AN ANALYSIS OF THE STIMULUS TRACE
AND SECONDARY REINFORCEMENT IN DISCRIMINATION
LEARNING IN THE WHITE RAT

DISSERTATION
PRESENTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
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CHAPTER I

INTRODUCTION

One of the problems faced by the proponents of a reinforcement theory of learning is the explanation of how an effect works backward to strengthen or inhibit a response that occurs earlier in time. Thus in a simple T-maze a turning response to the left, if correct, is reinforced after a lapse of time that is dependent upon the characteristic of the maze. Similarly, in other learning situations, whether a Skinner box or a visual discrimination apparatus, an interval of delay is present between the occurrence of the response and reception of reinforcement.

One of the earliest attempts to systematically account for this seemingly paradoxical state of affairs led to the formulation of a goal gradient hypothesis by Clark L. Hull in 1932 (11). Hull states that,

The goal reaction gets conditioned the most strongly to the stimuli preceding it, and the other reactions of the behavior sequence get conditioned to their stimuli progressively weaker as they are more remote (in time or space) from the goal reaction. This principle is clearly that of a gradient, and the gradient is evidently somehow related to the goal. We shall accordingly call it the goal gradient hypothesis.
Hull envisaged the excitatory gradient as being positively accelerated according to the logarithmic law and being extended upward from the beginning of the maze to the goal box. From this hypothesis Hull deduced the following principles of behavior:

1. That the animal will tend to choose the shorter of two alternative paths to the goal.
2. That the greater the difference between the length of the paths (the standard path remaining constant), the more readily will the shorter path be chosen.
3. That the readiness of choosing the shorter path will not be affected by the absolute difference between the alternates, provided the paths to be discriminated maintain a constant ratio to each other. (Weber's Law)
4. That animals will come to choose the direct path to a goal rather than enter blind alleys.
5. That long blinds will be more readily eliminated than short ones.
6. That the order of elimination of blind alleys will tend to be in the backward directions.
7. That long mazes will be learned with greater difficulty than short ones.
8. The animal in traversing a maze will move at a progressively more rapid pace as the goal is approached.
9. That of ten alternative paths to a common goal the animal will traverse the early section of the shorter path at a faster rate than that of the parallel section of the longer one.

10. That the final parallel sections of the two alternate paths each of different lengths leading to a common goal will be traversed at approximately equal speed.

11. That animals after having eliminated a blind will tend to pause at its entrance while pursuing the shorter path.

The publication of the principles of behavior deduced from the goal gradient hypothesis engendered considerable research in an effort to test the various hypotheses. In the original formulation of the goal gradient, Hull, largely on the basis of a study by Yoshioka (35), had posited the goal gradient as being a logarithmic function. In 1938 the logarithmic gradient was rejected in favor of an exponential equation. With the publication of the Principles of Behavior in 1943, Hull (13) presented a new formulation of the goal gradient hypothesis wherein the goal gradient was seen to be derived from other principles.

Some of the experiments leading to Hull's reformulation of the goal gradient are of particular relevancy for the study to be presented in this paper. Although no one experiment can be said to be instrumental in influencing the
reformulation, certainly the experiments concerning the effect of the delay of reinforcement on efficiency of learning are of extreme importance.

One of the earliest studies investigating the effect of a delay of reinforcement upon learning was that of J. B. Watson in 1917 (31). Watson required rats to tunnel through a sawdust floor to reach a goal box that held a food container. The animals after reaching the goal box were either fed immediately or delayed 30 seconds by placing a perforated lid on the food container. Watson concluded that there was no difference in efficiency of learning under the two conditions.

Warden and Haas (29) investigated the effect of delay in feeding upon speed of learning a maze. They found that a delay of one minute decreased efficiency but that a five minute delay group did not differ from the zero delay group. They concluded that the one minute delay group appeared to be less homogenous than the five minute or zero delay group and therefore no conclusions regarding the one minute delay were warranted.

Hamilton (9) utilizing a 5-unit multiple Y maze found a decrease in learning as measured by trial, error, and time scores in a group of rats delayed one minute between the end of the maze and presentation of the food reward, with delay of 3, 5, and 7 minutes no further decrease in speed of learning was evident.
Simmons (22) investigating a delay of feeding of 90 minutes found a decrease in efficiency as measured in terms of time and error scores but not in terms of trials to reach criterion.

