterson (1984), Eisenberger and Leonard (1980), Eisenberger, McDermitt, Masterson, and Over (1983).

A generalized hypothesis emerged from these investigations. Eisenberger, Carlson, Guile, and Shapiro (1979) proposed that "Effort customarily exerted in the successful performance of a reinforced behavior becomes a generalized component of instrumental behavior transferring to those quantitative dimensions of the transfer behavior which are monotonically related to reinforcement quantity, quality or rapidity."

Amsel (1972) also proposed a theory of general persistence based on frustration. He speculated that frustration from nonreinforcement could affect behavior in three ways: a) Nonspecific emotional and motivational effects resulting in increased vigor of behavior; b) frustration stimuli becoming associated with and controlling the direction of behavior, and; c) through conditioning of secondary anticipator frustration to stimuli accompanying nonreinforcement.

It was Amsel's assessment that persistence develops through counterconditioning of frustration (which should lead to less responding) to the performance of the response.

After careful examination, Amsel concluded that persistence in extinction was not controlled by external stimuli. Several studies (e.g., Ross, 1964) have demonstrated that the partial reinforcement effect can be carried at least across classes and perhaps within the classes of responses. Rats trained with partially reinforced bar-presses showed higher resistance to extinction of subsequently trained runway responding than animals that had not received the bar-press training. This effect was also obtained across different reinforcement modalities (e.g., water to food). Had persistence been influenced by external stimuli, such effects would not have been obtainable.

Since Amsel (1972) was unable to determine whether persistence generalizes, he suggested three alternatives: a) Persistence does not generalize, or b) persistence will transfer within a class of responses, or c) persistence transfers across classes of responses.

The work of Eisenberger and colleagues lends strong support to the suggestion that, at least in certain situations, persistence generalizes within a class of responses. There is, however, some evidence that persistence does not generalize across grossly divergent classes of behavior. Boyagin and Nation (1981) used a preparation in which transfer of effort was examined across similar and dissimilar situations. Human subjects were

trained to press a high- or low-effort bar to stop an aversive noise on either a partial or continuously reinforced schedule. In the transfer, part of the experiment half of the subjects in each of the four previous groups were trained to stop the same aversive noise in a shuttle paradigm. The other half were given anagrams to solve. Both situations were continuously reinforced. All groups were then placed on extinction.

Results indicated that transfer of effort to a similar task was more pronounced than transfer of effort to a dissimilar task. High-effort and partially reinforced groups were better and more persistent performers in all situations except anagram extinction, where there were no significant differences between groups. These results seem to indicate that there may be a limit to the difference in topography of response to which persistence transfers. Further investigation in this area is clearly warranted if the conditions under which generalized persistence occurs are to be understood.

Force and Distance As Variables

A careful examination of the literature and pilot work in our laboratory seems to indicate that force plays a far different role in behavior than distance. Additionally, other variables such as magnitude of reinforcement and deprivation level interact with force and distance requirements to make the picture even less clear.

Collier et al., (1975) used a preparation which examined the amount of spontaneous running in rats as a function of force and percentage body weight loss. They used two paradigms, a braked running wheel and an inclined treadmill fashioned out of a belt sander.

In the first experiment spontaneous work (defined as force * distance) was examined under four force requirements (5 g, 55 g, 105 g, 155 g). All animals had been deprived for seven days. Their results showed an increase in work done as force increased, with a total work done of 225 gm-Km at 105 g torque. However, as torque increased beyond this point, the amount of work done declined rapidly, resulting in the amount of work done at 155 g torque being about 150 gm-Km. These results seem to indicate that force when applied to behavior is an inverted U function. Low force requirements and very high force requirements resulting in less work done (decreased behavior), with more work at the middle range of force requirements.

It seems that distance requirements, on the other hand, affect work output in a much different way. Collier and Jennings (1969) found that rats trained to bar-press for a 64% sucrose solution would respond reliably on a fixed ratio (FR) of 320 presses per reinforcement. These results were replicated by Kanarek and Collier (1973). It might be argued that changes in FR schedules are basically changes in distance requirements in bar-press paradigms, with travel of

the bar being equated with distance. If this is so, then the above studies demonstrate reliable responding at very high distance requirements.

As far as can be determined, there are few studies which have examined the effects of high distance requirements on reinforced responding in a runway or in a running wheel. Seybert and Mellgren (1972) used a distance of 3.26 m in a runway and obtained reliable responding for 1-45 mg pellet. Petree (1991) used a running wheel preparation which required rats to run 9.14 m for 1 45 mg pellet of food. The force requirement in this case was also high (90 g tangential force required to turn a standing wheel). Conceivably, reliable responding could be achieved at much higher distances than this, especially if force requirements were kept very low.

Equally unresolved is the effect very high force has on performance. Pilot work has shown that, if force requirements are very high, animals either fail to acquire the response or perform the response at much lower rates than animals trained under lower force requirements. An exception to this may be when percentage of body weight loss is varied. Collier and Levitsky (1968) found that, as weight loss increased, the amount of spontaneous running increased regardless of the angle of inclination on an automated treadmill. This seems to apply to reinforced running as well. Capaldi and Singh (1973) found that rats

deprived to 75% of their ad-lib body weight ran significantly faster for two 45 mg pellets than rats deprived to 90% of their ad-lib body weight. Capaldi (1973) found the same results in a similar study.

When the force requirement was raised and distance was greater in a reinforced study (Viney & Jacobson, 1977), the results were similar to those of Collier, et al., (1975), with increased force requirements being negatively related to persistence. This seems to be the finding in pilot studies conducted at the University of Montana.

In the first study, four groups of rats were trained to run in braked running wheels to a required distance of 15 feet. The force requirement, defined as the tangential force required to overcome the standing inertia of a braked wheel, was set at four levels, 90 g, 110 g, 130 g, and 150 g. Groups were shaped by equal approximations to their respective tensions so that each group had equal preliminary training experience. Once the animals were shaped to run at the required levels, they were trained for 16 days with eight trials per day, with 5 Noyes 45 mg pellets after each trail for reinforcement. After each trial, there was an inter-trial interval of one minute in which the wheel was locked by an electromagnetic brake. After 16 days of training, all groups were put on extinction.

Results supported those of Capehart et al., (1958) and

Viney and Jacobson (1977) in that increased effort results in decreased performance in acquisition. The 90 g group showed a normal asymptotic performance curve. Groups 130 g and 150 g showed no performance, the plots for these groups basically reflecting a flat line. The 110 g group, however, showed the beginnings of approach to asymptote for the first 10 days of training, but on the 11th day performance of this group began to fall off and reached the level of the 130 g and 150 g groups on the 13th day of training. Since the 90 g group was the only one to successfully acquire the running response, it was the only group that showed any performance during the extinction phase. Therefore, there is no evidence that the higher-force groups would or would not be more resistant to extinction. This was examined in experiment 2.

The second study compared the effects of reinforcement magnitude on acquisition and extinction in two groups of rats run in a wheel with a 70 g tangential force requirement. Distance run for all groups was 305 cm. (10 ft.). Current theorizing (either persistence theory or partial reinforcement) would predict that the animals presented with larger magnitude of reward (8 pellets) would extinguish faster than the lower magnitude of reward (2 pellets). This was not the case. The higher magnitude group took longer to extinguish.

These results, if replicable, would seem to indicate

that increased force requirements play a much different role in behavior, both in acquisition and in extinction, than distance does. Increased force seems to be negatively related to persistence, at least over significant distance requirements. If this is the case, the partial reinforcement effect may be obtainable only under low force requirements or over extremely short distances if force requirements are high. Additionally, persistence effects may rapidly diminish as force increases, or may be more affected by reinforcement magnitude than distance changes.

In the Collier and Jennings (1969) study, the rats that were responding at FR320 were trained on and still receiving a 64% sucrose solution. Another three groups, which were trained on 16% sucrose had stopped responding at FR160. These results were replicated by Kanarek and Collier (1973).

Clearly, magnitude of reinforcement played a significant role in the outcome of these studies, and this seems to indicate that more reliable responding at even higher FR (distance) requirements might be obtained if magnitude of reinforcement increases. Whether this would also be the case for increased force requirements remains unclear, the only evidence being that of the pilot work done in the laboratory.

Since partial reinforcement and persistence literature tend to predict effects opposite to those found in our pilot work, the question of whether PRE is obtainable regardless

of force requirements becomes a theoretically, not only parametrically, important one. Using current PRE theorizing, it would be expected that the animal with the much higher force requirement would be much more resistant to extinction than the animal with a lower force requirement. Thus, a preparation in which distance and reward magnitude are held constant and only force is varied should demonstrate increased resistance to extinction as the force requirement increases.

Similarly, persistence theory (Amsel, 1972) should predict that a leaner schedule of reinforcement (as in Eisenberger and associates studies) should result in greater persistence since partial reinforcement is equivalent to leaner schedules of reinforcement used in operant paradigms. It is doubtful that either of these theories' predictions could be obtained under higher force requirements.

Partial Reinforcement

One of the most robust findings in animal learning is the partial reinforcement effect (PRE). Amsel (1972, pg. 409) defines the PRE in the following manner:

...subjects of the continuously reinforced group find reward at the goal on every occasion on which they make a simple instrumental goal approach response; subjects of the partially reinforced group find reward on some lesser percentage of trials for the same response. The so-called partial reinforcement effect (PRE) names a subsequent extinction phenomenon - that the partially reinforced subjects are more resistant to extinction - persistent - than are the continuously rewarded subjects.

Two robust hypotheses have emerged attempting to explain

this phenomenon, the frustration theory of Amsel (1958), Amsel (1962), Amsel, Rashotte, and McKinnon (1966), Amsel and Ward, (1965), and the sequential theory of Capaldi (1964, 1966, 1967).

