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Degree of Hunger in the Rat: A Review of the Psychological Literature

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COLLEGE OF WILLIAM AND MARY

Thesis

DEGREE OF HUNGER IN THE RAT:
A REVIEW OF THE PSYCHOLOGICAL LITERATURE

Submitted by

Donna Lee Erdahl

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the Degree of Master of Arts

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INTRODUCTION

Studies of drive began about 1920, and since that time they have steadily increased in number. With a cursory look at the literature one finds certain trends in experimentation, but more generally, confusion. This confusion arises mainly from the lack of similarity of methods and techniques which have been used. It seems, therefore, that at this time a careful review of the literature on drive, with particular emphasis on methods and results and their agreement or disagreement with existing theory, is needed. With this in mind the following paper has been written. The studies reviewed are, for the most part concerned very specifically with hunger drive. However, in many instances studies have been included which deal with thirst drive because of their relevance to theoretical issues. For the same reason it has been necessary to deal with certain studies of irrelevant motivation. In these tangential areas no attempt has been made to cover all of the literature.

Most investigators have used albino rats as subjects. There are some exceptions, however. This paper will not indicate the strain or sex of animals. In general, when animals of both sexes have been used there is some attempt to equate the experimental groups for age and sex.

In the first section have been included the early studies of drive, i.e., up to about 1940. This date has been selected because until that time there had been little theoretical organization. Since 1940 certain trends of experimentation can be readily seen. The second and third sections deal with the effect of drive on learning and on the performance of a learned response. In these areas there are specific theories which have been examined. The fourth section includes the problems of adjustment to feeding schedules, their effect on intake, and the effects of varied periods of deprivation on intake and activity.

EARLY STUDIES

The Obstruction Method

In determining motivational strength J. J. B. Morgan was the first to provide a principle. He stated that "the amount of inhibition necessary to overcome any tendency may be used as a measure of the strength of that tendency". (57, p. 94) Several investigators have followed this line of thought and devised some sort of resistance which must be overcome by the animal if a specific drive is to be satisfied. In his study of motivation Moss (58) manipulated drive by depriving the animals of food for varying periods prior to testing. His basic thesis was that "the behavior of any animal is the resultant of his drives to action and the opposing resistances." His primary objective was to develop a method for numerically measuring drives and resistances. Strength of drives was indicated by the number of animals crossing an electric grid in a uniform period of time. Periods of deprivation ranged from 12 hours to 72 hrs. He found that with a 72-hour hunger drive, 8 out of 10 animals will overcome the resistance of 28 volts, and he called this a threshold. In the same study Moss compared the strength of the hunger and sex drives by pitting them against one another. When rats were given a choice between an animal of the opposite sex and food, it was found that a 72-hour hunger drive was in most cases stronger than a sex drive. This predominance of the hunger drive over the sex drive was true of both sexes when both drives are at their maximum.[1]

Although Moss' work was exploratory, it provided a general method of attack on the problem of motivation and suggested many problems for further research in this area. For example, the Columbia Obstruction Method was developed and standardized by Jenkins, Warner, and Warden (42). In this Columbia Obstruction Box there were 3 compartments: an entrance compartment, an obstruction compartment with a grid floor and two glass plates to prevent the animal from jumping over the grid, and an incentive compartment. One advantage of the box was a better electrical unit which allowed precise regulation of the intensity of shock. Thus, individual differences in susceptibility to shock could be minimized by giving a greater intensity of shock to heavier animals, and less to lighter animals.

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[1] The problem of the relative strength of different drives was investigated in many early studies. Following the lead of Moss, Munn, in his review (59), reports that several investigators gave rats a choice between food and a sexual partner. Their results showed in general, that food preferences for rats as a group were much more frequent than sex preferences. There are also numerous studies which compare the relative efficacy of different drives in a learning situation. For example, Bruce (12) found a 24-hour hunger drive was more effective than a 24-hour thirst drive in a maze situation.

At about this same time Holden (36), in a more carefully controlled study, was using the Columbia Obstruction Method to determine the effect of systematic variation of the period of starvation upon drive behavior when a constant amount of electrical stimulation was employed in the obstruction section. She defined hunger drive as "nothing more than that the animal displayed a food search response." Prior to training, the animals were placed on a feeding schedule for one week, being fed once daily. Then on three consecutive days the rats were given preliminary training, during which they were allowed to explore the box for 10 minutes. The test periods were 10 minutes, and took place between 3 and 6 p.m. The rat was placed in the entrance compartment and if he crossed the grill was placed again in the entrance compartment. He was allowed to nibble food in the incentive compartment after every third crossing. There were 6 different starvation periods ranging from 12 to 72 hours. With low intensities of shock Holden found that the hunger drive, as measured by numbers of crossing, tended to increase as the starvation period was increased from 12 to 36 hours, and decreased after 36 hours starvation. With higher intensities of shock the same effects were noticed, but the variability of numbers of crossings within each group seemed to obliterate any group differences. Holden stated that greater intensities of shock do not give adequate measures of the relative effect of different periods of starvation.

Also using the Obstruction Box, Warner (83) subjected his rats to periods of starvation of 0, 2, 3, 4, 6 and 8 days. His results were similar to those of Holden in that the curve showing number of crossings as a function of length of deprivation had a maximum point at one of intermediate starvation intervals. However, his values for the period of deprivation which gives greatest drive (as reflected by number of crossings) were slightly higher than those of Holden. Warner reported that the mean number of crossings increased up to 3 days starvation, but he noted sex differences. The point of greatest hunger was at 2 days deprivation for females (this value is close to the one noted by Holden) and at 4 days deprivation for males.

Another type of obstruction box was devised by Stone (73) in 1937. It consisted of a tube shaped like a stovepipe with a 90-degree elbow at the bottom, which was filled with sand. The animal was required to paw a passage through the sand in order to reach to the incentive. One measure of strength of motivation was the number of times in 20 minutes that the rat pawed through the sand.

Also using "resistances" to be overcome by the animal in order to secure reinforcement, Crutchfield(16) deviated from the usual obstruction box approach and devised a method of studying strength of motivation by determining the energy expended in a string-pulling response. Results were reported in terms of the length pulled to obtain food, the time taken and the velocity of such pulling. His findings showed that rats which were 24-hours hungry at the time of the test trials pulled in greater lengths than did those who were 12- or 48-hours hungry. His main concern, however, was with the relationship between energy expended on training trials and on the test trials. He reports that the rats tend to reproduce in their test-trial-pulling certain "energy expenditure" characteristics of their previous training trial pulling.

Activity Studies:

Another method used to determine the strength of motivation was to record activity of the rat as a function of length of deprivation. One of the most complete studies of this type was one done by Richter (66) in 1922, in which he used a cage mounted on tambours. Animals were placed in a situation free from all external stimulation in constant complete darkness. He studied the spontaneous activity of the rats under two different conditions. In the first condition, the animals were fed once a day, usually at noon, and allowed to eat for 25 minutes. He found that activity in the first 12 hours following feeding is much greater than activity in the 12 hours just prior to feeding. He also noted that the periods of greatest activity occured between about 5 p.m. and 1-2 a.m. This was followed by a period of almost complete inactivity until 2 to 3 hours before feeding. Secondly, Richter found that when the animals were deprived of food entirely, activity increased for the first 2 or 3 days of starvation, and then steadily decreased. Although he was interested primarily in the effects of starvation on activity, rather than on overcoming some resistance, this study seems to show a maximum point of the hunger drive after approximately the same period as that reported by Holden and Warner. In another situation in which the rats had free access to food Richter (67) found that the periods of activity and inactivity seemed to come and go with the same regularity found previously. Also within each activity period the time spent in the food box was short compared with the length of the entire activity period. It was observed that there was a period of general activity before the animal exhibited food-seeking behavior. The active periods alternated with quiescent intervals every hour and a half or two hours. In a later study by Hunt and Schlosberg (38), Richter's short cycles of activity appeared, but the data show great variability among animals. Their results also agree with Richter's in that the curves of diurnal variation showed the greatest amount of activity during the dark hours.

In 1937 Heron and Skinner (33) measured strength of motivation by counting the number of responses to a lever during the same one-hour period each day. This method involved previous conditioning of the animals to press a bar in order to secure food. Before beginning the starvation period the rats had continuous access to food for 24 hours. Thereafter they were allowed only that food which they received every 4 minutes during the daily 1 hour period in which the number of responses was measured. (The periodic reinforcement was provided in order to avoid extinction.) The results showed that hunger, as measured by the number of responses to the lever per hour, increased with the period of starvation until a maximal degree is reached. After this point the rate of responding declined rapidly until death results from inanition. The curve for change in mean rate of responding during starvation reached its peak after five days of starvation. However, the individual records showed much variability, and the mean rate was found not to be a reliable indication of the extent or course of hunger in the individual. The typical curve for a single rat showed a steady rise throughout the greater part of the period before death.