Roberts (20) confined rats in a problem box from which they could gain access to a cage containing food if they brushed against a stick suspended from the top of the cage. Using four groups of rats Roberts tested the animals after 0, 5, 10, and 30 second delays. Roberts concluded that the efficiency of learning decreased with an increase in delay.

Warden and Diamond (28) studied the effect of delayed punishment in learning on the white rat in a simple Y shaped maze. If a reward was given for each correct trial and punishment after delays of 4, 8, 13, and 20 seconds for incorrect trials, Warden and Diamond found that there occurred a decrease in efficiency of learning with an increase in delay of punishment.

Wolfe (33) demonstrated the first consistent relationship between the efficiency of learning and the interval of delay. He used a T-maze with one arm painted black and the other white and investigated delays of 0, 5, and 30 seconds and 1, 2.5, 5, 10, and 20 minutes. His procedure was to delay the animals after they made the turn to one or the other arm of the T-maze; after the appropriate interval of delay the animals continued to the end of the maze where
they received immediate reward. Wolfe found a very sharp
drop in learning with the increase of delay up to one
minute; the gradient with increase in delay from one to 20
minutes was much more gradual.

The experimental results outlined above seem to be
in fundamental disagreement. The studies by Watson, and by
Warden and Haas offer no evidence for a goal-gradient
principle with the increase in the delay of feeding nor is
there found a decrease in efficiency of learning with a
delay of reinforcement. In the experiments by Hamilton and
Simmons there occurred a decrease in efficiency of learning
with a delay of feeding, but with further delay further
decrease in efficiency was not apparent.

The experiments by Roberts and by Wolfe on the delay
of feeding and the experiment by Warden and Diamond on delay
of punishment are in agreement in that their results are
consistent with the gradient principle.

Hull in his Principles of Behavior reconciles these
experimental paradoxes by reference to the concept of
secondary reinforcement which, according to Hull, was first
isolated in Pavlov's laboratory by Frolov. With reference
to experiments by Skinner (23), Bugelski (1), Cowles (2),
Wolfe (34), and Grindley (7), Hull formulated a law of
reinforcement to include the concept of secondary reinforce-
ment. The law of reinforcement reads as follows:

Whenever an effector actively occurs
in temporal contiguity with the afferent
impulse, or the perseverative trace of such
an impulse, resulting from the impact of a stimulus energy upon a receptor, and this conjunction is closely associated in time with the diminution in the receptor discharge characteristic of a need or with a stimulus situation which has been closely and consistently associated with such a need diminution, there will result an increment to the tendency for that stimulus to evoke that reaction.

The studies reported above that previously seemed to be in fundamental disagreement can now be readily reconciled. In the Watson study and the study by Warden and Haas the delay occurred in the food chamber; the food chamber being closely associated with the primary reinforcement of the food acquired secondary reinforcing properties. In the Hamilton and Simmons study and in particular the investigations by Wolfe and by Roberts the conditions necessary for secondary reinforcement were present but not to the extent as in the other studies. In the experiment by Wolfe the retention chamber was separated from the food box; thus the stimuli in the food box accrued secondary reinforcement to the same extent for both the delay and non-delay groups. With succeeding trials the stimuli leading to the food box, the door, the retention chamber itself gradually acquired secondary reinforcing power. The study by Roberts also minimized the amount of secondary reinforcement occurring in the experimental situation. The delay chamber in the experiment by Roberts was the problem box in which the animal learned the response that led to reinforcement. Here, as in the experiment by Wolfe, the retention chamber is separated from the food box which effectively minimizes differential
secondary reinforcement in delayed and non-delayed animals.

In both the Wolfe and Roberts study, the opportunity for secondary reinforcing powers to become associated with stimuli surrounding the food reward was minimized but not eliminated. These stimuli, since they have some strength as a secondary reinforcing agent, will serve to reward an animal immediately upon completion of a run thus reducing the effectiveness of the delay period.

In an attempt to investigate the effect of a delay of reinforcement apart from secondary reinforcement, Perin (16) devised a situation wherein the secondary reinforcement if not eliminated was reduced to a minimum. Perin cites the study by Roberts (20) as suggesting the manner in which this might be accomplished. In Robert's experiment the response and the delay occurred in the same compartment, whereas the food was received in a separate food box. A logical step, according to Perin, in eliminating or reducing secondary reinforcement would be to have the response which is to be learned, the delay, and the reinforcement all occur in the same compartment. Perin argues,

In this way the stimulus environment of the animal would be much more constant during the delay interval, and the train of external stimuli leading to the food reward, characteristic of the maze situation, would be eliminated....