Frustration-based Explanations

According to the frustration theory, trials followed by no reward (N) after a sufficient number of continuously rewarded (CR) training trials (to establish reliable responding) will result in frustration. This will set up an emotional conflict (approach/avoidance) in the animal as it approaches the goal, which may or may not contain the reward, resulting in the stimulus cues found in the runway being conditioned to frustration as well as reward as the animal runs to the goal box. The stimulus of anticipatory frustration is thus associated with the approach response, especially in the latter stages of partial reinforcement training. Once anticipatory frustration has been conditioned to the goal response, partially reinforced animals, when placed on extinction (complete absence of reward), will persist longer because frustration in itself has come to be associated with the approach response.

Sequential Explanations

Capaldi's (1967) sequential theory proposes a different approach based more on memory. The cues from the situation as well as the memory of recent reward or non-reward are remembered as leading to reward occasionally. The animal

thus learns to make the response in the presence of memories of no reward. The memory of no reward then becomes conditioned to responding.

In this case, sequence of reward (R) and non-reward (N) plays an important role. For example, in the sequence RNNRRNR, the fourth and last trials are the most important. On these trials, the subject's memory would inform it that it had not been rewarded just before these trials. The assumption is that the animal learns that it will be reinforced for responding when its memory is that of no reward on preceding trials. This learning creates persistent responding in extinction after partial reinforcement.

These two theories have been regarded as competing, but an impressive amount of evidence supporting both has been gathered. It may well be that neither theory is completely incorrect, but that they reveal the importance of different aspects of behavior. The frustration theory addresses the emotional aftereffects of nonreward while the sequential theory clearly demonstrates the importance of hedonic memories in regulating behavior.

Summation

Effort studies are notable for their lack of consensus, both in procedures and in findings. This lack makes it extremely difficult to arrive at any firm conclusions about the effects of effort on acquisition or extinction.

Additionally, studies which use runway preparations cannot be easily compared to studies using operant preparations (Mellgren & Olson, 1983; Nevin, 1988). However, there is a possibility that some consensus can be reached using a running wheel, since it should be possible to closely replicate either discrete or operant paradigms and use the running response in both situations. In our laboratory, low-inertia running wheels have been connected to a computer which records data for every 1/16 of a wheel rotation as well as precisely controls reinforcement, inter-trial interval (if required), and response cues such as those found in runway preparations. Lightened Wahmann running wheels have been fitted with a computer mouse to record wheel rotations, a braking system which controls wheel torque and an electromagnetic braking system which can be used to make the wheel much more difficult to turn, if not stop it from turning entirely.

This preparation used procedures analogous to those used in discrete-trial runway procedures so that the effects of force on partial reinforcement could be examined in a setting replicating a runway as closely as possible. The design for the study was a 2 (condition) X 4 (force levels), employing either partially or continuously reinforced subjects across four tangential force requirements of 20 g, 40 g, 60 g, and 80 g. Based on pilot work in the laboratory, and on the review of literature, the following

predictions were made:

1. Subjects running under higher force requirements will take longer to complete trials than subjects under lower force requirements as well as the behavior breakdown effects noted by Applezweig (1951) and others, and by greater post reinforcement pausing.

2. Subjects extinguished under high force requirements will extinguish sooner than subjects receiving the same level of reinforcement but under lower force requirements.

3. Subjects extinguished under high force requirements and partially rewarded will extinguish sooner than subjects under the same force requirement and continuously rewarded. However, partially reinforced subjects running under lower force requirements may be more persistent in extinction than continuously reinforced subjects.

4. Subjects under high force requirements will take longer to learn the required response, and will perform the required response at lower levels than subjects under lower force requirements. More subjects under higher force requirements will fail to learn the response.

5. Continuously rewarded subjects will acquire the required response sooner than partially rewarded subjects under the same force requirements.

Method

Subjects

Subjects were sixty male albino male rats of the

Sprague Dawley strain. At time of arrival in the colony, they were sixty-seven days old. Subjects were individually housed in the colony with ad-lib food and water. After five days to become acclimated to their new surroundings, subjects were handled for a few minutes every day. Since there were several undergraduate students assisting in the experiment, each student handled 10 animals every day, switching to another set of ten every day to insure that all the animals and the experimenters became familiar. When the animals were 78 days of age, Noyes pellets were placed in their cages and their food supply was slightly reduced in order to induce them to consume the pellets. Handling continued throughout this time.

When the animals were 84 days old, they were weighed and matched in four groups based on their weights. The animals were then put on a deprivation schedule designed to reduce their weights to 85% of ad-lib. Weight was controlled to plus or minus 10 g of the 85% target by animals being weighed twice a week and their food ration being adjusted. Close monitoring of weight was necessary since there is some evidence that there are much different performance levels at different body weights (Collier, et al., 1975; Capaldi, 1973; Capaldi & Singh, 1973).

It was deemed necessary to match animals by weight in any preparation examining the effects of force, since, if the baseline force requirement is the effort necessary for

the animal to start the wheel moving, the effort exerted by a smaller animal will be higher. If light animals happened to be concentrated in one group and heavier animals in another, the results would have been confounded.

Apparatus

Four Wahmann running wheels were modified as follows: Colborn Instruments pellet feeders were attached to the frames of the wheel assemblies with the feeder tube extending down to a cup placed in the door. The opening which was previously used to allow access to the rest cage normally attached to the wheel was expanded to approximately 8 cm in height and cut along the bottom in 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 (1 1/2") PVC cap cut lengthwise was attached using sheet metal screws. A PVC tube with a ninety degree bend in it passes to the feeder tube. A 7.62 cm aluminum disc approximately 1.3 cm thick was attached to the wheel axle where the original revolution counter was attached (this was discarded). A metal bar of approximately 20 cm length rested on top of the disc with the opposite end attached to the frame by a bolt in such a manner that the bar floated on the wheel by being allowed to freely turn on its attaching 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. The pressure on the shaft can be varied by turning a thumbscrew which pressed on the spring and thus on the shaft, allowing force on the wheel to be adjusted by the bar being pressed with greater force against the disc.

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

Each wheel was fitted with an electromagnetic braking system controlled by a computer. The system consisted of two solenoids fitted with brake shoes. When activated, the solenoids applied 2.2 kg of force onto each side of the 7.62 mm disc, thereby stopping the wheel and preventing its movement during intertrial intervals.

Attached to the frame of the wheel was an IBM-compatible mouse, mounted in such a way so that any movement of the wheel caused movement of the sectored disc in the mouse, thus creating a signal that was read by a computer (Petree, Haddad, & Berger, 1992).

The IBM-compatible computer was programmed using the Turbo-C language. The program read the rotations of the wheel via the mouse, and worked as a timer. It was therefore relatively simple to record rotation rate for any

period of a trial. Additionally, the computer ran the feeders and the braking system via an Alpha Products MB120 interface card system connected to the computer. The system control led a series of relays which operated the feeders and brake by switching electricity from a 24-volt power supply.

The running wheels were placed in sound attenuated chambers. The chambers were positively vented by a fan system pulling air through a baffle and out an exhaust port. A house light controlled by the computer changed illumination level as the animal ran on each trial. Initiation of each trial was signalled by the braking system's releasing clicks and a house light illumination of 2 w. After the first quartile of the required distance was run, the illumination was increased to 4 w, and after the third quartile, to 6 w.

In order to control for extraneous effects in the boxes themselves, eight boxes and running wheels were assembled. Each group was divided so that about half of each group ran in one of two boxes set up specifically for that group's tension requirement. There were no apparent differences between boxes.

Procedure

Shaping

Due to problems with the apparatus, the animals were not placed in the running wheels until they were 100 days

old. The original plan had been to start them when they were 85. The following shaping procedure was based on pilot studies done in the laboratory. The animals were placed in a running wheel with no added tangential force requirement on it (a free wheel requires 12-20 g tangential force), and allowed to run as much as they would for eight minutes. There was no reinforcement given, nor was there a change in illumination. The computer recorded the total distance ran. This was repeated for another day. On day three of shaping, animals were required to run a distance of 240 cm, after which they were continuously reinforced with five 45 mg pellets. Each animals ran eight trials per day. If subjects needed some help running, the experimenter turned the wheel slightly for any subjects which did not turn it after thirty seconds. This was done for five days until all the animals were running reliably and consuming the pellets. During this time, the light intensity varied as described above, but there was no intertrial interval (ITI).

Shaping to the required force levels of 20g, 40g, 60g, and 80g began on the seventh day of running, with 25% of the final tension being added to the wheels. However, since free running wheels require 12-20g force to turn, little if any change was experienced by the 20g groups. An additional 25% of final tension was added for the next three days until all animals were running at the final requirement. Training at the final tension continued for three days in the manner

described above. Tension on the wheels was checked and adjusted as necessary weekly, with little difference being found at those times.

A floor value of 20 g tangential force was used to insure that the running response, which is in itself reinforcing, can be controlled by food reinforcement. Pilot work and the other studies done in our lab (e.g., Haddad, Petree, Karkowski, Foss, & Berger, in preparation) have not used force requirements this low in a running wheel (the lowest previously was 45 g), and part of this study was to ascertain if 20 g might be sufficient to control running with reinforcement.

Each group was then subdivided by again matching for weight, with one half of each group placed on the partial reinforcement schedules shown in Table 1. The other half of each group was continuously reinforced. All groups were run 240 cm per trial, and all subjects were given eight trials per day.

After thirty days of running, asymptote (defined as nonsignificant repeated measures over five days for the slowest group ($F \leq 1$) was reached, and all groups were put on extinction. All animals were run every day of the twelve days of extinction, but were removed if they failed to complete a trial in 300 seconds. Running time for that day was the average of all the completed trials with the 300 seconds used as a completed last trial. No animal failed to

complete at least one trial before stopping until day 11.

Results

Summation of Results

Acquisition: Analysis of the last five days of acquisition revealed significant main effects for: a) days, revealing that the 80 g groups had not stabilized; b) octiles, which showed that the running times between octiles were different. This difference was found in the running times for the first octile and sometimes for the last octile, with all other octiles not being significantly different from each other. This difference indicated that the animals in different groups were taking longer to begin trials, and sometimes taking longer to slow down and finally stop at the end of trials, but taking about the same amount of time in the middle octiles of the trial.