Another approach to the problem of the effects of deprivation on activity is found in a study by Bousfield and Elliott (8). They were concerned with the relation between hours of deprivation and eating behavior during limited feeding periods. They delayed feeding randomly for periods of 3½, 12, 24 and 48 hours. They found that with longer periods of delay the amounts of food consumed during a one-hour feeding period remained relatively low for 2 or 3 days, and there was a marked irregularity in intake when the periods of delay were varied. Also with longer periods of delay before feeding there was a decrease in the amount eaten. In a second experiment they found that with delays of 1, 2 and 3 days, the rate of eating progressively decreased during the one hour eating period. In general, then, with 3½, 12 and 24-hour delays there is evidence of a rhythmic effect within the eating period. However, with longer fasts, and a resultant decrease in amount of intake, the rats ate more steadily and persistently. In another article by Bousfield and Elliott (9) they discussed the different methods used in controlling hunger drive. They feel that the technique used in their experiment, i.e., complete deprivation for a specified number of hours, is the method open to least criticism. They pointed out that even this has its drawbacks - it does not take into account the rhythmic changes associated with periodic hunger-contractions.

This brings forth the necessity of a feeding schedule prior to training. They found that a single daily feeding was sufficient to maintain growth after the age of 3 to 4 months provided that sufficient time (1½ to 2 hours) was allowed for eating. When periods of deprivation longer than 24 hours are used there must be longer interval between test trials to allow the animal to make up the deficit incurred during the deprivation period. In conclusion Bousfield and Elliott stressed the point that there should be standardization of methods of controlling the internal conditions which constitute the core of motivation.

Thus far two techniques utilized by early investigators have been examined. In one the strength of drive is measured by the number of times an animal will overcome a specific resistance, e.g. electrical shock, after varying hours of deprivation. In the other, some measure of activity level is employed after varying lengths of deprivation. In general, it has been concluded that drive strength increases up to a maximum point and then decreases. Investigators have found this maximal value to occur anywhere between 1 and 5 days of deprivation.

Optimal drive for learning

Turning now from the effects of hunger on spontaneous activity and general eating behavior, we find in the literature many experiments dealing with the level of drive which will produce the most efficient learning. Here we find a great variety of methods used to produce different degrees of drive, coupled with the use of many different learning situations, and the emergence of some rather general and vague theories of motivation. As early as 1917, Dodson (20) reported a study of the effects of varying degrees of motivation on the learning and retention of a black-white descrimination. Although Dodson had no previous articles to which to refer, he was relatively successful in designing a technique for manipulating drive, a design which has been generally followed, with modifications, by many investigators even to the present day. Prior to training, the animals were placed on a feeding schedule, with feeding periods twice daily. The different hunger conditions under which training took place were produced by depriving the rat of food for 24, 31, 41 or 48 hours. Training trials were given between 3 and 5 p.m. Ten trials were given every three days to allow the 48-hour deprivation group to repair their deficit. He found that for different degrees of hunger there was a rapid increase in the rate of habit formation (as measured by the number of trials to criterion) up to 24-hours of hunger, then aslower increase to 41 hours, and a sudden decrease from 41 to 48 hours of hunger. When the animals were tested for retention there were no marked differences in the groups. Dodson concludes that maximum hunger is reached somewhere between 41 and 48 hours, and that motivation is important to learning but not retention.

Over 10 years later Ligon (53), following the lead of Dodson, used shorter intervals of deprivation and recorded running time in a maze. The maze was composed of 7 compartments, and to get from one to another the rat had to step on a trap to release the doors between the compartments. The animals were run 0, 6, 12, or 21 hours after feeding and given one trial daily for 25 trials. The group deprived of food for 21 hours was superior to those deprived of food for shorter intervals of time. However, the 6-hour group was superior to the 12-hour group. The group which ran the maze immediately after feeding was the poorest.

Interest in the effects of hunger on maze learning was also shown by Tolman, Honzik and Robinson (80). In their experiment a maze was used in which the correct path was straight ahead. There was a longer and shorter blind to either side. The method of producing varying degrees of hunger was slightly different than any encountered thus far. The animals in what they called the 'less hungry group' were fed enough to gain weight. In the 'hungry' group the animals were fed sparingly in order to lose weight. The hungry animals learned the maze much more rapidly than less hungry rats.[2] Tolman, Honzik and Robinson also found that a decrease in hunger caused an increase in long-blind entrances relative to short blind entrances. They hypothesized that for less hungry rats the long blind offers more opportunity for random curiosity, and is thus more distracting and eliminated less readily. This suggested that when animals in a maze are more highly motivated, their behavior is more characteristically food-seeking, and is less variable. Elliott (24) confirmed this observation that motivation decreases variability. In his experiment he used a maze which had 3 alleys leading from a wedge shaped compartment, all paths being equally rewarded. When rats were sufficiently hungry they tended to choose a particular path more frequently than the less hungry animals.

In a series of lengthy experiments E. E. Anderson (1, 2, 3, 4) worked out and tested a theory of maze learning which he called "externalization of drive". His studies began with the interrelationships of different drives in a battery of tests, and the results indicated that with repeated and

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[2] In another experiment in the same laboratory (79) it was shown that in a 14-unit T maze, hungry rats learned the maze more rapidly than less hungry animals, when performance was measured by both running time and errors.

varied testing there seems to be a "general drive" factor influencing performance on a large number of the tests. He proposed that a drive such as hunger is originally aroused by internal conditions of the organism, but with continued arousal the drive mechanism which leads to persistent and motivated behavior gradually becomes arousable by characteristics of the external situation. In order to test this hypothesis he did an experiment (3) in which rats were tested on 3 different mazes under different motivational conditions. More specifically, all animals were first trained on a 14-unit T-maze prior to their daily feeding. Next the animals were divided into groups and tested on a 6-unit T-maze under conditions of hunger or satiation (rats in this group were fed directly before the daily run). The results of this first test showed that the hungry animals learned the second maze faster than the satiated animals. However, there was evidence of learning under the satiated condition. When the rats were tested on a third maze (a 12-unit double-alternation maze) under the same motivational conditions, the results in terms of errors were similar for both groups. When the experimental groups were compared with the control group, which had no previous practise on the first maze, it was found that rats with previous maze experience do better, whether they are satiated or hungry, than rats which have had no previous maze training. Anderson interpreted these results as supporting the theory of "externalization of drive".

Anderson elaborated his theory testing it in a study (4) of the effect of pre-feeding on maze performance when the rats were hungry but received no food reward. If the phenomenon called "externalization of drive" is present in maze learning then, he proposed, presentation of a reward before the animal is put in the maze should improve the performance by increasing the degree of arousal of the drive, even though there is no food reward at the end of the maze. To test this he gave rats a number of trials on a 6-unit maze under conditions of hunger and no food reward. During the test periods the animals were allowed to eat a small amount of food before running the maze. His results confirmed his hypothesis, i.e., there was a reduction in error scores with the introduction of prefeeding, although no reward was present at the end of the maze.

A few years later Bruce (12) repeated this experiment with certain modifications. In the first place he used a thirst drive as well as a hunger drive. He also varied the amount of food and water that an animal received before running by giving either 10, 20, 40 or 80 seconds of eating or drinking. With both drives he found that reward prior to training on a 14-unit T maze produced superior performance. Better performance was obtained from thirsty rats than hungry ones when a preliminary reward is given. The significant facet of his results was that a preliminary reward produces a decrease in time scores but not in error scores. This was in opposition to the results of Anderson. Bruce suggested that perhaps the role of motivation in learning had been overemphasized. Motivational stimuli in this case seemed to be more important in the use of a habit already acquired than in the acquisition of a habit. He did not deny, however, the fact that through their effect on performance, motivational stimuli may have some effect on the learning process. Bruce was the first investigator to suggest such a distinction between learning and performance.

Skinner (72) found that the rate of responding in a lever-pressing situation was inversely proportional to the amount of food eaten prior to testing. Though at first this appears contrary to the results reported by Bruce it is not because Bruce was dealing with very short periods of pre-feeding. Skinner pre-fed up to 6 grams. Thus, small amounts of pre-feeding have been shown to give superior performance, but as the amount is increased the effect is to lessen motivational level and subsequent performance.

In summary, it does appear that the amount of drive influences time required for learning and perhaps errors during learning, though the effect on errors is less clear-cut. In addition, however, Bruce has proposed that the <u>major</u> effect of drive on behavior is on performance, rather than on learning.

CURRENT PROBLEMS

Having examined some of the earlier studies of hunger let us now look at the current problems in this area, and the theories and experiments which have dealt with these problems. Around 1940 several studies were published which have been repeated and modified over a period of almost two decades. The purpose of these studies can be roughly divided into two categories: on the one hand there was interest in the effect of drive on learning; and on the other hand, there were many studies of the effect of drive level on performance. Both of these problems are dealt with in Hullian theory (39, 40) and the relationships have been set down in precise quatitative terms. It appears that Hull's theory has been the basis for the majority of the experimentation in this area for several reasons. First of all Hullian theory lends itself to testing more easily than most theories because of its precise nature. Further, Hull deals with the concept of drive to a greater extent than any other theorist. Finally, it is the only theory that has produced detailed statements of the relationship of drive to learning and performance.

One problem inherent in the above discussion is the separation of performance (SER) and learning (SHR). According to Hull (34, 39, 40) habit strength is seen to be a function solely of the number of reinforcements. Thus, drive does not effect SHR per se, but rather SER. Further, SER is also a function of SHR, and the drive level thus has its influence on performance rather than learning. In his interpretation of Hull's theory Hilgard (34, p. 132) states that "... most of the influences . . . . . are upon reaction potential (SER) rather than upon habit strength (SHR). The distinction between performance and learning, so long insisted upon by Tolman, was formally accepted in the 1943 postulates, but by now has greatly reduced the quantitative influence of reinforcement upon associative learning. We would expect the magnitude of each reinforcement to be pertinent in determining the contribution of reinforcement to habit strength, but we are now told that this is not the case, so long as some unspecified minimum of reduction in S_D occurs." Reaction potential, then, is thought of as being the result of four variables; primary drive (D), stimulus-intensity dynamism (V), incentive reinforcement (K), and habit strength (SHR). These variables combine multiplicatively to give SER. In the determination of reaction potential the major magnitude is D rather than SHR. Drive is very important in Hull's system for three reasons: (1) primary reinforcement is dependent upon drive; (2) drive activates habit strength into reaction potential, so that without it there could be no response; and (3) without the distinctiveness of drive stimuli an organism could not learn to go to one place for food when hungry, and to another place for water when thirsty.