Accordingly, Perin employed a modified Skinner box that effectively served as a problem box, delay compartment, and food box. The Skinner box was modified so that after
each response, that the animal made, the bar could be withdrawn and various delays introduced before the pellet of food dropped into the container. With this technique, Perin investigated delays of 0, 2, 5, 10, 20, and 30 seconds using as his measure of habit strength, latency of response. Perin's practice curves indicate that the maximum habit strength that will be reached with extensive practice, is a function of the length of delay period preceding reinforcement: the longer the delay, the less will be the habit strength ultimately reached with a maximum number of reinforced trials.

In a second experiment, Perin (17) in an attempt to obtain a better measure of habit strength adapted the Skinner box with a bar that could be moved to the left or right, in this manner he could get a measure of learning in terms of the number of errors to reach a criterion after various intervals of delay. Again he found that the strength of the habit was a function of the length of delay. Furthermore extrapolation of his practice curves indicated that with a delay interval longer than 30 seconds no learning would occur. Perin concluded that in a learning situation where the primary reinforcement is remote from the response which is to be learned secondary reinforcement is a necessary requisite if learning is to take place. As a result of Perin's investigation Hull concluded that in the case of the albino rat the gradient of habit strength as a function of the delay in reinforcement extends over a relatively short period of time.
The study by Wolfe, however, suggested to Hull that when there occurs ample opportunity for secondary reinforcement the gradient may extend for a relatively long period. In view of these experiments Hull concluded:

This means that what was originally regarded as a single principle has turned out upon investigation to involve two fairly distinct principles: (1) the short gradient reported by Perin, which will be called the gradient of reinforcement*, an expression coined by Miller and Miles; and, (2) the more extended gradient which is presumably generated as a secondary phenomenon from Perin's gradient of reinforcement acting in conjunction with the principle of secondary reinforcement. This second and more extended gradient may with some propriety retain the original name of the goal gradient, an expression employed by the present author in his first discussion of the subject.

It becomes apparent then, that the goal gradient may be conceived largely as a gradient of secondary reinforcement. It is only the response that occurs near the goal that receives primary reinforcement. All other responses are reinforced as a result of the acquisition of secondary reinforcing properties of stimuli closely associated with the goal.

In a theoretical paper in which he examined the concept of secondary reinforcement in delayed reward learning, Spence (25) pointed out some logical difficulties encountered in the position held by Hull. Spence concedes that the longer the delay path the longer the time required for the

* Hull points out that both Thorndike (27) and Washburn (30) had made reference to a gradient of reinforcement principle.
secondary reinforcement to move forward and with each successive step the weaker the secondary reinforcement becomes. However, according to Spence, it is difficult to explain how a gradient of learning occurs with different amounts of temporal delay since such delay does not require any more steps in the conditioning process.

According to Spence, the primary reinforcement gradient is in actuality a gradient of secondary reinforcement. With reference to a rat in a Skinner box, Spence would argue:

As the rat presses the bar certain distinct proprioceptive stimuli are aroused. A trace of these stimuli remain for a period of time or until the moment that the reward occurs. What is conditioned in such a situation is the stimulus trace still remaining when the reinforcement occurs, and it is this trace that acquires secondary reinforcing properties.

Similarly in a T-maze situation the proprioceptive cues following the correct response acquire secondary reinforcing properties since the correct response leads to food; whereas the proprioceptive cues following the incorrect response do not acquire such properties. Spence concludes that,

Differential secondary reinforcement based on such differential proprioceptive cues presumably can occur in the delayed reward situation for at least the length of time the two proprioceptive patterns remain discriminatively different from one another.