There were also three significant two-way interactions: a) tension X octile, showing that tension had an effect on responding during acquisition; b) condition X octile, demonstrating that reward level was playing some part in responding; c) days X octiles, showing a lack of stability in groups.

There was also a significant 4-way interaction of tension X days X condition X octiles. This was concentrated in the 80 g groups, as was the condition X octile interaction.

The first 25 days of acquisition were also examined for

differences by comparing mean speeds of partially and continuously reinforced groups. The only significant difference between groups indicated that the two 80 g groups acquired the response more slowly than the other six groups, which did not differ significantly from each other.

Extinction: Analysis revealed main effects for: a) condition, indicating that reinforcement schedules affected extinction results; b) days, indicating decline of behavior as extinction trials continued. There were two significant interactions: a) condition X octiles, showing that reinforcement schedule affecting extinction results; b) days X octiles, showing that the number of days of extinction affected the running times for octiles.

Acquisition

A 2 (condition) X 4 (effort level) 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. This analysis revealed significant differences for the main effect of days [$F(4,204) = 3.04, p < .05$], indicating that the groups had not completely stabilized when measured by octiles. The stabilization measure was based on quartiles and this was not significant. There were also significant differences for the main effect of octiles [$F(7,357) = 87.64, p \ll .01$], indicating that the running times for the first octile and sometimes the last octile were much higher than for the other octiles.

The analysis also found three significant two-way interactions: tension X octile [$F(21,357) = 4.28, p < .01$]; condition X octile [$F(7,357) = 2.46, p < .05$]; days X octiles [$F(28,1428) = 2.59, p < .05$]. There was also a 4-way interaction of tension X condition X days X octiles [$F(84,1428) = 1.29, p < .05$]. However, the 4-way interaction was primarily due to the behavior of the 80 g groups. When the original analysis was run using only the 20 g, 40 g, and 60 g groups, the 4-way interaction was not significant nor was the 2-way interaction for condition X octiles. The reason may be seen in Figure 3, which shows the differences between the three groups and four groups analyses. The partially reinforced 80 g group influences mean for octile 1, raising it sharply.

Tension X Octiles (Figure 1). Tukey's HSD post hoc analysis was conducted on the tension X octile interaction. This analysis showed that octile 1 was significantly different from all other octiles for all tension levels. The only exceptions to this are easily seen in Figure 1a, and these were nonsignificant differences between octile 1 for the 20 g groups when compared to the octile 1 for the 40 g and 60 g groups. Additionally, octile 8 for the 80 g groups was not significant when compared to octile 1 for the 20 g groups.

There were no other significant differences. This can best be explained by examination of Figure 2, from which it

Acquisition Tension X Octiles

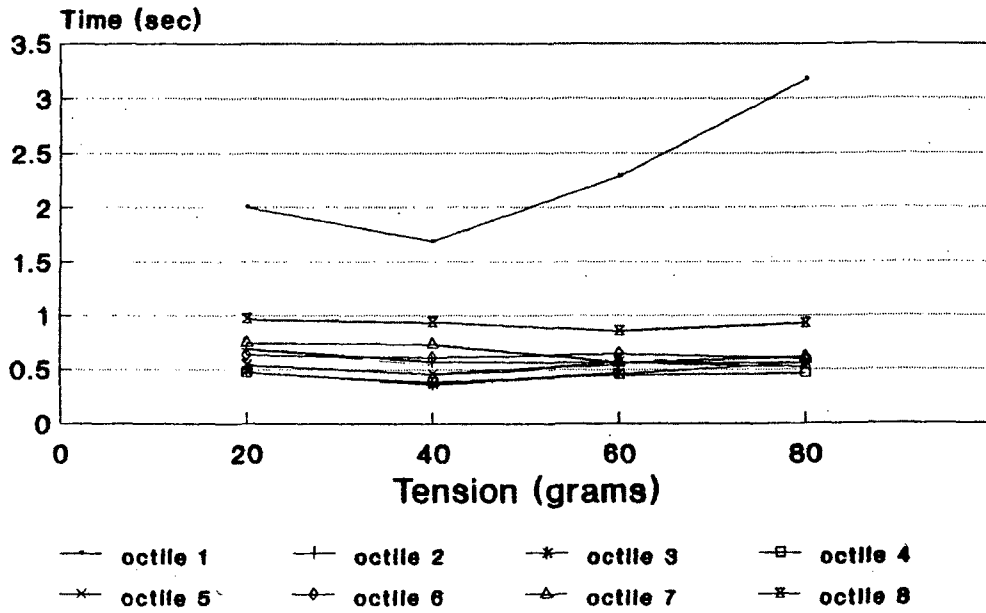
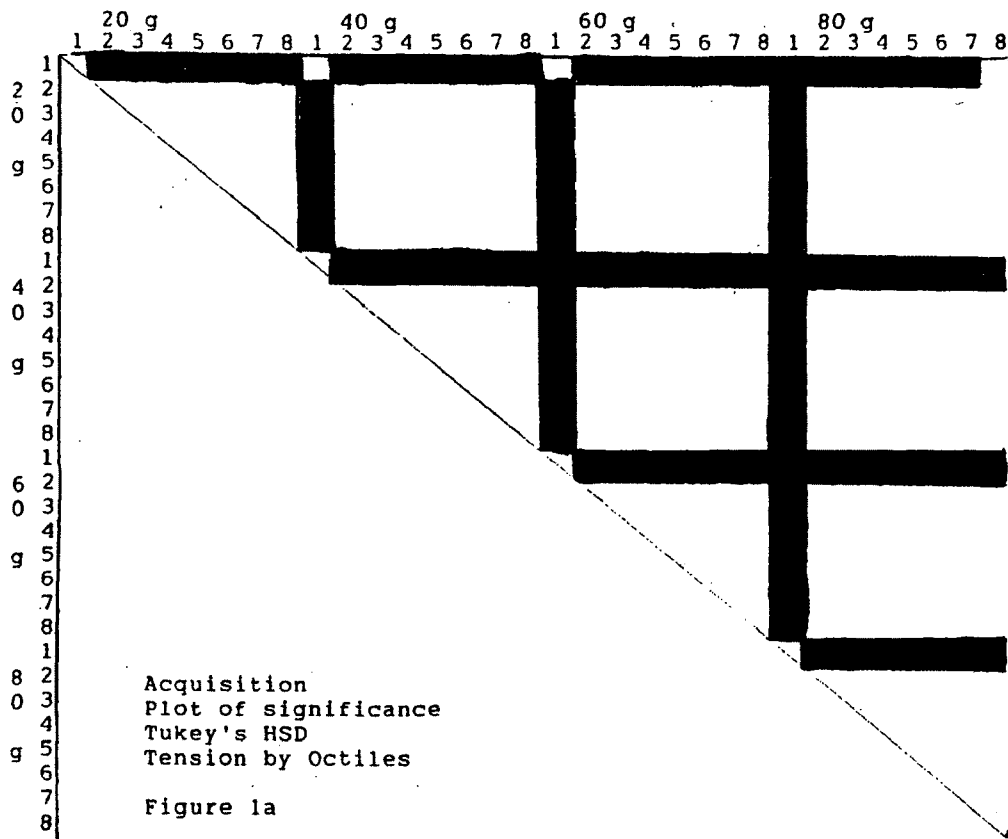


Figure 1



Acquisition Tension X Octiles

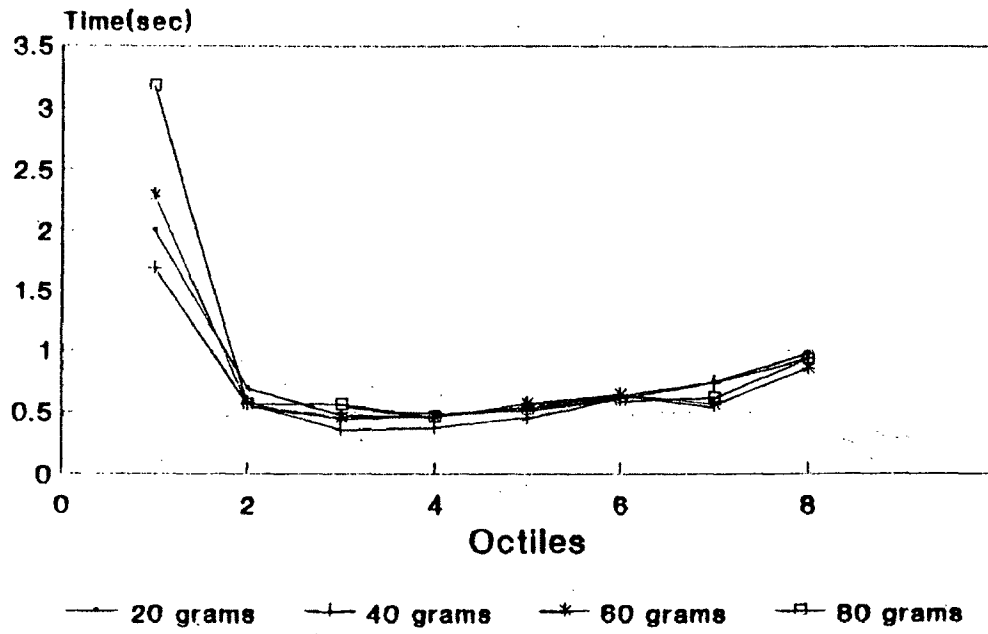


Figure 2

can be seen that the stereotypical running pattern for all groups was something of a reversed J. The trial started with slow starting times in octile 1 to very fast times in octiles 3 and 4. The times then gradually increased as the animals approached the end of the run.

Condition X Octiles (Figure 3). Tukey's HSD post hoc analysis conducted on the condition X octile interaction revealed significant differences between octile 1 and all other octiles. Figure 3a shows that there were also significant differences between octile 8 for the partially reinforced groups and octiles 3, 4 and 5 for the partial groups. There were in addition significant differences between octile 8 for the partial groups and octiles 3 and 4 of the continuous groups. There were significant differences between octile 8 for the continuously reinforced groups and octiles 3 and 4 for the partial groups, and octile 4 for the continuous groups. Study of Figure 3 also shows the effect that the 80 g partial group had on the first octile means. When the three group (20g, 40g, 60g) analysis is compared with the four groups, octile 1 changes dramatically. The condition X octile interaction is not significant in the three group analysis.