Investigators have studied these relationships using a variety of techniques and obtaining a variety of results. One problem which is faced in many studies is that of distinguishing between measurements of performance and measurements of learning. How is it possible to separate and measure accurately either of these variables when the interrelationship between them is complex? In order to study the effect of drive on habit strength and reaction potential perhaps we must look at each problem separately, examining the techniques used and results of each in turn. Let us first look at studies of the relationship of drive and habit strength.

STUDIES OF THE EFFECTS OF DRIVE ON LEARNING

Methods of varying drive level:

In most studies of the hunger drive the level of motivation is varied by subjecting different groups of animals to varying hours of deprivation (11, 13, 19, 21, 22, 25, 26, 35, 44, 45, 52,55, 61, 74, 76). This is in accordance with Hull's definition of drive. However, this is where the similarity between studies ends. The hours of deprivation to which the animals are subjected vary widely from one study to another, and in only a few experiments are the same values used. The procedure most commonly used is that of first adapting the animal to a feeding schedule, and then, after a certain period of time, feeding him, usually for a specified period of time, a certain number of hours prior to experimentation. This technique points out the following problem which shall be dealt with in another section of this paper. What is the function of a feeding schedule prior to experimentation, and what is the minimum amount of time required for the animal to adjust to periodic feeding?

A second method of varying drive level is to feed the animal varying amounts of food a constant length of time before experimentation. This technique is used exclusively in only one study (65), but is used in conjunction with varying hours of deprivation in some other studies (11, 61).

Apparatus and dependent variables

When drive level has been varied during learning some measure must be made of its effects on the learning process. Does an increase in drive level facilitate learning or does it have no effect on the learning process? The techniques used to answer this question vary somewhat with the type of apparatus used. Let us first examine types of apparatus and the dependent variables used before turning to experimental designs and results. Some investigators have employed the Skinner Box in an instrumental response type of situation. In this situation the most common measure of habit strength is resistance to extinction. Finan and Taylor (26), Finan (25), and Strassburger (74) used the number of responses during extinction and extinction time as indices of the resistance to extinction. Strassburger also added to this list the rate of responding during extinction. Kendler (43) using irrelevant drive during learning and extinction, also measured the number of responses to extinction. Learning time was used by Finan and by Strassburger as another index of the effect of drive. In this case the animal, after a period of adaptation to receiving food in pellet form with an accompanying click, was required to press the lever a constant number of times to receive food. The total time in minutes for this learning process was recorded. In these experiments differences between the various deprivation groups with respect to the measures employed were thought to reflect differences in habit strength due to the motivational conditions present at the time of learning, i.e., it is expected that with an optimal drive level during training learning time will be shorter, there will be a greater number of responses to extinction, the time required for extinction will be longer, and the rate of responding during extinction will be more rapid.

Runways of various lengths have been employed in several experiments (13, 19, 52, 61, 65). Running time, i.e., the time required to run from a starting box after the door is opened to the goal box is, quite naturally, one of the measures of habit strength used in each of these studies. Reynolds (65), Lewis and Cotton (52), and Campbell and Kraeling (13) used a constant number of learning trials followed by a series of extinction trials in which there was no reinforcement in the goal box, and measured <u>running times</u> during both sets of trials. During extinction they also measured the <u>number of trials to extinction</u>. In a slightly different situation O'Kelly and Heyer (61) continued learning trials until the median running time showed three successive trials without significant improvement. Retention tests were run after 3 and 6 weeks. <u>Latencies during retention</u> were compared to those during learning to determine any effects which drive might have had on habit strength. The use of a learning criterion introduces another problem. Any significant differences which are found between the motivational groups may be due in part to the fact that animals reach the criterion after differing numbers of reinforcements during training.

A few studies have been done using mazes (35, 45, 55, 76). With this type of apparatus there is another dependent variable which can be measured - the number of errors during learning and test trials. MacDuff (55) and Hillman, Hunter, and Kimble (35) used the number of errors during learning and retention as a measure of habit strength. MacDuff, using a 16-unit T-maze, measured the number of trials, the number of errors, and learning time required to reach a learning criterion, the number of errors on a retention test 6 weeks later, and the number of trials and errors for relearning. Hillman, Hunter and Kimble, using 15 training trials on a 10-unit T-maze, measured time and error scores during learning and test trials which were conducted under changed amounts of deprivation. In a single T-maze Teel (76) also employed a learning criterion and subjected the animals to extinction, measuring in both cases the number of trials to the criterion. Kendler and Mencher (45) used a single-unit T-maze during learning, and gave test trials on a maze with 6 radiating alleys. They counted the number of correct responses during testing, a correct response being one which was reinforced.

There are two studies which use a brightness discrimination problem to test the effects of varying motivational levels on learning (21, 22). Eisman, Asimow and Maltzman (22) used a learning criterion followed by a test period. Number of errors during learning and the number of trials to the criterion were measured. The test period in this casewas reversal training, i.e., the animal was rewarded when he went to the stimulus which had been previously unreinforced. They have a rather unusual measure of resistance to extinction. They used the number of responses during testing to the previously positive, reinforced stimulus as an index of resistance to extinction. This eliminates the use of an extinction criterion. Using a learning criterion also, Eisman (21) recorded the number of errors and trials during acquisition.

To summarize, Skinner boxes, straight runways, T-mazes, and discrimination boxes have been used to study the effects of drive on habit strength. The dependent variables in these studies vary with the type of apparatus. Common to the Skinner box studies are measures of resistance to extinction. In runways all investigators have measured running times. With maze and discrimination problems the prevailing measure has been number of errors.

Types of experimental designs

There are two main experimental designs which have been used in studies of the effect of drive on the learning process. In the first method, learning for the different experimental groups takes place under varying motivational conditions and then the animals are tested under constant drive level to discover if there are any differences between the groups with respect to degree of habit strength. This technique was used by the earlier experimenters in this area, but it is not the most common one. Most investigators, have utilized a second design - a 2x2 factorial. Here each experimental group is trained under a different motivational level. Then the groups are subdivided with each of the subgroups representing one of the motivational conditions under which training took place and then tested. The data is treated by the analysis-of-variance technique and the effects of drive upon habit strength and performance can be separated. Any effect on habit is demonstrated if the measures obtained on the test trials are significantly different for the animals trained on the learning trials under different degrees of motivation. An effect on performance is demonstrated if the same measures are significantly different for animals run under the different motivational levels on the test trials. Let us now look at these experimental designs more carefully and the results which have been obtained using each.

Results

__Studies in which drive is varied during learning and constant during testing__. In this group of experiments Strassburger (74) alone reports results which are consistent with Hull's theory, i.e., which demonstrate that habit strength is independent of drive at the time of learning. He used deprivation periods of ½, 1, 4, 11, 23 and 47 hours during acquisition of a bar-pressing habit, and extinguished all groups under a constant deprivation period of 23 hours. 30 reinforced acquisition trials were given to animals under 4, 11, 23 and 47 hours drive; 10 reinforcements were given under ¼, 1, 4 and 23 hours deprivation; 1 reinforced response was given under conditions of 1, 11, 23 and 47 hours deprivation. There were from 10 to 12 animals in each of these 12 experimental groups. Strassburger found that there were no significant differences between the groups with respect to resistance to extinction, even though the total time required to complete the reinforcement process was significantly shorter under 11 and 23 hours of deprivation than under 47 hours deprivation, but he concluded in addition that the effect of reinforcement upon the strength of a bar-pressing response is not modified by deprivation periods from ½-hour to 47 hours.

The Strassburger experiment is a replication of the Finan (25) study, which reported quite different results. Finan had earlier given 30 reinforced training responses under deprivations of 1, 12, 24 and 48 hours and extinguished all groups under 24 hours deprivation. He found that the mean number of responses during extinction increased from 1 to 12 hours of deprivation and dropped off at 24 and 48 hours deprivation. The only significant difference between groups, however, was found between the 1- and 12-hour groups. These results were similar to those of an earlier experiment by Finan and Taylor (26).

MacDuff (55) used the same amounts of deprivation during learning as Finan with the exceptions of the 1-hour group. However, in her experiment each series of training trials was separated by an interval of 1 week, and the trials were continued until a learning criterion of 8 errors or less on a 16 unit T-maze was reached on 3 out of 4 successive trials. In the second part of the experiment MacDuff used massed training trials to the same learning criterion. Retention tests were given after 6 weeks in the first part and after 2 weeks in the second part. The results showed that in both cases the animals run under stronger drive made fewer erros during learning than rats run under weaker drive. Also there was better retention with a stronger drive, as shown by both the number of errors made and the mean number of trials to relearn the maze. MacDuff interpreted the superiod retention of the 48-hour group to the fixative qualities of stronger motivation.