In an effort to test the effect of differential secondary reinforcement arising from the external environment, Perkins (18) conducted an experiment wherein he
eliminated the possibility of the occurrence of such reinforcement. Using a special type of T-maze which was enclosed top and bottom with opal flashed glass Perkins effectively precluded visual cues from outside the maze. During the training period the two delay boxes were randomly changed from side to side which eliminated the possibility of the goal boxes acquiring differential secondary reinforcement. The maze was rotated 180° each day to exclude constant auditory cues as a factor. Under these conditions, Perkins investigated delays of 0, 5, 15, 45 and 120 seconds, and he obtained a decrease in efficiency of learning with an increase in delay. The 45 second group was compared with a control group that learned the maze with the delay boxes always on the same side of the T. A comparison of these two groups showed a significant difference in learning in favor of the control group. Since some learning was evident with each interval of delay even though the secondary cues from the environment were eliminated, Perkins argued that,

The extent and slope of the gradient of reinforcement obtained in the present experiment is possibly dependent on the rate of change of the perseverative (kinesthetic) trace resulting from the response being learned.

When the secondary cues from the environment were not eliminated, as was the case with the 45 second control group, differential secondary cues from the environment were sufficiently intense that the control group learned the maze in significantly fewer trials.
Both Denny (3) and Saltzman (21) corroborated the results obtained by Perkins by showing that training a group of rats in a T-maze with differential end boxes significantly enhanced learning in comparison with a group of animals trained to run to identical goal boxes.

A more crucial test of the hypothesis that delayed reward learning is a function of secondary reinforcement from differential internal cues occurs in the area of discrimination learning. In discrimination learning no one spatial response is consistently reinforced since the stimulus cues are randomly shifted left and right; this effectively eliminates differential internal cues. Moreover, if a delay is involved the delay chamber follows one stimulus cue as often as the other so that it would be impossible to build up differential cues to the external environment. It would follow, then, that in a discrimination learning situation, with the opportunity for the occurrence of both internal and external differential secondary reinforcement eliminated, learning with a delay in reward would be virtually impossible.

Riesen (19) is credited with first carrying out an investigation designed to determine the effect of delayed reward in a discrimination learning problem. Using a color discrimination situation with chimpanzees he found that with intervals of delay longer than 4 seconds little or no learning was evident. In a discussion of the results of the
experiment Riesen concluded that,

Learning with delayed reward, and cases of failure of such, can best be explained by the assumption that such learning is dependent upon intraorganic S-R-S sequences which serve as representation of the critical stimuli until reward or non-reward occurs.

Riesen suggests that such representation may be provided by either a proprioceptive system or from sensory after-discharge following external visual stimulation. It would seem that Riesen anticipated Spence by several years since this is the conclusion at which Spence arrived seven years later.

Grice (6) studied the relation of secondary reinforcement to delayed reward in visual discrimination learning in the white rat and obtained results comparable to those in Riesen's study. He trained rats on a black-white discrimination problem with delays in reward of 0, .5, 1.2, 2, 5, and 10 seconds and found a very steep learning gradient as a function of the delay. The five second delay group learned only at a very low level of accuracy, and the ten seconds delay made the task so difficult that only two out of five rats reached the criterion. The maze on which he trained these animals was painted a neutral gray except for the black and white stimulus alleys. To test for the effect of differential secondary cues from the external environment Grice had one group of animals learn the discrimination with a five second delay and the goal boxes the same color as the
stimulus alleys, i.e. black and white. The animals that ran to black and white goal boxes learned the discrimination in significantly fewer trials than the group that had the five second delay but ran to gray goal boxes. Grice cites this as evidence that learning is greatly facilitated when immediate secondary reinforcement is introduced into the situation.

Similarly, to test the effect of differential secondary cues arising from within the organism, Grice placed in one of the stimulus alleys a wood block 9" long cut to form a 15° incline. In the other alley he attached to the side of the maze two blocks $2\frac{1}{2}$" x 5" and extending to the top of the maze; one of the blocks was attached to one side the other block to the other side two inches beyond the first. An animal traversing the maze had to make differential motor responses which effectively afforded differential proprioceptive cues in the two stimulus alleys. A comparison of the five-second control group with the group of animals that made differential motor responses showed a significant difference in learning in favor of the latter.

Grice agrees with Spence and Perkins that differential secondary cues are a necessary condition if learning is to occur in a delayed reward situation. Moreover, Grice raises the question as to why, if there is no true gradient of reinforcement, there occurs both in his study and in Riesen's study a short gradient that would certainly be similar if not identical to that predicted from a gradient
of primary reinforcement. Grice arrives at the same conclusion as Riesen in that he states,

So long as any trace of the black and white stimuli remain discriminably different at the time of reward, there is the possibility of differential secondary reinforcement. The stimulus trace from the positive white stimulus in the choice chamber could thus acquire secondary reinforcing potency through generalization from its perseverative trace which is contiguous with the food reward.