Days X Octiles (Figure 4). Tukey's HSD post hoc analysis conducted on the days X octiles interaction showed significant differences between octiles 1 and 8, and between these octiles and all other octiles. There are exceptions

Acquisition
Condition X Octile
Four Group and Three Group

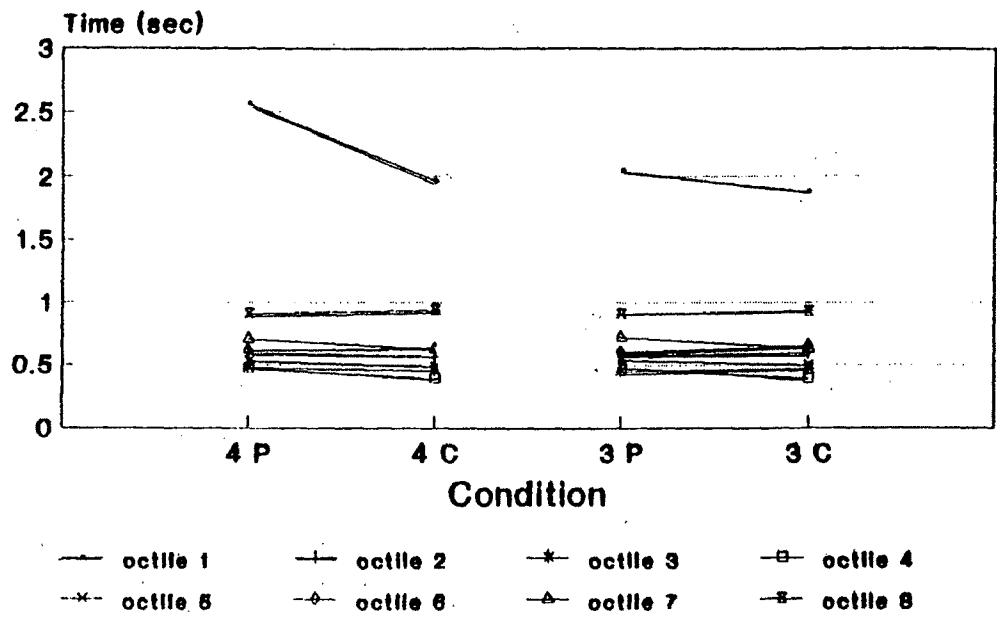


Figure 3

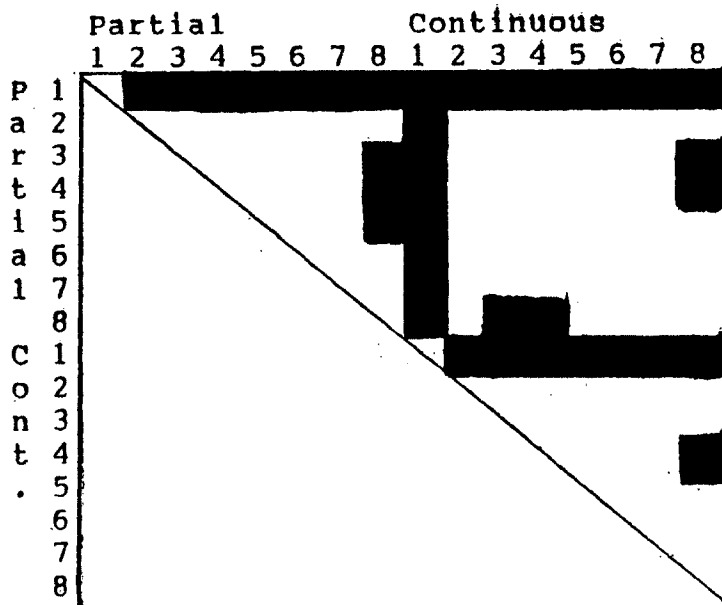


Figure 3a Acquisition
 Plot of significance
 Tukey's HSD
 Condition by Octiles

Acquisition

Days X Octiles

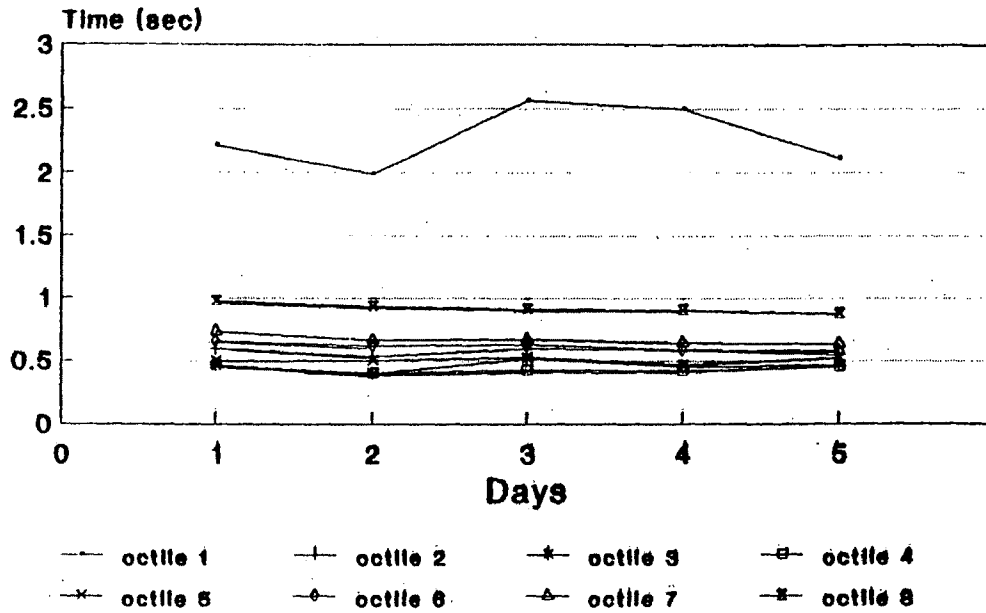


Figure 4

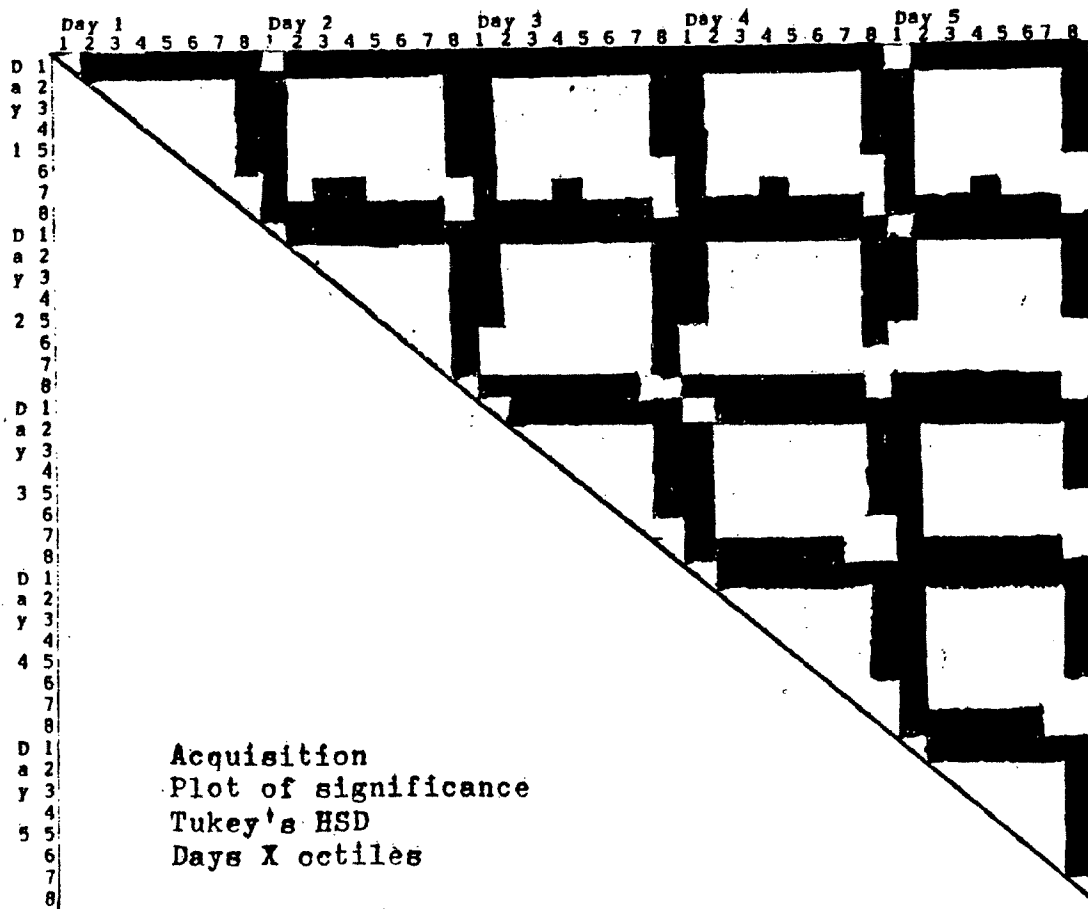


Figure 4a

to this as can be seen by an examination of Figure 4a, which shows the plot of significance for this interaction.

Additionally, a series of one-way ANOVAS was run comparing the mean speeds of the continuously reinforced group of each tension level with the mean speeds of the partially reinforced group of the same tension level for the first 25 days of acquisition. There were no differences for the 20 g groups [$F(1,46) = .20$, $p > .05$], 40 g groups [$F(1,46) = .26$, $p > .05$], and the 60 g groups [$F(1,46) = 2.99$, $p > .05$]. It should be pointed out, however, that the 60 g group was fairly close to significance, the actual probability being .091. The 80 g group displayed significant differences [$F(1,46) = 5.63$, $p < .05$], with the partially reinforced group being significantly slower in acquisition of the behavior.