Using thirst rather than a hunger drive, O'Kelly and Heyer (61) obtained results similar to these of MacDuff. With a single trial per deprivation period, they continued training trials until the median running time on a runway showed 3 successive trials without significant improvement. Training trials were run under conditions of 11½ and 35½ hours of water deprivation. And additional group was used in which the animals were deprived of water for 35 hours, and ½ hour before running they were given 2/3 of an average 36-hour total water intake. The retention tests were given after 3 or 6 weeks. The 35½-hour group showed the greatest efficiency of performance during learning, and on retention tests after both 3 and 6 weeks. The effect was more pronounced after 3 weeks without practise than after 6 weeks. O'Kelly and Heyer stated that their results were contrary to Hullian theory. The motivational variable was significant.

One further study must be mentioned here. Reynolds (65) attempted to vary drive level at the time of training by varying the amount of food given a constant number of hours prior to training trials. He hoped that the use of this technique would give results contrary to those of Finan and MacDuff, and thus lend support to Hull's hypothesis. Reynolds first subjected his animals to a 24-hour maintenance schedule, feeding them 12 grams daily. Then he fed the low drive animals 12 grams and the high drive animals 3 grams at their usual feeding time, and gave them 25 training trials 24 hours later. Extinction trials were carried out on the fifth day following training at 24 hours deprivation. Reynolds found that, under these conditions, training with a lower level of drive will elicit a greater number of trials to extinction than when animals are trained with a higher level of drive, when level of drive is equated before extinction. However, he interprets his results to mean not that habit-strength of the low drive group was greater, but rather that the habit acquired by the high drive group had a greater amount of conditioned inhibition within it because of the shorter latencies of the high drive group. Thus the high drive animals showed a faster rate of extinction.

It has been seen that when drive is varied during learning and habit strength is subsequently tested under a constant motivation, most investigators have found an optimal drive level for learning. Strassburger alone has reported conclusive results showing that habit strength is not a function of drive at the time of acquisition.

Studies in which a 2x2 factorial design is used. A 2x2 experimental design has provided a greater number of studies which find that drive level at the time of learning has no significant effect on habit strength. In this method a constant number of training trials is usually given. Although the total number of training trials varies from one study to another there are three studies which report similar results (13, 35, 76). Teel (76) used 56 training trials on a maze, ¼ of which were forced to insure equal number of reinforced and unreinforced runs for all animals; Hillman, Hunter and Kimble (35), using water deprivation, gave one maze trial a day for fifteen days; and Campbell and Kraeling gave two trials a week on a runway for 7 weeks. The deprivation intervals used during training vary as much as the number of training trials given. Teel used 1, 7, 15 and 22 hours of deprivation; Hillman, Hunter and Kimble trained under 2 and 22 hours of water deprivation; and Campbell and Kraeling used 12 and 60 hours deprivation for learning. Despite this lack of similarity in the independent variable values the results of these three studies support Hull. Teel found that an analysis of variance, performed on extinction data, indicated lack of significant differences in SHR resulting from variations in drive strength during conditioning. Hillman, Hunter and Kimble reported that there was no evidence that the number of errors was related to strength of motivation at any point; and that the learning curves showed that speed of running seemed to depend almost entirely upon motivation during the trials when it was measured. An analysis of variance showed that the only significant experimental contribution to variability was that from the motivational level at the time that the measures were obtained. Campbell and Kraeling found that, using mean running speeds, the variance attributable to drive level during training was significant, whereas variances due to drive level during extinction and the interaction were not significant. An analysis of the resistance-to-extinction data showed no significant differences between any of the four groups.

A modified factorial design was used by Deese and Carpenter (19). They gave 24 training trials on a runway either 1 hour prior to daily feeding or 1 hour following the daily feeding, and then reversed the drive levels for the two groups. When the drive level was changed the animals trained under low drive immediately reached the asymptote established by the animals under high drive. Deese and Carpenter interpreted this as indicating that training under low drive had been as effective as that under high drive.

There are several other studies which support these findings and are thus in accordance with Hull's position. These conclusions, however, are only incidental to the main purpose of the experiment. Kendler (43 reported an experiment in which the hunger (rewarded) drive was indirectly affected by manipulating water intake. In this study 30 food reinforcements were given during training under conditions of either 12 or 22 hours of water deprivation. With a 2x2 design, by comparing groups which had the same motivation during acquisition but different motivation during extinction, Kendler found no difference between the effects of a 12 and 22 hour co-existent thirst drive during extinction. He concluded that variation of the additional drive (thirst) did not affect the acquisition of the bar-pressing response.

In another study Kendler and Mencher (45) investigated the effects of motivation on spatial learning. After 20 training trials on a T-maze, under conditions of 6 or 21 hours of deprivation, the animals were given test trials in which they could go down one of six radiating alleys. Only the alley leading to the previous location of the food was reinforced on test trials. It was found that the intensity of motivation during the training series had no effect upon the amount of spatial learning shown in the test series.

There is one other study which might be said to agree with the Hullian position. Brown (11) investigated the habit strength of a new response reinforced only by secondary reinforcement, and found that the hunger drive does not affect the secondary reinforcing power acquired by a neutral stimulus.

In the only experiment of this section which gives conclusive contrary results, a learning criterion was employed rather than a constant number of training trials. Using deprivation intervals of 4, 22 and 46 hours, Eisman, Asimow and Maltzman (22) trained animals to a criterion of 14 correct responses out of 16 trials. An analysis of variance revealed signifiant differences in resistance to extinction as a function of the drive during learning. The 4- and 22-hour groups did not differ significantly, but the 46-hour group was significantly different from the other 2 groups at Beyond the .01 level. The authors concluded that SHR bears some functional relationship to drive during learning. But as was pointed out earlier, the use of a learning criterion complicates the findings. Lewis and Cotton (52) report a study that offers only a tentative conclusion that drive does affect habit strength.

A final study must be noted. Eisman (21), using varying hours of deprivation, employed a new parameter of drive, i.e., the hours of deprivation during a unit of time. He proposed that when animals are deprived 47 out of 48 hours varying the number of hours of deprivation at time of measurement will not produce differences in learning. With respect to mean number of errors and trials to reach the learning criterion, this hypothesis was verified and the animals that were deprived 47 out of 48 hours performed significantly better than those which were deprived 24 out of 25 hours.

Summary

A variety of methods of studying the effect of drive on learning have been reviewed. The types of apparatus employed in the study of this problem are: Skinner boxes, straight runways, and T-mazes. In most studies drive level is varied by subjecting different experimental groups to varying hours of deprivation prior to acquisition and/or testing. There are two main experimental designs. In the first, drive is varied at time of acquisition, and all animals are tested under a constant drive level. With the second design, a 2x2 factorial design, drive is varied both at the time of acquisition and at the time of testing. It has been noted that with only one exception all those studies using the first method have found an optimal drive level for learning. However, studies in which drive is varied during both learning and testing have generally concluded that there are no differences in habit strength as a function of drive at the time of learning.

TABLE I: SUMMARY OF STUDIES OF THE EFFECTS OF DRIVE ON LEARNING

	Length of feeding schedule	No. of reinfs. during learning	Learning to Criterion	Drive at time of learning	Apparatus used	Drive at time of testing
Brown	?	20	-----	22 hrs.food dep.; 12,22 hrs.wat.dep.	Skinner Box	22 hrs.food dep.; 12,22 hrs.wat.dep.
Campbell & Kraeling	?	14	-----	12, 60 hrs. food dep.	4 foot runway	12,60 hrs. food dep.
Deese & Carpenter	9 days	24	-----	run either before or after feedin	3 foot runway	run either before or after feedin
Elsman	2 weeks	------	14 trials out of 16 correct		Black-white discrim.	-----
Elsman, Asimow, & Maltzman	21 days	------	14 trials out of 16 correct	4, 22, 46 hrs. food deprivation	Black-white discrim.	4, 22, 46 hrs. food dep.
Finan	5 days	30	-----	1, 12, 24, 48 hrs. food dep.	Skinner Box	24 hrs. dep.
Finan & Taylor	4 days	30	-----	1, 12, 24, 48 hrs. food dep.	Skinner Box	24 hrs. dep.
Hillman, Hunter, & Kimble	2 days	15	-----	2, 22 hrs. water dep.	10 unit T-maze	2,22 hrs. water dep.
Kendler	?	30	-----	22 hrs. food dep.;12,22 hrs. wat.dep	Skinner Box	22 hrs.food dep.;12,22 hrs.wat.dep.
Kendler & Mencher	7 days	20	-----	6, 22 hrs. food dep.	6 choice maze	6,22 hrs. food dep.
Lewis & Cotton	7 days	30	-----	1,6,22 hrs. food dep.	4 foot runway	1,6,22 hrs. food dep.
MacDuff	10 days	------	less than 8 errors of 3 out of 4 tr	12, 24, 48 hrs. food dep.	16 unit maze	24 hrs. dep.
O'Kelly & Heyer	?	------	3 trials with no change	11½, 35½ hrs. water dep.	12 foot runway	11½ hrs. dep.
Reynolds	several weeks	25	-----	Pre-feeding 3 or 12 gms.	20 foot runway	24 hrs. dep.
Strassburger	4 days	1, 10, 30	-----	½,1,4,11,23 47 hrs. food dep.	Skinner Box	23 hrs. dep.
Teel	?	56	-----	1,7,15,22 hrs. food dep.	Single unit T-maze	1,7,15,22 hrs.food dep.