The experimental evidence tends to give indirect support to the contention of Spence's that the gradient of learning with delayed reward results from differential secondary reinforcement. Results of the experiments by Perkins, Denny, and Saltzman substantiate this view. The experimental evidence also suggests that in visual discrimination learning, where the experimental procedure is such that differential secondary reinforcement is cancelled out, any learning that occurs with a delay in reward depends on a trace of the critical stimulus being present at the time of reward. Accordingly, in the experiments by Riesen and by Grice there occurred an exceedingly steep gradient of learning that fell to zero at about five seconds. This gradient they interpreted in terms of the presence of a stimulus trace.

To test the implication that the delay of reward gradient is related to the extent that stimulus traces resulting from the positive and negative cues remaining discriminably different with time, Smith (24) conducted the following experiment. A T-maze was designed so that the
rats were required to turn left or right depending on whether a section of the alley through which they had just passed had been white or black. By placing a delay chamber between the white or black cue alley, the time between the cue stimulus and the response could be varied. Testing groups of rats with delays of 0, 0.6, 0.75, 2.0, and 5.0 seconds, Smith found a gradient similar to that found by Grice in discrimination learning. Smith interpreted his results, "As evidence that the difference in the visual stimulus traces decrease rapidly in time, to become almost indiscriminable after five seconds in the case of the hooded rats."

The study by Smith demonstrates that a rat can learn to make differential responses on the basis of a stimulus trace present at the time of the response. Indirectly this supports the hypothesis set forth by Grice and Riesin in that the experiment shows that with no differential cues present at the time of reward the differential traces of the critical stimuli could be immediately reinforced. However, the experiment by Smith is not exactly comparable to a black-white discrimination problem with delay in reward. In Smith's T-maze the critical stimulus, the stimulus on the basis of which the rat responds, occurs before the left or right turning response which is to be learned. In discrimination learning with a delay in reward the response to be learned, the approach toward a black or white stimulus alley, is concomitant with or is the critical stimulus.
The studies reported in the literature concerning the relationship between secondary reinforcement and discrimination learning have all approached the problem in about the same manner. The experimental paradigm has been to maximize the differential secondary reinforcing cues for one group and to minimize them for the other. Any difference in the efficiency of learning between the two groups is then accounted for in terms of the presence or absence of differential secondary reinforcement.

The present experiment proposes a different approach to the problem; instead of maximizing or minimizing the occurrence of differential secondary reinforcement it is proposed to provide secondary reinforcing cues in a visual discrimination problem that are contrarily identical to the positive and negative stimulus alleys. Thus, if a white rat responds to one of two visual stimuli, as he approaches the point of reinforcement the stimulus cues are such that they are identical to the other stimulus and opposite the cue to which the response was just made. According to the theorizing by Spence and on the basis of the experiment by Grice and others a visual discrimination under these circumstances would be exceedingly difficult if not impossible to learn. An analysis of the experimental situation on the basis of differential secondary reinforcement would lead one to assume that the secondary reinforcing cues nearest the reward would accrue stronger reinforcing properties than the cues more
remote from the goal. The secondary cues in this case would be cues that are identical with the opposite stimulus alley. If the rat were to respond on the basis of these cues alone the discrimination would not be learned.

There have been no studies reported in the literature that suggest the nature of the stimulus trace that Spence, Grice, and Riesen posit to account for the learning that occurs in a visual discrimination problem where all differential secondary cues are eliminated. Smith demonstrated that a response which occurs after the cessation of the visual stimulus can be learned, but concluded only that the stimulus trace diminishes rapidly as a function of time. There exists the possibility that the nature of the stimulus trace is such that contradictory secondary reinforcing cues would not prohibit learning. If learning is evident in the experimental situation described above it is proposed to investigate the nature of the stimulus trace by introducing various delay periods between the positive and negative stimulus alleys and the secondary reinforcing stimuli in the food chamber.
CHAPTER II

STATEMENT OF THE PROBLEM

A survey of the literature reveals the importance of secondary reinforcement in visual discrimination learning. With all secondary reinforcing cues eliminated or controlled so that differential secondary reinforcement of responses cannot occur, several experiments have been conducted showing that efficiency of learning is seriously impaired. However, with differential secondary reinforcement eliminated, some learning is still evident. The learning that occurs under these circumstances results, according to some investigators, from a visual trace of the critical stimulus being present at the time of reinforcement.