With condition collapsed into tension, there was further support that high force requirements cause some effect in acquisition. A series of one-way ANOVAS was run on the mean speeds of the collapsed groups for the first 25 days of acquisition. The results revealed significant differences between groups [$F(3,92) = .46$, $p < .05$]. Further analysis showed no significant differences between the 20 g group and the 40 g group, but significant differences between these two groups and the 60 g and 80 g groups, which were not significantly different from each other.

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). A 2 (condition) X 4 (effort level) X 8 (octile) split plot analysis of variance was conducted on the mean running times for the eight daily trials of the ten days of extinction. This analysis revealed significant differences for the main effect of condition [$F(1,46) = 4.24, p < .05$], indicating that partial versus continuous reinforcement in acquisition had some effect in extinction; days [$F(9,414) = 35.71, p < .05$], indicating the gradual decline of the running behavior when all reward has ceased; and octiles [$F(7,322) = 28.52, p < .05$], indicating that, relative to their acquisition times, the groups were taking much longer in the first few octiles and taking much less time in the last few octiles.

There were also two significant interactions; condition X octiles [$F(7,322) = 3.25, p < .05$], and days X octiles [$F(63,2898) = 2.07, p < .05$].

Condition X Octiles (Figures 5 and 5a). Tukey's HSD post hoc analysis conducted on the condition X octile interaction revealed blocks of significance for the mean proportions of the running times. The partially reinforced

Extinction

Condition X Octile

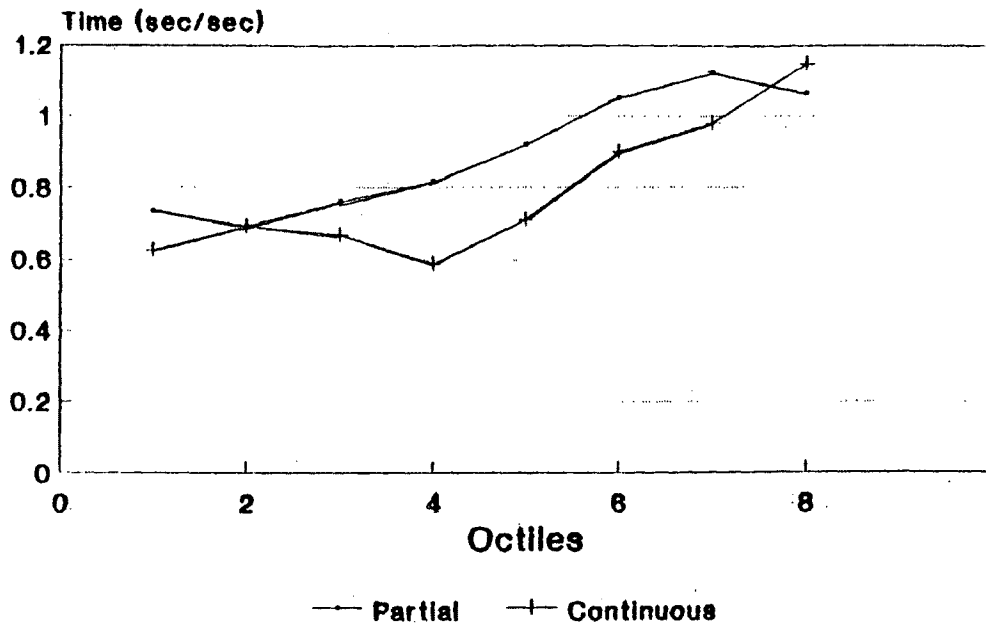


Figure 5

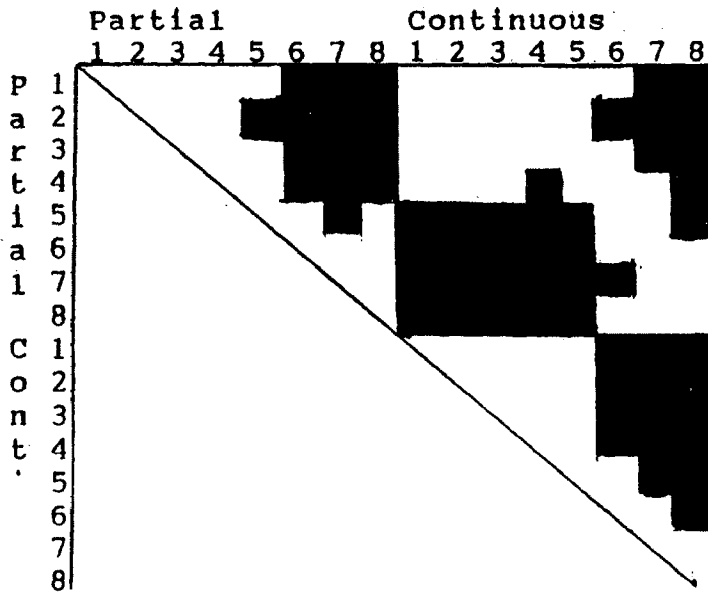


Figure 5a Extinction
 Plot of significance
 Tukey's HSD
 Condition by Octiles

groups were significantly lower when comparing the mean proportions of the running times of octiles 1 through 4 with octiles 6 through 8. They were also significantly lower when comparing the mean proportions of the running times of octiles 1 through 5 and the mean proportions of the running times of continuous groups octiles 7 through 8. The partial groups also differed significantly when comparing the mean proportions of the running times of octiles 5 through 8 when compared to the mean proportions of the running times of continuous groups octiles 1 through 5.

The continuous groups differed significantly when comparing the mean proportions of the running times of octiles 1 through 4 when compared to octiles 6 through 8.

An examination of Figure 4a shows the plots for significance, which basically shows that groups were running faster at the end of a trial than they were at the beginning.

Days X Octiles (Figure 6). No post hoc analysis was conducted on this interaction, since it required a matrix of 6400 numbers, and an analysis of this size has its own problems. However, Tukey's HSD analyses were conducted on individual days and octiles.

Comparison of Days: (Figure 7) For day 6 (the first day of extinction), the mean proportions of the running times of octiles 1, 2 and 4 were significantly less than the mean proportions of the running times of both octiles 6 and