STUDIES OF THE EFFECTS OF DRIVE ON PERFORMANCE

Methods of varying drive level

In this group of studies again the predominant definition of drive is in terms of hours of deprivation (11, 14, 15, 17, 18, 30, 32, 37, 47, 54, 62, 63, 68, 69, 77, 84, 87). With only two exceptions (41, 46) the investigators in this area have varied drive level by prefeeding a constant amount at a varying number of hours before testing. Kimble (46) used this technique with higher levels of drive, but for testing under conditions of low drive he varied the amount of time allowed for eating after 24 hours of deprivation, interrupting feeding after 10 or 15 minutes. There is only one experiment which produced differences in drive by varying the percent body weight. Jenkins and Daugherty (41) using pigeons, trained under 80% body weight and then ran extinction trials under 70 and 90% body weight.

A number of experimenters besides Kimble have examined the effects of a low degree of hunger drive on reaction potential. This has produced a methodological problem of how to insure complete satiation. A procedure such as that used by Saltzman and Koch (69) is usually followed. They placed moist food in the animals' cage for about 1 hour. When the animal had stopped eating the experimenter alternately offered it dry and moist food by hand until the food was refused. After this, the food container was left in the cage until there elapsed a two minute interval during which the animal did not eat.

Apparatus and dependent variables

The most popular apparatus in this series of experiments is again the Skinner box. The number of responses during extinction has been used by a number of investigators as a measure of the magnitude of the reaction potential, when drive level during extinction is varied (11, 32, 47, 62, 68, 69, 88). Sackett (68) also measured the average time elapsing between each conditioning and each extinction response. There are three experiments which used widely differing motivational levels during extinction but which employed identical measures of reaction potential. Perin (62), Koch and Daniel (47) and Saltzman and Koch (69) measured the number of extinction responses, the time required for extinction, and the latency for the first 3 extinction responses. For this last measure, the animal was permitted one extinction response, removed from the apparatus for one minute, retested, removed for one minute and retested again. These recovery intervals were used in the hope that through spontaneous recovery, the major part of the extinction effects resulting from the preceding non-reinforcements would be eliminated. Using an extinction session followed by a relearning session, Brown (11) measured the number of responses during relearning, as well as the number of responses during extinction. Remond (63), in a repetition of an experiment by Loess (54), used a double-bar Skinner box. In this apparatus a series of training trials was given with a free choice trial followed by 2 forced choice trials. On the forced trials only one of the bars was presented to the subject. With this technique measures were made of the latency of response on the forced choice trials, and the percent choices of the more frequently reinforced bar on the free choice trials.

Straight runways have been employed in only two studies. Danziger (17) and Cotton (15) used running time as a measure of the effect of drive level upon performance. Danziger, in addition, measured latency, i.e., the length of time it takes the animal to leave the starting box.

Some modified runways have been used which require the animal to make a discrimination. Cautela (14) used a situation in which the animal had to discriminate between a white and a black alley and measured the number of responses to the learning and extinction criteria, and the number of correct responses during learning. Davenport (18) devised an unusual apparatus with a starting alley and 2 platforms, one of which contained reinforcement. As in the Ramond study, a free choice trial was followed by 2 forced choice trials, and percent choice of the more frequently reinforced side was calculated. The rate-of-approach to the choice point was also measured.

A type of apparatus, involving a panel-pushing response, has been used in a series of experiments studying reaction potential (30, 37, 46, 84, 89). The techniques involved in these studies are, in general, quite similar. The animal is placed in the experimental box, and a guillotine door at one end is raised, exposing a panel. The response required was to push the panel so that it swings open and the animal can obtain food pellets from a cup located behind the panel. When the guillotine door is lifted a timer is started. Pushing the panel open stops the timer, thus giving a latency measure. Horenstein (37) and Webb (84) measured reaction potential during extinction by recording the number of extinction responses and response latencies. In addition Horenstein calculated food intake subsequent to extinction, and Webb measured the total time required for extinction. Kimble (46) and Grice and Davis (30) used what they refer to as test trials during which drive level was varied, and measured running time on these trials. Actually the test trials of Grice and Davis were similar to extinction trials in that no reinforcement was given. In addition to latencies they measured the number of responses and the rate of responding during testing. Kimble, however, provided reinforcement and measured latency only during the test trials. Zeaman and House (89) also dealt with the general problem of drive and reaction potential and used a panel-pushing response, but concerned themselves with escape from a light compartment to a dark one. The implications of this study shall be discussed at a later point.

There is only one experiment which makes use of a T-maze. Teel and Webb gave an equal number of reinforced and unreinforced runs on a single-unit T-maze and reported the percent of correct responses during test trials. A correct response was defined as one to the previously reinforced side.

In summary, studies of the relationship between drive and reaction potential various types of apparatus have been used, e.g., single and double-bar Skinner boxes, runways, discrimination boxes and panel boxes. The measures of reaction potential which have been employed are: resistance to extinction, response latency, percent of correct choice, running time, learning time and food intake.

Types of Experimental designs

In dealing with the problem of the relationship between drive and reaction potential the main technique has been to keep drive level constant during training and then vary drive in a subsequent test period. With this method a predetermined number of training trials are usually given, but in any case, it is always assumed that the habit strength of all animals is equal before drive is varied and test trials are given. In more recent years other techniques have been introduced. These have varied widely and, necessarily, must be dealt with separately.

Results

Studies in which drive level is constant during training and varied during testing.

The paper by Perin (62) represents the most important work in this area, mainly because it served as the model for Hull's theoretical formulations. It is also important however, because the quantative relationship between drive and reaction potential which it presents has been the basis for much disagreement. Prior to Perin's work two studies had been done which exerted much influence on Hull's thinking and Perin's study. The first of these was an experiment by Sackett (68). Although Sackett's results were not significant he suggested that resistance to extinction is decreased by a corresponding increase in drive at the time of extinction. Following this, a paper by Heathers and Arakelian (32) presented evidence that animals with stronger drive make more extinction reactions than do animals with a weaker drive. Their results indicated that extinction effects may be conditioned to a given strength of drive. Heathers and Arakelian proposed that effective strength of a habit varies directly with the strength of the drive present at the time of extinction. With the framework constructed it was left for Perin to give conclusive evidence of the relationship between reaction potential and drive, and to quantify this relationship.

Perin described his experiment as a multi-variable one "in that it is designed to show behavior as a mathematical function of two antecedent variables, the degree of training, and the intensity of the hunger drive present at the time the behavior potential is measured", (62, p. 93). The design was in three-dimensional form with the two independent variables representing two of the dimensions, and the dependent variable, behavior potential, occupying the third dimension. More specifically, Perin had two groups: in the first, drive was held constant at 24-hours and the number of reinforcements given during acquisition of a bar-pressing response, with all groups subsequently extinguished under 3 hours of deprivation. The second group received 16 reinforcements during learning, but extinction took place under varying hours of deprivation. The data for a third group was obtained from a previous experiment by Williams (85). This group was like the first, in that the animals received a varying number of reinforcements on the learning day, but extinction was carried out under 22 hours deprivation. In general, the results indicated that the number of extinction reactions and the time required for extinction are both increasing functions of the number of previous reinforcements and the number of hours food deprivation. Hunger (as defined by the number of hours of deprivation) and the number of reinforcements combine multiplicatively in their determination of the number of extinction responses - the measure of behavior potential. Although there was no group which was extinguished under zero hunger drive, extrapolation from from the curves indicated that a number of non-reinforced responses may be expected under such a condition.

The amount of reaction potential at zero drive has led to a number of studies and much controversy. Koch and Daniel (47) and Saltzman and Koch (69) used a bar-pressing habit of maximum strength (70 reinforcements during training) and low intensities of hunger drive, and found that Perin's theoretical values were incorrect. Perin found relatively high values of behavior strength at zero hunger, with only small increments in the curve as hunger is increased to the 2-hour level. However, the results of the Koch and Daniel study showed near zero reaction potential values at zero hunger. Saltzman and Koch, using values of ½, 1 and 2 hours of deprivation before extinction, found a rapid and progressive build-up of behavior strength. They pointed out that as hunger intensity increased from zero to 2 hours the amount of disagreement between their values of behavior strength and those predicted by Perin progressively decreased. It was suggested that all derivations in Hull's system involving intensities of hunger from 0-2 hours will be incorrect. In a critical review of the Koch and Daniel paper Woodbury (86) interpreted the rapid rise in behavior strength in the first hour after satiation as the result of modification of internal stimuli.

This modification was probably greatest in the first hour after satiation, and resulted in a rapid rise in effective habit strength. Woodbury therefore concluded that Hull's assumption of a linear relationship between drive stimuli and drive strength was incorrect. Danziger (17), though not dealing directly with Hullian theory, found that even under conditions of satiation, behavior will show evidence of the continued action of some sort of hunger drive, provided that the animals had been previously rewarded in the same situation. Danziger used an experimental group which was reinforced during 12 training trials and a control group which received no re-reinforcement during the training trials. When the animals were then run immediately after eating with reward in the goal box, there was a significant difference between the groups. He explained the results in terms of an "externalization of drive" theory similar to that of Anderson (2, 3).