The experiment to be presented in this paper proposes to investigate the role of secondary reinforcement and the stimulus trace in visual discrimination learning. The experiment is designed to set up secondary reinforcing cues that are contradictory to the stimuli on the basis of which the animal made the response. These secondary cues, being the opposite of the positive stimulus alley and identical to the negative stimulus alley, should reinforce
the incorrect response. If the animal responds on the basis of a stimulus trace, the trace of the secondary cues should accrue a greater amount of secondary reinforcing properties than the trace of the stimulus alleys. It would be predicted then, that under the proposed experimental circumstances learning would be exceedingly difficult if not impossible.
CHAPTER III
APPARATUS AND EXPERIMENTAL PROCEDURE

SUBJECTS
The subjects in the experiment were 134 female albino rats selected at random from the animal laboratory maintained by the Ohio State University Psychology Department. The animals were between 60 and 100 days of age at the beginning of the experiment. Of the 134 animals, three died during the course of the experiment and three refused to respond in the apparatus within a set criterion. The 128 remaining animals constituted the subjects for the experiment.

APPARATUS
A visual discrimination apparatus was constructed in the form of a modified Y-maze. The arms of the Y were parallel to the base to minimize the degree of turn necessary in making a response. The arms of the maze were constructed in sections in a manner and for a purpose which will be described. For one group of rats trained with zero delay the maze consisted of two alleys each alley consisting of two sections placed end to end. Each section of the alley was 10" in length, 4" wide and 4½" high. Between the two
sections a door, constructed of cardboard, was suspended from the top of the alley and made to swing open if the rat pushed against it and to swing shut as the animal passed through. To keep the door from swinging in both directions, and also to assure a tight fit between the door and the maze, strips of wood 3/8" x 1/2" were fastened to the sides and bottom of the maze at the point where the door divided the two sections. The door was suspended from the end of the second section while the strips of wood were at the end of the first section. This effectively divided the two sections so that as the animal traveled along the first section of the maze the second section was completely blocked from the rats' view. This is important since the two sections of the maze are to be painted different colors.

At the far end of the second section of both alleys a block of wood 1" wide and 1" high was fastened the width of the alley and 2" from the end. The compartment formed by the block of wood served to keep the food from being seen by the rat as he entered the second section of the maze. A removable food container was not used since Ehrenfreund (4) has shown that a food container serves as a secondary reinforcing cue.

The four sections that made up the two alleys were completely interchangeable. By painting one of the alleys white and the other black, it becomes possible to combine the sections so that the one alley could be all black and
the other all white, or the first section of one alley could be black and the second section white, while the alternate alley is just the opposite. The maze was constructed so that the doors separating the two sections could be readily changed from one alley to the other. Two sets of doors were used, one set was painted the same color on both sides, i.e. black or white, while the other set was painted black on one side and white on the other.

With the four sections of the two alleys and the two sets of doors, it now becomes possible to combine the sections in such a way that the maze consists of two alleys one black and one white, or two alleys one half black and white and the other half white and black.

Two intervals of delay were introduced by placing between the sections a neutral gray alley, either 18 inches or 36 inches in length. This necessitated adding another door at the end of the delay chamber and painting the doors white and gray or black and gray. The approach to the stimulus alleys was in the shape of a Y, ten inches in overall length and painted a neutral gray. The starting box was ten inches in length and breadth and six inches high; a vertically sliding door provided entrance to the approach alley. The goal box was also painted a neutral gray. The entire maze was constructed of \( \frac{3}{4} \) inch white pine. The top of the maze was covered with clear glass and illuminated by three overhead shaded 150 watt bulbs spaced approximately two feet apart.
For preliminary training, a straight runway painted gray, 24 inches in length, and similar to the maze used in the experiment was constructed. A door swinging from the top was placed 15 inches from the front end of the runway. The starting box was the same box used in the main experiment.