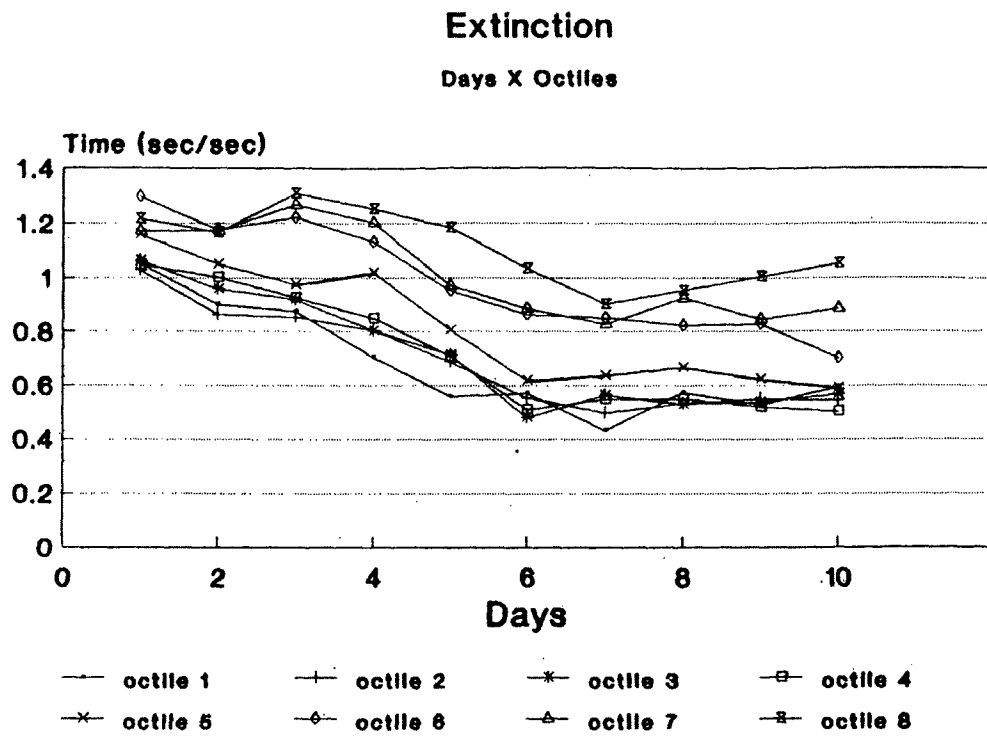


Figure 6

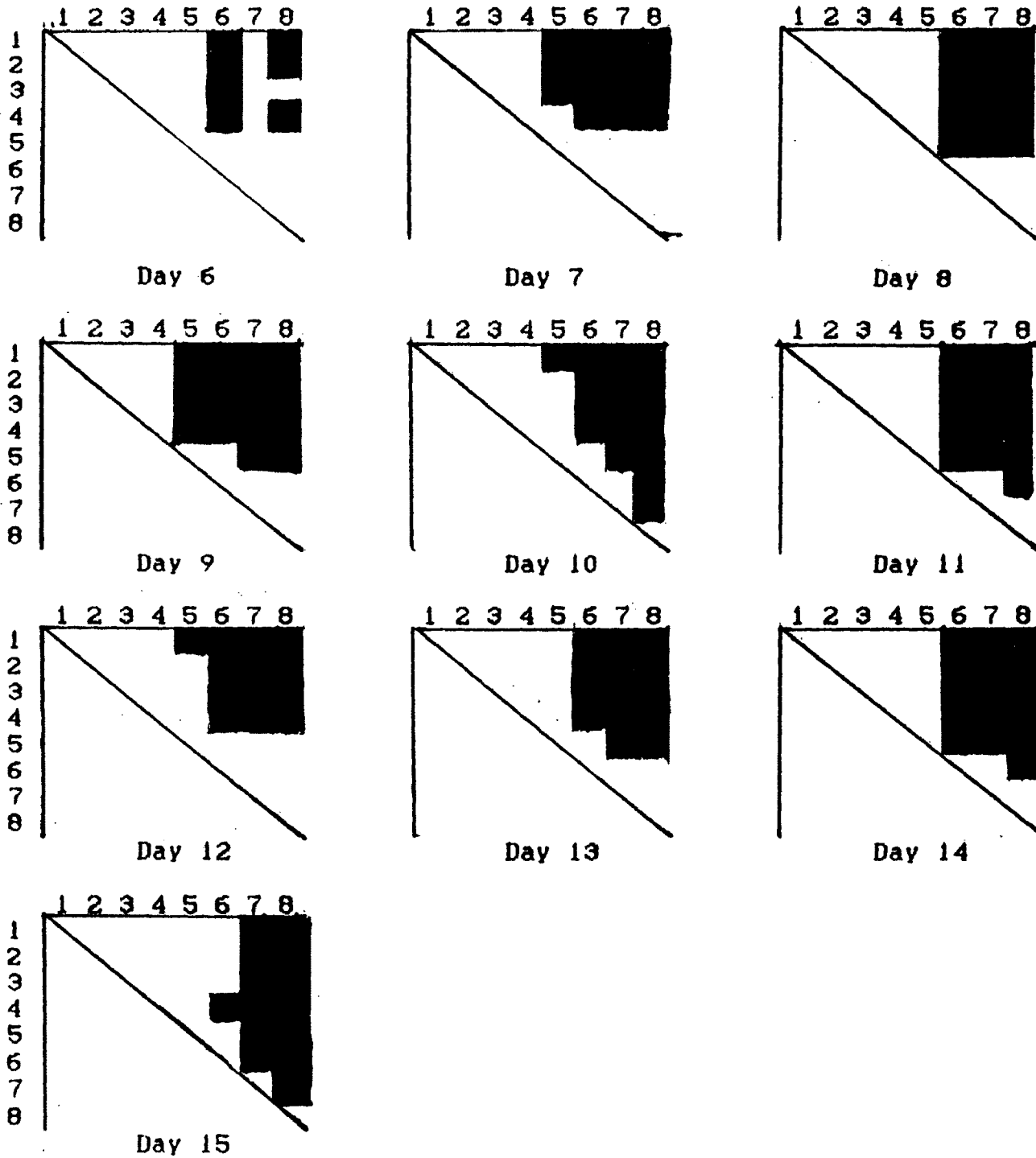


Figure 7

Extinction
 Plots of Significance
 Tukey's HSD
 Octiles per day

8.

Octile 3 was significantly different from octile 6 only.

On day 7, the mean proportions of the running times of octiles 1, 2, 3 and 4 were significantly lower than compared to octiles 5, 6, 7 and 8. Octile 5 was significantly lower when compared to octiles 6, 7, and 8.

On day 8, the mean proportions of the running times of octiles 1, 2, 3, 4, and 5 were significantly slower than the mean proportions of the running times of octiles 6, 7, and 8.

On day 9, the mean proportions of the running times of octiles 1, 2, 3, and 4 were significantly less than the mean proportions of the running times of octiles 5, 6, 7, and 8. The mean proportions of the running times of octile 5 differed significantly from the mean proportions of the running times of octiles 7 and 8 only.

For day 10, the mean proportions of the running times of octile 1 were significantly lower than the mean proportions of the running times of octiles 5, 6, 7, and 8. The mean proportions of the running times of octile 2, 3, and 4 were significantly slower than the mean proportions of the running times of octiles 6, 7 and 8. The mean proportions of the running times of octile 5 were significantly lower than the mean proportions of the running times of octiles 7 and 8. The mean proportions of the running times of octiles 6 and 7 were significantly lower

than octile 8.

Day 11 found the mean proportions of the running times of octiles 1, 2, 3, 4 and 5 significantly slower than the mean proportions of the running times of octiles 6, 7 and 8. Octile 6 differed from the mean proportions of the running times of octile 8 only.

On day 12, the mean proportions of the running times of octile 1 were significantly lower than the mean proportions of the running times of octiles 5, 6, 7, and 8. Octiles 2, 3 and 4 were significantly less than the mean proportions of the running times of octiles 6, 7 and 8.

Day 13 found the mean proportions of the running times of octiles 1, 2, 3 and 4 significantly lower than octiles 6, 7 and 8. Octile 5 was significantly lower than the mean proportions of the running times of octiles 7 and 8.

On day 14, the mean proportions of the running times of octiles 1, 2, 3, 4 and 5 were significantly lower than octile 8. Octile 6 was also significantly lower than octile 8.

For day 15, the mean proportions of the running times of octiles 1, 2, 3, 5 and 6 were significantly lower than the mean proportions of the running times of octiles 7 and 8. The mean proportions of the running times of octile 4 differed significantly from the mean proportions of the running times of octiles 6, 7 and 8, and the mean proportions of the running times of octile 7 differed

significantly from octile 8.

Comparison of Octiles (Figure 8). In octile 1, the mean proportions of the running times of days 6 and 7 were significantly higher than the mean proportions of the running times of days 8 through 15. The mean proportions of the running times of day 8 were significantly higher than the mean proportions of the running times of days 9 through 15, and the mean proportions of the running times of day 9 were significantly higher than the mean proportions of the running times of days 2 and 14 respectively.

For octile 2, the mean proportions of the running times of day 6 were significantly higher than the mean proportions of the running times of days 8 through 15 inclusive. Day 7 differed significantly when comparing the mean proportions of the running times of day 6 and the mean proportions of the running times of days 10 through 15. The mean proportions of the running times of days 8 and 9 were significantly higher than the mean proportions of running times of days 11 through 15, and the mean proportions of the running times of day 10 were significantly higher than the mean proportions of the running times of day 13 only.

In octile 3, the mean proportions of the running times of day 1 were significantly higher than the mean proportions of the running times of days 9 through 15. The mean proportions of the running times of days 7 and 8 were significantly higher than the mean proportions of the

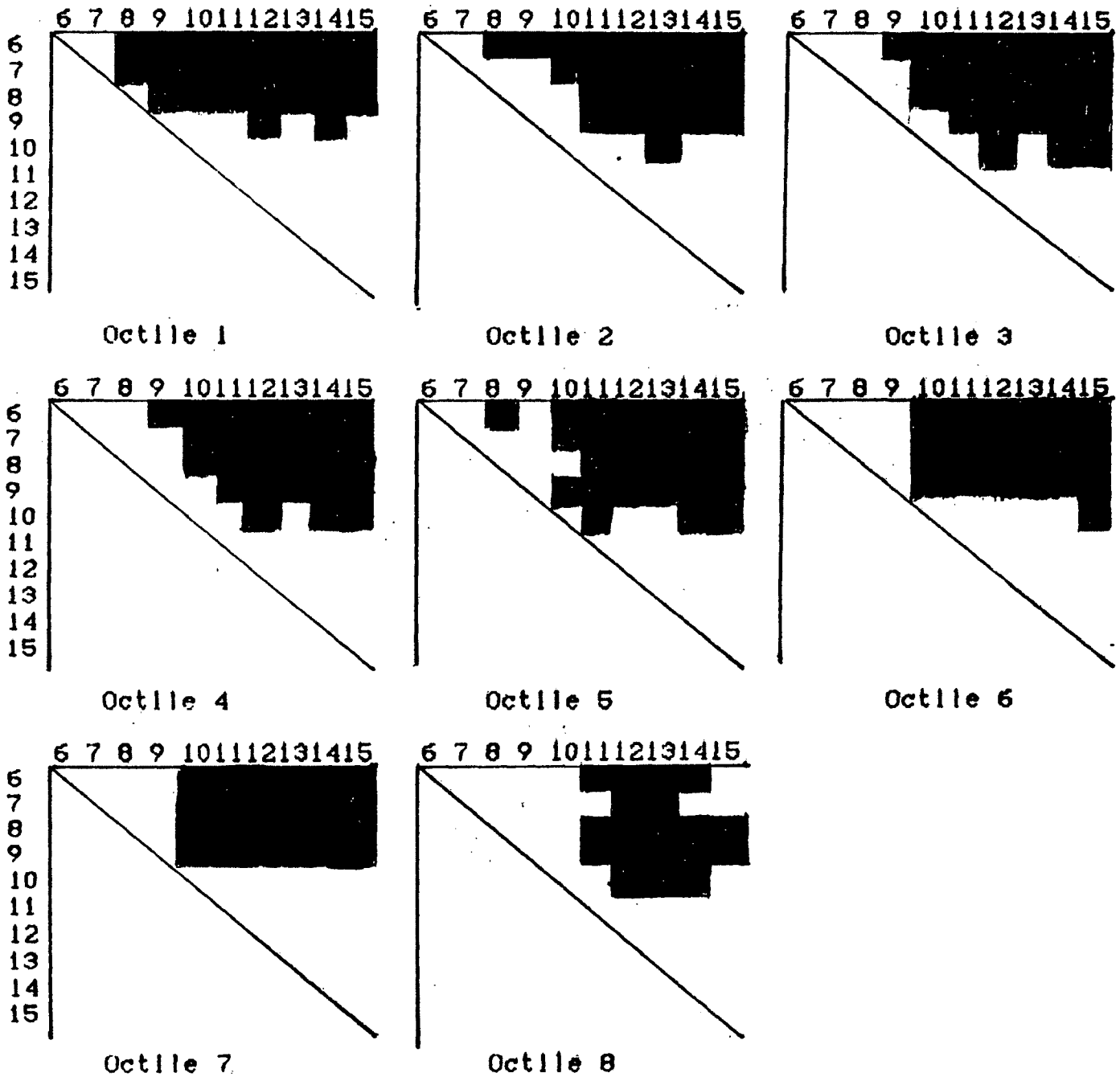


Figure 8

Extinction
 Plots of Significance
 Tukey's HSD
 Days per Octile

running times for days 10 through 15. The mean proportions of the running times of day 9 were significantly higher than the mean proportions of the running times of days 11 through 15. The mean proportions of the running times of day 10 were significantly higher than the mean proportions of the running times of days 12, 14 and 15.