There are three studies (14, 37, 46) which substantiate the combined empirical evidence of the Perin and Saltzman and Koch studies. Kimble (46), using 15 reinforced learning trials in a panel-pushing situation and 0, 2, 8, 15 and 24 hours of food deprivation at the time of testing, reported that there was no increase in behavior strength for about 1 hour after eating to satiation and a sharp rise in the second hour. In the period from 2 hrs. to 24 hrs. after satiation the curve relating reciprocal latencies to hours of food deprivation was similar to that described by Hull. When the drive-controlling operation was prefeeding, it was found that there was a rapid drop in the reciprocal latency associated with an increase in time allowed for prefeeding. This too would be predicted from Hull's theory. Horenstein (37) was interested in describing the manner in which each of three measures of behavior strength - resistance to extinction, latency, and food intake - changed as a function of the strength of the hunger drive at the time of testing. Test trials were given 0, 2, 12, and 23½ hours after satiation. Curves for all three measures showed the sharp rise between 0 and 2 hours deprivation that was reported by Saltzman and Koch. There was a gradual rise from 2 to 23½ hours of deprivation, consistent with the results of Perin. According to Horenstein the habit strength evoked by the stimulus value at which reinforcement occurred (23½) should be the greatest evoked along the stimulus continuum. This pointed to the cue value of drive and suggested that for values greater than the one at which reinforcement occurred, there should also be a decrease in the reaction potential evoked. In the Cautela (14) experiment this was found to be the case. In this study training on a runway took place under 23 hours deprivation to a criterion of 18 out of 20 correct trials, the last 10 being correct. Extinction was carried out under one of the following conditions: 0, 6, 12, 47 or 71 hours deprivation. The curves for responses to extinction increased up to 23 hours deprivation, then decreased slowly to 71 hours deprivation. The author stated that these results are anticipated by Hull. "According to Hull drive acts both as a multiplicative factor with habit strength to produce reaction potential, and as a cue stimulus" (14, p. 302). In this case the stronger drive level (71 hours deprivation) would increase reaction potential, but also would operate to reduce the reaction potential, since its cue value was a generalized one on the stimulus generalization gradient.

One other study, which is revelant to the problem considered in this section, used a pecking response in pigeons (Jenkins and Daugherty, 41). Twenty reinforced responses per day for 5 days were given during training. As noted previously, their method of varying drive level was to vary per cent body weight. In spite of these deviations from most of the other studies, the results clearly indicate increasing numbers of extinction responses with increasing drive, and are in agreement with Hull and Perin.

Thus it appears that when drive level is constant during training and varied during subsequent testing, reaction potential rises sharply in the first 2 hours of deprivation, and from 3 to 24 hours of deprivation the increase is gradual.

<u>Studies employing a series of forced and free trials</u>. Chronologically the first study to employ this technique was one by Teel and Webb (77). They were interested in the level of occurrence of a response in the absence of the drive under which it was originally acquired. The animals were given 4 T-maze trials daily, two forced and two free choice, for 14 days, under 23 hours deprivation. After the training trials each day the animals were fed, and from the second day until the end of training, satiation trials were given immediately after eating. The results were presented in percentages of correct responses on the free choice trials each day, for both the satiated trials and the non-satiated training trials. They showed that even on the first day of satiation trials 70% of the animals responded to the side on which reinforcement was obtained during training. These results are in opposition to those obtained

by Koch and Daniel, who reported a reaction potential close to zero after satiation. Teel and Webb explained their results in terms of the motivational properties which the stimulus complex acquires, and suggest that this is a possible explanation for the difference between their results and those of Koch and Daniel, i.e., in the Skinner box situation of the latter experiment secondary reinforcement cues are minimized, whereas the maze used by Teel and Webb might possess a more specific stimulus character.

Three other studies (18, 54, 63) have used this technique of giving forced and free trials to test the more general hypothesis of Hull that reaction potential is a multiplicative function of drive and habit strength. Loess (54), using deprivation groups of 4 and 22 hours hunger induced the animals to choose one bar rather than the other by manipulating the delay of reinforcement, so that the animals came to choose the short delay bar on free trials. Because of the presence of an additional variable, delay of reinforcement, the results were inconclusive. Ramond (63) improved the technique of Loess and obtained results which supported the Hullian position. Ramond's hypothesis was that if two habits are built into an animal under differing levels of drive, the choice behavior is a function of the difference between the excitatory potentials of the responses between which the choice is made; 40 blocks of three trials each were given over a period of 22 days. In each block of trials the first was a free choice trial with both bars presented to the animal. The forced trials were achieved by presenting only one bar to the animal. In each block of trials there were two trials to Bar A and one trial to Bar B, thus insuring twice as many reinforced responses to one bar. The drive level for the two groups was 4 and 22 hours of deprivation. The results showed that the high drive group chose the more frequently reinforced bar significantly more than the low drive group. The difference in choice behavior of the two drive groups was interpreted as supporting Hull's assumption that drive and habit strength combine multiplicatively to produce reaction potential.

Davenport (18) modified the Ramond experiment, adding a 48-hour deprivation group, and using a spatial discrimination. His results, however, were quite different, showing a low degree of discrimination in all deprivation groups. The percent choice of the more frequently reinforced side was not clearly shown to be an increasing monotonic function of the more frequently reinforced side. The inconclusiveness of the data was considered to be due to the apparent presence of a high degree of generalization between the stimulus complexes to be discriminated and the operation of an extraneous position habit.

In summary, when investigators have employed blocks of forced and free trials, it has been indicated that habit strength and drive combine multiplicatively to give reaction potential. With this design it also appears that even with zero drive there is substantial reaction potential.

Studies in which animals are subjected to repeated periods of deprivation. Although two studies have been done which used repeated deprivation periods, the techniques within this general category vary widely. Despite these differences the results of each study confirm the Hullian hypothesis that response strength increases with increased deprivation time. Let us examine the techniques individually.

In order to obtain a bar-pressing habit of maximum strength, Yamaguchi (87) gave 88 training trials under 3, 12, 24, 48 or 72 hours of deprivation. These were followed by massed extinction trials, each group being extinguished at its training level of hunger, to a criterion of 2 minutes of no responding. The training trials were given in groups of 4 trials per session, 1 session per 5 days. In order to achieve this all hunger groups were on a 5-day maintenance schedule with 72 hours of hunger followed by 48 hours of feeding ad libitum and ending with enforced satiation. Each subject was trained at the appropriate time within the 72-hour hunger period, depending upon its deprivation group. The results showed that when reaction potential was plotted as a function of hours of deprivation the curve was concave between 3 and 24 hours of hunger, just as Perin's was found to be. Based on the median number of extinction responses the empirical maximum reaction potential is at 48 hours, and the theoretical maximum is between 48 and 72 hours of deprivation.

In another experiment, Cotton (15) endeavored to show the relationship between reaction potential and drive during testing, excluding the effects of extraneous variables such as drive-stimulus generalization. In order to eliminate gneralization effects each animal spent one day under each of the deprivation conditions - 0, 6, 16, and 22 hours. Each subject was given 10 rewarded runway trials daily. Drive conditions changed each day in a random order.

After 17 days of preliminary training, the training period continued from days 18 through 61. The same procedure was followed throughout the test period, until all animals in a group had made a minimum of 49 acceptable responses under each of the drive levels. Responses were considered unacceptable when there were one or more competing responses such as retracing, washing, biting, touching the walls of the maze, etc. A second test period was run on one of the groups in order to provide 49 additional acceptable responses. The results supported previous findings that "response strength, which is inversely related to mean daily running time, increases with increased deprivation time" (15, p. 196). In the analysis of the data latencies were plotted both with and without competing responses. Cotton pointed out that when the trials with competing responses were eliminated, the magnitude of the group trend was reduced, indicating that the major effect of higher levels of drive is one of reducing the occurrence of competing responses rather than increasing speed of running per se.

Thus, it has been seen that when extinction trials are carried out at the training level of hunger, again the curve of reaction potential rises gradually between 3 and

24 hours of deprivation. With drive-stimulus generalization eliminated, response strength still increases with increased deprivation time.

Studies using irrelevant drives: Irrelevant drives have been used to explain the presence of substantial reaction potential under zero motivation. In the Hullian system, when the primary drive is satiated, there is present a 'generalized drive' state which functions as a determiner of response strength.

In an experiment by Webb (84) all animals were trained under conditions of 22 hours food deprivation. Training consisted of 90 panel-pushing responses. In all experimental groups extinction trials were carried out with the relevant drive, hunger, satiated. Different groups, however, were subjected to differing degrees of an irrelevant thirst drive. The conditions of thirst were 0, 3, 12, or 22 hours of water deprivation. The results suggested that response strength did vary with the changes in intensity of an irrelevant drive. This effect on reaction potential was interpreted as a contributor to a 'generalized drive' state. Webb's results also agreed with Perin with respect to the strength of response at zero relevant drive. Perin found that the number of trials to extinction at zero drive varied between 17 and 28 percent of the number of responses at 24 hours drive. In the Webb experiment the corresponding percent of response was 17. These results have been confirmed by Brandauer (10) in a repetition of the Webb study. Contrary results, however, have been supplied by Grice and Davis (30). In their experiment four groups of animals were trained under hunger motivation. The extinction trials were carried out under different motivational conditions: one group was extinguished under 22 hours food deprivation; one group while satiated; one under 22 hours water deprivation; and one group was allowed to drink for 30 minutes prior to testing. The results showed no significant difference between the satiated and thirsty group. This was contrary to the results of Webb, who found the irrelevant thirst drive groups superior to the satiated group. Grice and Davis concluded that although their results do not lend support to the generalized drive theory, there are other studies which have upheld it. They implied that the Webb study did not necessarily support the theory either because the positive relation that he found between hours of water deprivation and the strength, during extinction, of a response learned under conditions of food deprivation, may be due to increasing strength of the hunger drive accompanying the increase in the thirst drive.