A floor plan of the maze is shown in Figure 1; Figure 2 is a floor plan of the straight runway; Figure 3 and Figure 4 are photographs of the maze showing the three experimental and control conditions used in the experiment.
FLOOR PLAN OF MAZE SHOWING DIMENSIONS OF VARIOUS SECTIONS

FIGURE 1
STRAIGHT RUNWAY USED IN PRELIMINARY TRAINING

FIGURE 2
PHASE I

PHASE II

PHASE III

FIGURE 3: EXPERIMENTAL CONDITIONS
PHASE I

PHASE II

PHASE III

FIGURE 4  CONTROL CONDITIONS
EXPERIMENTAL PROCEDURE

Preliminary training: Prior to the discrimination training all of the animals were handled twice a day for a period of three days. During this time, each rat was taken from the living cage, handled, placed on a table, picked up several times, and then replaced in the living cage.

Starting with the fourth day the animals were placed on a 22 hour deprivation diet. All food was taken from their home cages, and they were given their daily ration of Purina dog chow in separate feeding cages. After the animals were placed on the deprivation schedule, they were handled but once a day, and that, just before feeding.

Beginning with the seventh day and continuing for the next fifteen days, the animals were trained in the neutral gray straight runway. For the first ten days, each animal was given one trial per day, for the next five days they were given two trials each day. The food reward was placed at the end of the runway and consisted of two small pellets of Purina dog chow. The pellets are made by the Ohio State University Pharmacy Department and contain a small amount of sugar in addition to the Purina dog chow; this food was found to be highly preferred by the rats.

At the end of the day's training session, the subjects were placed in feeding cages and allowed to feed for 1½ hours after which they were returned to their home cages. An abundant supply of Purina dog chow was kept in
the feeding cages at all times, and water was always available in both the feeding and the home cages.

**Discrimination training:** The discrimination training consisted of three different phases, each phase being a different discrimination situation. The 128 animals were divided at random among the three experimental conditions. In phase I and II, the experimental and control groups each contained 22 animals, and in phase III, the experimental and control groups contained 20 animals.

The treatment of the animals in the three experimental conditions was identical. Each rat was given five trials a day, the trials being separated by at least two minutes. For half of the animals, both in the experimental and control groups, the black alley was the positive cue, and for the other half, the white alley was positive and the black negative. The right and left position of the stimulus alleys was determined by Gellerman's (5) series to prevent scores above chance from occurring by position and alteration habits. Upon making a correct response, the animals received two of the small pellets of food and were retained in the maze until these were consumed. If a rat made an incorrect response, he received no food and was retained in the maze for ten seconds. The criterion of learning was 18 out of 20 trials correct.

The animals in phase I were trained on the maze situation as presented in Figures 3 and 4. This group of
animals was considered as an immediate reward group. In phase II an 18" gray section was placed between the two colored sections of the maze. Although the animals in this group were not timed in running through the gray section, the situation is comparable to the experiment by Grice (6). Grice considered the 18" section as affording a delay of 0.5 seconds. In phase III the gray section was increased to 36", and the animals were timed in passing through the gray section. The times were obtained for trials 31 to 35 and the mean for the control group was 1.31 seconds and the experimental group 1.25 seconds. Accordingly, phase III was considered to be a 1.3 second delay group. The position of the maze in phase II and III is also presented in Figures 3 and 4.
CHAPTER IV

RESULTS

The results of the experiment in terms of the mean, standard deviation, and the variance, for both the trials to reach criterion and the error scores, are summarized in Table I. A comparison of the mean number of trials to reach the criterion of 18 out of 20 correct responses is presented in Table II. The tests of significance between the experimental and control groups in the three experimental conditions reveals the effect of the contradictory secondary cues. In Phase I, the immediate reward group, the t-test of the difference between the experimental and control group is 1.67 which is not significant; in Phase II, the 0.5 delay group, the t-test of the difference is 0.57 which again is not significant; in Phase III, the 1.3 second delay group, the difference between the experimental and control group is significant beyond the .02 level of confidence, t = 2.70.

Table III shows a comparison of the various groups in respect to the number of errors made in reaching the criterion of 18 out of 20 responses correct. The t-test of significance based on error scores reveals the same results as the tests of trials to reach criterion. In Phase I and
Phase II the difference between the control and experimental groups is not significant; the t is .92 and .62 respectively. In Phase III, however, a t is obtained that is significant below the .01 level of confidence, $T = 3.05$.