Octile 4 found the mean proportions of the running times of day 1 being significantly higher than the mean proportions of the running times of days 9 through 15. Days 7 and 8 found their mean proportions significantly higher than days 10 through 15. The mean proportions of the running times of day 9 were significantly higher than the mean proportions of the running times of days 11 through 15. The mean proportions of the running times of day 10 were significantly higher than the mean proportions of the running times of days 12, 14 and 15.

In octile 5, the mean proportions of the running times of day 6 were significantly higher than the mean proportions of the running times of days 8, 10, 11, 12, 13, 14 and 15. The mean proportions of the running times of days 7 and 9 were significantly higher than the mean proportions of the running times of days 10 through 15, and the mean proportions of the running times of day 8 were significantly higher than the mean proportions of the running times of days 11 through 15. The mean proportions of the running times of day 10 were significantly higher than the mean

proportions of the running times of days 11, 14 and 15.

Examination of octile 6 found that the mean proportions of the running times of days 6, 7, 8 and 9 were significantly higher than the mean proportions of the running times of days 10 through 15. The mean proportions of the running times of day 10 were significantly higher than the mean proportions of the running times of days 15 only.

For octile 7, the mean proportions of the running times of days 6, 7, 8 and 9 were significantly higher than the mean proportions of the running times of day 10 through 15.

For octile 8, the mean proportions of the running times of day 6 were significantly higher than the mean proportions of the running times of days 11, 12, 13 and 14. The mean proportions of the running times of day 7 were significantly higher than the mean proportions of the running times of days 12 and 13 only. The mean proportions of the running times of days 8 and 9 were significantly higher than the mean proportions of the running times of days 11 through 15. The mean proportions of the running times of day 10 were significantly higher than the mean proportions of the running times of days 12, 13 and 14.

Discussion

Several predictions were made in this study and each will now be examined. The first prediction was that subjects running under higher force requirements will take

longer to complete trials than subjects under lower force requirements. This was to be due to the increased force requirement as well as the behavior breakdown effects noted by Applezweig (1951) and others, and by greater post reinforcement pausing. In the general sense, this finding was supported when examining the last five days of acquisition and the extinction data. However, a close examination of Figure 1 shows that a more accurate statement would be that subjects running under high force requirements will take longer to begin trials than subjects under lower force requirements. However, once the response began, there were no differences in performance between tensions. This high response latency will be discussed later.

The second prediction was that subjects extinguished under high force requirements will extinguish sooner than subjects receiving the same level of reinforcement but under lower force requirements. This finding was not supported, there being no significant interactions, either in acquisition or extinction, for tension X condition.

The third prediction, that partially rewarded subjects extinguished under high force requirements would extinguish sooner than continuously rewarded subjects under the same force requirement. This finding was not supported", " there being no significant tension X condition interactions in extinction or in acquisition. The 4-way interaction found in the acquisition data is reflective only of the 80 g

groups, in which the first octile times were significantly different between the partially and continuously rewarded rats. However, this was not reflected in extinction, where force requirements played no part in extinction results.

In general, the opposite of this prediction was true. A partial reinforcement effect, in which the mean proportions of the running times of partially reinforced rats were higher than the mean proportions of the running times of continuously reinforced animals, was found in the extinction data. This supports the robustness of the partial reinforcement effect.

The second part of prediction three was that partially reinforced subjects running under lower force requirements might be more persistent in extinction than continuously reinforced subjects. Given the above explanation, it is obvious that this prediction was supported, but across all tension levels, and not just for low force subjects.

Prediction four stated that subjects under high force requirements would take longer to learn the required response, and would perform the required response at lower levels than subjects under lower force requirements. More subjects under higher force requirements would fail to learn the response. This was not the case. All animals learned the response at the same rate. This was in some sense a given in that all animals were shaped with exactly the same number of trials and with the same percentage of terminal

force requirement added. There was a greater increase in force for the higher requirement animals (20 g for the high tension group vs. 5 g for the lowest tension group), but there was no observable difference in performance between groups during shaping.

The fifth and final prediction was that continuously rewarded subjects would acquire the required response sooner than partially rewarded subjects under the same force requirements. This prediction was supported only in the 80 g groups where the partially reinforced group ran significantly slower during acquisition than the continuously reinforced group. These findings seem to show that increased force leads to differential responding when reward level is varied.

With condition collapsed into tension, there was further support that high force requirements cause some effect in acquisition. There were no significant differences between the 20 g group and the 40 g group, but significant differences between these two groups and the 60 g and 80 g groups, which were not significantly different from each other. The two higher force requirements seem to have caused slower acquisition of behavior, since their mean speeds were much slower. This supports the findings of Solomon (1948a) and Mowrer and Jones (1943), who noted that increased effort in acquisition resulted in slower learning of the response.

The findings of early research concerning effort were by and large not supported in this study. Mowrer and Jones (1943), found that "the rate at which a rewarded response extinguishes is highly (negatively) correlated with the effortfulness of that response." Similar findings were echoed by Capehart, et al., (1958), and these were not demonstrated here. In fact, effort played no role in extinction. A second finding of early studies was that higher effort responses will result in more erratic behavior and could result in failure to acquire the behavior. Mowrer and Jones (1943) also noted more erratic behavior on the part of the higher effort animals during extinction. This was the case for some of the higher effort animals. Some of them managed to chew holes in the mesh of the running wheel and escape. Whether or not the lower effort animals would have done the same is not known since the mesh of their wheels was of a different type and could not be chewed open.

Erratic behavior probably needs a good definition. If one uses the usual assumption of gnawing, biting, jumping, etc., then it is not known if this finding was supported since the running wheels were housed in chambers which prevented observation. However, if one desired to include delayed start of trials, then this finding was supported. Animals running under higher response effort requirements took significantly longer to start each trial in acquisition. However, once the running response was

initiated, there were no significant differences between tensions (see Figure 1a).

There was also some discussion in the literature concerning the difficulty of higher effort animals in learning the response (Solomon, 1948; Applezweig, 1951; Aiken, 1957; Maatsch, et al., 1954). Failure to acquire the behavior was not a problem in this study, with all 60 animals acquiring the behavior. It might be reasonably said that much of the difficulty in response acquisition in at least some of the early studies was probably due to shaping. In this study, the animals were brought up to their terminal force requirements gradually, and there was little difficulty on the part of any of the animals in learning the response at the force level required of them.

Additionally, many of the early studies also used responses which the rats had to be shaped to perform. Rats will engage in spontaneous running in a wheel. Shaping in this study was mostly done in order to insure that the animals would run at the required effort level. It is possible that the different response requirements in earlier studies have played a significant role in the discrepancy between early findings and the findings of this study.

The third prediction derived from early studies was that higher response effort requirements will lead to earlier extinction than lower response effort requirements. This was not supported in that response effort played no

part in the extinction results. This supports the findings of Aiken (1957), Applezweig (1951), and Maatsch, et al. (1954) in which animals trained and extinguished at the same effort level showed no differences in extinction for effort requirements.

The results of this study do appear to support some of the research on persistence. Amsel (1972) was unable to determine whether or not persistence generalizes. One of the alternatives he proposed was that persistence will transfer within a class of responses. This study was not directly intended to examine this question but it appears to support the idea that persistence does not transfer within response classes. The task for the rats was the same both in acquisition and extinction. Had persistence been evident, the higher force requirements of the high tension running wheels should have yielded extended running during extinction trials. This clearly was not the case.

Varying force requirements does not seem to affect performance in a running wheel. The literature is minimal concerning the effects of force. Viney and Jacobsen (1977) and Collier, et al. (1975) found that, as force requirements increased, persistence decreased. This finding was not supported in that there was no effect for tension in extinction trials. However, it may be that force requirements were not high enough for this to be demonstrated.

There are several open questions concerning force and distance effects on performance of a task. The literature is scanty and conflicting. The running wheel may be a good vehicle for the study of these effects in that force and distance are easily varied and controlled. Much further study in these areas is warranted, especially in acquisition of behavior, which seems by and large to be disregarded.

There is also the matter of just where the running wheel fits in studying behavior. Based on this study, other studies and pilot work done in the laboratory, the running wheel cannot be said to be directly analogous to the runway. Whether it is more analogous to the operant chamber is unknown at this point. It was originally hoped that the running wheel could be used to answer many of the questions concerning operant vs. discrete trials paradigms. It may still be that the wheel is capable of providing answers to such questions, but the evidence presented here is not conclusive.