In a study by Zeaman and House (69), using light aversion as the drive, it was shown that even with zero drive, irrelevant drives motivated habit structure. These investigators used a "light" drive because it provides no secondary reinforcing associations and does not interact with other drives. They used an experimental group which was trained to escape from a light compartment into a dark one, and a control group for which both compartments were dark during training. Then test trials were given in which both compartments were dark. At the time of testing it was found that the reaction potential, as measured by mean latency, of the group which learned under conditions of no drive was equal to approximately 50% of the maximum strength produced by learning under drive.

There remains one other study which does not properly fit into any of the foregoing categories, but should be mentioned because it deals with the effects of drive on performance. Brown (11) has used secondary reinforcement in a Skinner Box to study the effects of high drive (32 hours deprivation) and low drive (8 hours deprivation) on the learning, extinction, and relearning of an instrumental response. After a pairing session the learning, extinction, and relearning trials were carried out under high and low drive conditions with only secondary reinforcement being given. The design was 2x2x2 factorial. It was found that in general drive affected performance, but did not affect the secondary reinforcing power acquired by a neutral stimulus.

Summary :

In studies of the relationship between drive and reaction potential most investigators have used a constant drive level during training, and then given a series of test trials under varying level of motivation. Skinner boxes have been the most frequent type of apparatus, but run-ways and mazes have also been used. It is generally agreed that habit strength and drive combine multiplicatively to produce reaction potential, and that within certain limits (between 2 and 24 hours of deprivation) reaction potential increases slowly with an increase in drive. In the first 2 hours subsequent to satiation a sharper increase in reaction potential is found.

Table II: Summary of Studies of the Effect of Drive on Performance

	Length of feeding schedule	No. of reinfs. during learning	Learning to Criterion	Drive at time of learning	Drive at time of testing	Apparatus used
Brown	?	20	-----	8,32 hrs. dep.	8, 32 hrs. dep.	Skinner Box
Cautela	7 days	-----	18 out of 20 correct	23 hrs. dep.	0,6,12,47 71 hrs. dep.	Black-white discrim.
Cotton	?	44	-----	0,6,16,22 hrs.dep. chgd.daily	Same as training	10 foot runway
Danziger	?	12	-----	23½ hrs. dep.	0 hrs. dep.	Runway with 3 hurdles
Davenport	?	104 reinf. 52 unreinf.	-----	3, 22, 48 hrs. dep.	Same as training	Runway & spatial discrim.
Grice & Davis	7-9 days	45	-----	23½ hrs. dep.	0,23½ food dep. 22 hrs. water dep.	Panel-pushing response
Heathers & Arakelian	1 week	80	-----	23 hrs. dep.	0, 23 hrs. dep.	Skinner Box
Horenstein	10 days	20	-----	23½ hrs. dep.	0,2,12,23½ hrs. dep.	Panel-pushing response
Jenkins & Daugherty	?	100	-----	80% body wt.	70% & 90% body wt.	Pigeons & pecking response
Kimble	11 days	15	-----	24 hrs. dep.	0,30,50,16 m & 2,8,15,24 hrs.dep. pre-feed 10,15 m.	Panel-pushing response
Koch & Daniel	7 days	70	-----	23½ hrs. dep.	0 hrs. dep.	Skinner Box
Loess	?	?	-----	4,22 hrs. dep.	Same as training	Double-bar Skinner Box
Perin	1 week	16	-----	23 hrs. dep.	1,3,16,23 hrs. dep.	Skinner Box
Ramond	7 days	80 reinf. 40 unreinf.	-----	4,22 hrs. dep.	Same as training	Double-bar Skinner Box
Sackett	5 days	15	-----	S's fed 7/8 daily ration 7 hrs. bef.tr.	1 gp. 24 hrs. dep. Other 7/8 daily ration 77 hrs.bef	Skinner Box
Saltzman & Koch	7 days	70	-----	23½ hrs. dep.	½,1,2 hrs. dep.	Skinner Box

Table II, Cont'd.

	Length of feeding schedule	No. of reinfs. during training	Learning to Criterion	Drive at time of learning	Drive at time of testing	Apparatus used
Teel & Webb	1 week	28 reinf. 28 unreinf.	-----	dep. of $23\frac{1}{2}$ hrs.	0-hrs. dep.	Single unit T maze
Webb	7 days	90	-----	22 hrs. food dep.	0 hr hung. drive; 0, 3, 12, 22 hr thirst drv.	Panel-pushing response
Yamaguchi	?	88	-----	3, 12, 24, 48, 72 hrs. dep.	Same as training	Skinner Box

STUDIES OF THE EFFECTS OF REPEATED DEPRIVATIONS

There is general agreement in the literature that feeding behavior is cyclical in nature. It has already been mentioned that Richter (66, 67) and Hunt and Schlosberg (38) have demonstrated that maximum intake occurs during early evening, and minimum intake occurs during the day. More recently Siegel and Stuckey (71) measured food and water intake every 6 hours for 3 days, and obtained curves of eating and drinking which were similar to those of Hunt and Schlosberg. Gilbert and James (29) also measured food and water intake every 6 hours, but regulated the day-night conditions by alternating periods of 12 hours in which the light in the animal's cage was on with periods of 12 hours in which the light was turned off. With this technique they found that about three-fourths of the daily intake occurs during the 12 hours of night-time conditions. When the light was left on continuously for 24 hours a significant depression of the rhythmicity was found. A depression of rhythmicity was also observed when the animal was deprived of water for 24 hours. When conditions of light-on and water deprivation were present simultaneously the eating cycle was obliterated completely. These results suggest that rhythmical eating is not dependent solely on either internal or external cues. Bare (7) has shown that after a single deprivation period the effects of the day-night cycle are still apparent. This leads us to the problem of what occurs when the animal is placed on a feeding schedule and the feeding cycles are restricted. In most of the experiments mentioned thus far the animals have been placed on a feeding schedule prior to experimentation, and subjected to further deprivations of varying intervals during either learning or testing or both. What then is minimum time required for an animal to adjust to a feeding schedule, and what effects do different deprivation periods have on such measures as food intake, activity, exploratory behavior, body weight, etc.?

Adjustment to feeding schedules:

It has been found in several studies (6, 28, 49, 64) that when animals were placed on a feeding schedule the daily intake and the time spent in consummatory behavior increased during the first 8-10 days of restricted feeding. Reid and Finger (64) actually found a decrease in intake during the first 5 days of a 23-hour feeding schedule. Thereafter they found a gradual increase in food and water intake, which reached an asymptote of 60% of the base intake by the 20th day. Lawrence and Mason (49) found, however, that with a 22-hour schedule intake will reach an asymptote after 5-7 days. This period of adjustment was shorter with each subsequent exposure to a feeding schedule. Using feeding schedules of 12, 24, and 36 hours deprivation Baker (6) found that the amount consumed during feeding increased during the first 10 days. At this point most animals were eating twice as much as they had on the first day. The amount of time spent in feeding increased gradually in the first 20 days. Although her animals were on a 23-hour food deprivation schedule for only 7 days, Ghent (28) found an increase in amount of time spent in eating during this period. When body weight is measured, both Reid and Finger and Lawrence and Mason found that weight decreased when animals were placed on deprivation schedules. Lawrence and Mason found an asymptote after about 5-7 days, but Reid and Finger found weight losses occurring throughout the first 10-15 days. Regardless of the differences in details of these experiments, the results of each point to the hypothesis that the animal learns to eat on a restricted feeding schedule when the food is present.

It has been found that activity, as measured with an activity wheel, also increased during the period of adjustment to a feeding schedule. Hall, Smith, Schnitzer, and Hanford (31) found that although the activity of a control group remained relatively stable, the activity of animals on a 23-hour deprivation schedule rose to 1400% of normal at the 12th day of restricted feeding. Thereafter there were fluctuations in the activity curve, but they were variable. In the Reid and Finger experiment it was found that the activity rose to a maximum of 1362% of the base during the 35 days of restricted feeding. They pointed out that according to this measure adjustment to a 23-hour feeding schedule was incomplete even after 35 days. There were indications that activity is not the preferred measure of adjustment to a feeding schedule, and the other measures used by Reid and Finger indicated that 15 days is the minimum period for adjustment to restricted feeding. After this time there are further increases in activity, but changes in weight and intake are small.

The effects of the length of deprivation interval:

With respect to food intake there are two studies (6, 50) which have shown that there is an increase in amount eaten with increasing deprivation. In the Baker study (6) it was found that there was a perfect negative correlation between the length of deprivation and the intake. This was found to be true for those animals on either a 12, 24, or 36-deprivation schedule and for those animals who were subjected to varying periods of deprivation. Lawrence and Mason (50) investigated the relationship between an established eating rhythm and the amount of food ingested after varying intervals of deprivation. They had four periodic groups in which the animals were fed for 3 hours daily at the same time each day. (These groups were fed at either 9 a.m., 1 p.m., 6 p.m., or 9 p.m. and there were no differences in intake with respect to the time at which feeding occurred.) An aperiodic group was also fed for 3 hours at a time, but the deprivation interval varied irregularly from 4-48 hours. After 27 days on one of these schedules all animals were tested after intervals of deprivation ranging from 4-48 hours. Both groups showed an increase in amount eaten with increasing deprivations up to 24 hours. Beyond 24 hours the periodic group showed a decrease but the aperiodic group showed no change. The animals of the periodic group tended to eat more food if the test feeding came at the regularly scheduled time of day than if it came at any other time. The authors stated that this difference in eating behavior of the 2 groups supports the hypothesis that the amount an animal eats after a deprivation interval is determined, in a large part, by past experience.

Studies of the relation of deprivation interval to activity have shown increases in activity with longer periods of deprivation. Siegel and Steinberg (70) determined the activity level of animals, then divided the animals into 4 groups and measured activity after a single deprivation of 12, 24, 36 or 48 hours. The curve of activity as a function of hours of deprivation was found to be negatively accelerated. In another experiment, Finger (27) recorded activity daily for a period of one week of ad libitum feeding. The animals were then subjected to either a 24- or 48-hour deprivation and put back on an unrestricted feeding schedule. The 24-hour deprivation led to small but reliable increases in activity, and a deprivation period of 72 hours led to a 94.2% increase in activity. When the food was restored the activity level was depressed far below normal; 57% of normal for the 24-hour group and 17.6% of normal level for the 72-hour group. This effect continued for several days. Finger referred to this depression of activity as the satiation syndrome, and pointed out that it can distort the measurement of responses in studies in which the hunger drive is manipulated. In both of the studies mentioned in this paragraph, activity has been locomotor. Strong (75) devised an apparatus which measured both locomotory and non-locomotory activity. After determining a nondeprivation base activity level he put the animals on 0-, 24-, 48-, or 72-hour deprivation schedules. The results showed that hunger primarily increases locomotor activity, and decreases finer, non-locomotor activity.

Studies of the effect of deprivation on exploratory behavior have led to conflicting results. Using a Y-maze Montgomery (56) showed that a 24-hour food deprivation significantly reduced the amount of exploratory behavior. Longer periods of 48 and 72 hours of food deprivation produced no further reduction in exploratory behavior. Two groups were used in this experiment: a control group had free access to food and water at all times in their home cages, and the animals were tested for 10 minutes daily in the maze; the experimental group was on a 24-hour feeding schedule for 5 days prior to experimentation, and then food was removed from the home cages, and 10-minute test trials on the maze were given each day, providing measures of exploration after 24, 48, and 72 hours of deprivation. Alderstein and Fehrer (5) used a different technique to study the exploratory behavior of hungry and satiated rats in a complex maze, and found that when rats are 23-hours deprived they explore significantly more units of the maze than when they are satiated. The two groups of animals were exposed to the maze under conditions of both hunger and satiation. One group was given 3 sets of test trials on the maze under conditions of hunger followed by 2 sets of satiated trials. Each set of trials was separated by 3 days of continuous access to food and water. The animals in the second group were first given 2 sets of trials under conditions of satiation, and then 1 set under hunger. Satiation was defined as continuous access to food and water, and the hunger condition was 23-hours food deprivation.

Summary:

In this section the studies have been reviewed which deal with adjustment to a restricted feeding schedule and the amount and rate of intake after various periods of deprivation. It has been found that a period of at least seven days is necessary for the animal to adjust to a feeding schedule. During this adjustment the animal gradually learns to eat at the time in which food is available. Thus if the daily feeding occurs at a time when the animal would not ordinarily eat, he will learn to eat at this time. Also when an animal has been placed on a feeding schedule and is then subjected to a deprivation period the amount and rate of intake is a function of the hours of deprivation, i.e., both measures increase with increasing deprivations. Activity has also been seen to increase with longer deprivation periods.

SUMMARY AND CONCLUSIONS

This review has attempted to examine and organize the literature on hunger drive in the rat. Drive has been studied in relation to learning, response strength, activity, food intake, and feeding schedules. In the earliest studies strength of motivation was defined either in terms of the resistance that an animal would overcome to obtain food, or in terms of the level of general activity of the organism. The general finding was that activity level, as well as the number of barrier crossings to reach food, is an increasing function of the length of deprivation up to at least 36 hours of food deprivation. There gradually developed an interest in the question of whether there is an optimal drive level for learning. Several investigators did find that learning would occur more quickly and retention of a habit would be better under higher drive levels. However, it was later suggested that drive may affect the performance of a learned response, but not the strength of the habit. In 1943 Hull's theoretical formulations were published, providing testable hypotheses for the experimental work which followed. Hull states that drive level at the time of learning does not affect the strength of the resulting habit. The main variable in habit strength ($S^{H}R$) is the number of reinforcements given during learning. Drive and habit strength combine multiplicatively to produce reaction potential ($S^{E}R$), an intervening variable roughly equivalent to response strength.

One source of conflict is relationship between drive level at the time of learning and habit strength. Whether the level of drive at the time of learning does or does not affect habit strength is a function of the experimental design employed. Two experimental designs have been used. In the earlier studies the technique was to vary drive level during training and hold it constant during testing. Data from this type of experiment have shown, with few exceptions, that drive level during training does affect habit strength, a result apparently contrary to Hull's theory. In more recent years a 2x2 factorial design has been more frequently used and has brought forth results which support Hull's position that drive does not affect habit strength. With a 2x2 factorial design, drive is varied during learning, each of the experimental groups is then sub-divided, and testing occurs for each sub-group under one of the drive levels used during learning. This design is superior to the earlier one in that it affords control for the generalization of the drive stimulus.

Of special interest is the fact that when a learning criterion has been employed the data have consistently shown that drive affects habit strength. Furthermore, when a 2x2 factorial design is used, the only two studies in which the results are interpreted as conclusive evidence contrary to the Hullian position have used a learning criterion. The use of a learning criterion introduces an additional variable insofar as differing numbers of acquisition trials are given. Since the number of reinforcements during learning is the main variable in habit strength according to Hull, it follows that when the animals have received a varying number of training trials it is not possible to separate out the effects of drive, because each animal has a different degree of habit strength at the conclusion of training.

In studies of the effect of drive on reaction potential there seems to be more agreement. Most investigators find that habit strength and drive combine multiplicatively to produce reaction potential. Between 3 and 24 hours of food deprivation reaction potential is an increasing function of drive level. The period between 0 and 3 hours has been the subject of controversy. According to Hull even with zero hunger drive there should be a substantial reaction potential due to the presence of irrelevant drives. However, several investigators have indicated that with conditions of satiation no measurable degree of reaction potential is present. Others have found a substantial amount of reaction potential at zero hunger. The sum of evidence seems to suggest a sharp rise in response strength in the first two hours following satiation.

One further aspect of drive must be mentioned. It has been shown numerous times that if an animal is placed on a feeding schedule, at least seven days are required for the organism to adjust to restricted feeding. During this adjustment period the animal learns to eat during the time that food is available. Most investigators have used feeding schedules for varying periods of time prior to experimentation. But the length of time an animal has been on restricted feeding does not seem to affect the data obtained, in that studies using feeding schedules of three days have reported results similar to studies with a three-week feeding schedule.

Table III: Independent and Dependent Variables in Studies of Hunger Drive (Thirst drives indicated by *)

Table includes only studies using either hunger or thirst drives

		DEPENDENT VARIABLES														
						during testing									Measures taken during both acquisition and testing	
INDEPENDENT VARIABLES		No.trials to reach learning criterion	Time required for learning	Rate of respond-ing	No.of errors	No.of crossings in ob-struction method	Retention (No.of errors	Resistance to ext.	Rate of respond-ing	% correct response	Latency on forced trials	Intake	Rate of Intake	Activity	Body Weight	Latency	Running time
Feeding schedule prior to experimentation		55,22,14 20,21	26,27 74,55	68	55,35* 22,20 21	36	55,35* 45,22 20	26,27,65,52 22,68,32,62 47,69,14,37	74,72	63,77	63	37,8 64,49 50	8,56	66,56 64,31	64,49	19,46	65,35*
No.of reinf. during learning	Const.	76,20	26,27, 74	68,53	35*,20 3		35*,45 20	26,27,65,14 52,76,68,32 62,47,69,87 37,41	74,41	63,18	37					19,17 46	65,14,52 35*,17,15
	Varied by no.trials req.to rch lrn.crit.	15,22 14,21	26,27 74,55		22,21, 55,		55,22	22,14				61*				61*	
Drive at time of acquisi-tion	Varying hrs.of dep.	55,76 22,20	26,27 74,55	53	22,20,21 55,35*		45,22,20 55,35*	26,27,14 52,75 22,87	72	63,18 54	63,18	61*				61*,19	14,52 35*,15
	Varying amts.of pre-feed.		12		12			65									65
	Const. hrs.of dep.	14		68	3			68,32,62 47,69,14 37	77	77		37				17,46	17
	Varying % body weight		79		80,79			41	41								
Drive at time of testing	Const. for all groups	55	26,27 74,55		55		55	26,27 65,47	74	77		61*				61*,17	65,17
	Same drive levels as used dr. learning	75, 22, 20			35*,22 20		35*45 22,20	15,52,76 22,87		63,18 54	63,18	8	8			19	35*,15 14,52
	Varying hrs. of dep.	14		68	3	84,36 58,73		68,32,62 69,14,37	33			37, 6 64,50	6	6,56,27 70, 5	6,27	46	
	Varying amts.of pre-feed.								72							46	
	Varying % body weight							41	41								

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