20 Grams
Partial & Continuous

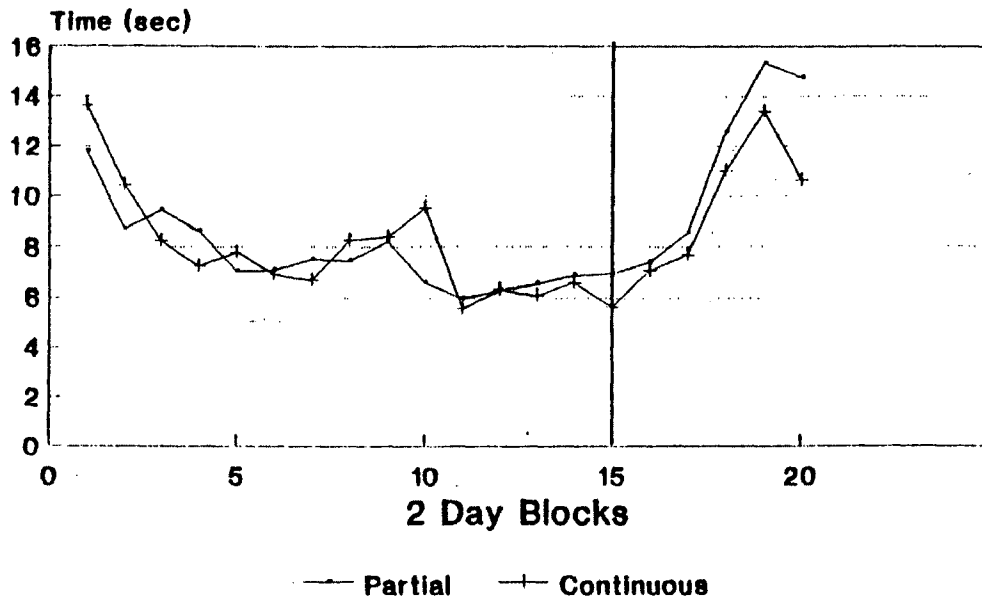


Figure 9

40 Grams
Partial & Continuous

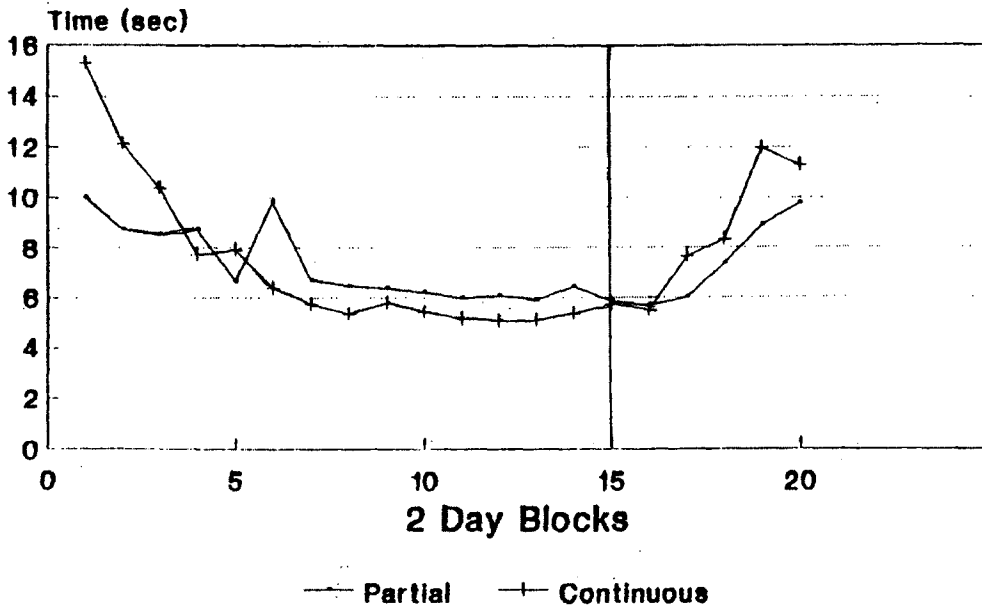


Figure 10

60 Grams
Partial & Continuous

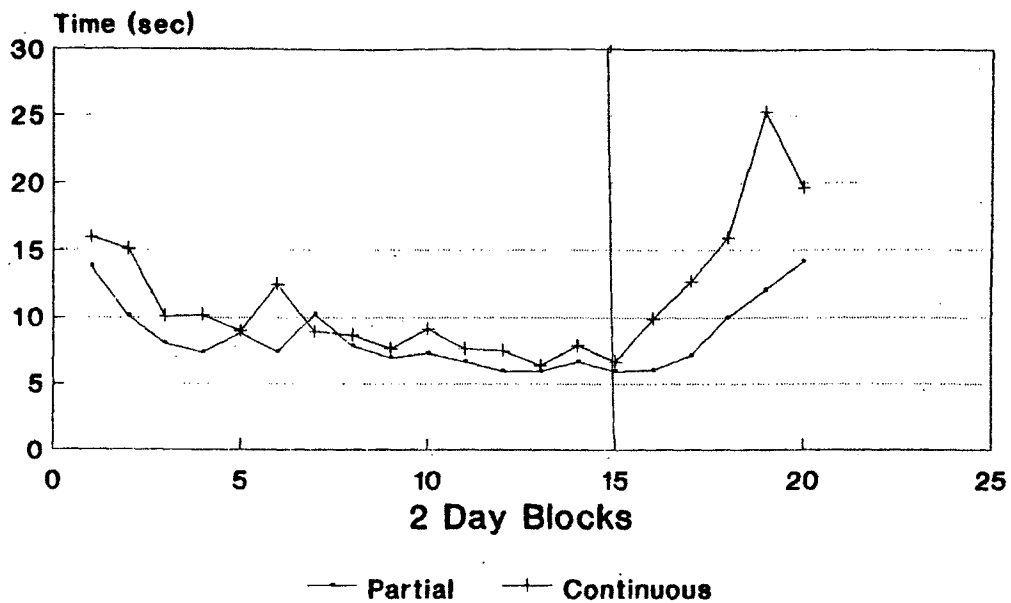


Figure 11

80 Grams
Partial & Continuous

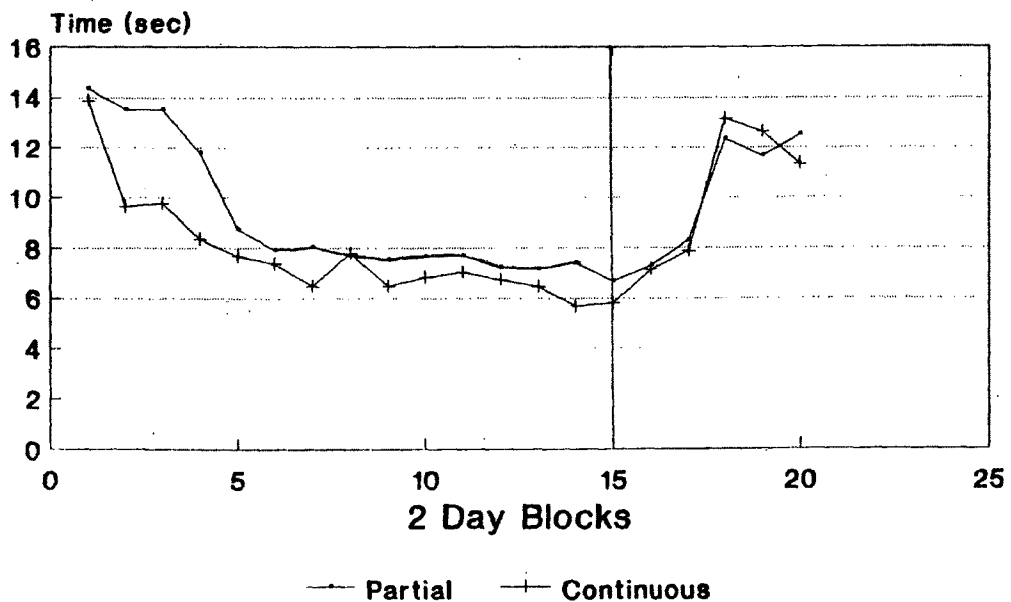


Figure 12

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Table 1

<u>Days</u>	<u>Trials</u>							
	1	2	3	4	5	6	7	8
1	N	R	N	R	N	R	R	N
2	R	N	N	N	R	N	R	R
3	R	N	N	R	N	R	R	N
4	N	R	R	R	R	N	N	N
5	N	R	N	R	R	R	N	N
6	N	R	N	R	N	N	R	R
7	N	N	N	R	R	R	N	R
8	R	N	R	R	N	N	N	R
9	R	N	N	R	N	N	R	R
10	R	R	N	N	R	N	R	N

Partial reinforcement schedules used with the four partially reinforced groups (R = rewarded trial, N = non-rewarded trial). If more than 10 days of acquisition training are required, the sequence will repeat itself starting at day 1 and continuing as long as necessary.

Table 2ANOVA for the Average Daily Octile RunningTimes in Acquisition

<u>Source</u>	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
<i>BETWEEN</i>					
SS/Tension x Condition	91.09	51	1.79		
Tension	11.67	3	3.89	2.18	.102
Condition	5.75	1	5.75	3.22	.079
Tension x Condition	1.31	3	3.77	2.11	.110
<i>WITHIN</i>					
Days x SS/Condition x Tension	1.72	204	.25		
Days	3.09	4	.77	3.04	.018
Tension x Days	2.23	12	.19	.73	.717
Condition x Days	.98	4	.25	.97	.425
Tension x Condition x Days	5.10	12	.43	1.68	.074
Octile x SS/Condition x Tension	431.85	357	1.21		
Octile	742.09	7	106.01	87.64	.000
Tension x Octile	89.79	21	4.28	3.53	.000
Condition x Octile	20.82	7	2.97	2.46	.018
Tension x Condition x Octile	37.46	21	1.78	1.47	.083
Days x Octile x SS/Condition x Tension	257.65	1428	.18		
Days x Octile	13.10	28	.47	2.59	.000
Tension x Days x Octile	13.94	84	.17	.92	.682
Condition x Days x Octile	5.14	28	.18	1.02	.440
Tension x Condition x Days x Octile	19.61	84	.23	1.29	.042

Table 3ANOVA for the Average Daily Octile RunningTimes in Extinction

<u>Source</u>	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
<i>BETWEEN</i>					
SS/Tension					
x Condition	143.43	46	3.12		
Tension	14.50	3	4.83	1.55	.214
Condition	13.21	1	13.21	4.24	.045
Tension x Condition	11.73	3	3.91	1.25	.301
<i>WITHIN</i>					
Days x SS/Condition					
x Tension	169.75	414	.41		
Days	131.78	9	14.64	35.71	.000
Tension x Days	15.29	27	.57	1.38	.099
Condition x Days	2.75	9	.31	.75	.668
Tension x Condition					
x Days	6.26	27	.23	.57	.963
Octile x SS/Condition					
x Tension	168.95	322	.52		
Octile	104.75	7	14.96	28.52	.000
Tension x Octile	15.93	21	.76	1.45	.095
Condition x Octile	11.94	7	1.71	3.25	.002
Tension x Condition					
x Octile	8.24	21	.39	.75	.782
Days x Octile x					
SS/Condition					
x Tension	271.06	2898	.09		
Days x Octile	12.19	63	.19	2.07	.000
Tension x Days					
x Octile	19.41	189	.10	1.10	.178
Condition x Days					
x Octile	6.94	63	.11	1.18	.160
Tension x Condition					
x Days x Octile	17.65	189	.09	1.00	.494