Figure 5 is a graph of the results showing the percentage of correct responses in blocks of five trials. In Figure 6 the rate of learning as a function of the interval of delay is illustrated.
TABLE I

MEANS, STANDARD DEVIATIONS AND VARIANCES FOR THE
CONTROL AND EXPERIMENTAL GROUPS IN THE THREE
EXPERIMENTAL SITUATIONS

<table>
<thead>
<tr>
<th>PHASE</th>
<th>CONTROL</th>
<th>EXPERIMENTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TRIALS</td>
<td>ERRORS</td>
</tr>
<tr>
<td>I</td>
<td>M = 29.955</td>
<td>M = 7.864</td>
</tr>
<tr>
<td></td>
<td>= 7.390</td>
<td>= 5.833</td>
</tr>
<tr>
<td></td>
<td>2 = 54.617</td>
<td>2 = 34.028</td>
</tr>
<tr>
<td>II</td>
<td>M = 61.590</td>
<td>M = 22.409</td>
</tr>
<tr>
<td></td>
<td>2 = 724.729</td>
<td>2 = 208.063</td>
</tr>
<tr>
<td>III</td>
<td>M = 83.200</td>
<td>M = 29.200</td>
</tr>
<tr>
<td></td>
<td>= 43.833</td>
<td>= 19.859</td>
</tr>
<tr>
<td></td>
<td>2 = 1921.326</td>
<td>2 = 394.379</td>
</tr>
</tbody>
</table>
TABLE II
A COMPARISON OF CONTROL AND EXPERIMENTAL GROUPS IN
THE MEAN NUMBER OF TRIALS REQUIRED TO REACH CRITERION
IN THE THREE EXPERIMENTAL CONDITIONS

<table>
<thead>
<tr>
<th>PHASE</th>
<th>N</th>
<th>EXPERIMENTAL</th>
<th>CONTROL</th>
<th>DIFF</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>44</td>
<td>33.9</td>
<td>29.9</td>
<td>3.9</td>
<td>1.67</td>
<td>Not Sig.</td>
</tr>
<tr>
<td>II</td>
<td>44</td>
<td>67.2</td>
<td>61.5</td>
<td>5.6</td>
<td>.57</td>
<td>Not Sig.</td>
</tr>
<tr>
<td>III</td>
<td>40</td>
<td>130.0</td>
<td>83.2</td>
<td>46.8</td>
<td>2.70</td>
<td>.02</td>
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</table>

TABLE III
A COMPARISON OF THE MEAN NUMBER OF ERRORS MADE IN
REACHING CRITERION IN THE THREE EXPERIMENTAL CONDITIONS

<table>
<thead>
<tr>
<th>PHASE</th>
<th>N</th>
<th>EXPERIMENTAL</th>
<th>CONTROL</th>
<th>DIFF</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>44</td>
<td>9.3</td>
<td>7.8</td>
<td>1.4</td>
<td>.92</td>
<td>Not sig.</td>
</tr>
<tr>
<td>II</td>
<td>44</td>
<td>24.8</td>
<td>22.4</td>
<td>2.4</td>
<td>.62</td>
<td>Not sig.</td>
</tr>
<tr>
<td>III</td>
<td>40</td>
<td>57.0</td>
<td>29.2</td>
<td>27.8</td>
<td>3.05</td>
<td>.01</td>
</tr>
</tbody>
</table>
CONTROL

PHASE I

PHASE II

PHASE III

EXPERIMENTAL

---

PHASE I

PHASE II

PHASE III

PERCENT CORRECT RESPONSES IN BLOCKS OF FIVE TRIALS

FIGURE 5
CHAPTER V

DISCUSSION OF RESULTS

With differential secondary reinforcement controlled or eliminated in a visual discrimination problem, Riesen (19), Grice (6), and Spence (25) contend that learning with a delay of reward would be exceedingly difficult, and the learning that does occur results from some representation of the critical stimulus present at the time of reinforcement. In the present experiment, wherein the secondary cues are not eliminated but rather maximized it would follow that the secondary cues should accrue considerable secondary reinforcing properties. These secondary reinforcing cues being the opposite of the positive stimulus alley and identical to the negative stimulus alley should reinforce the incorrect response.

The results of the experiment do not support the prediction based on the above hypothesis. In the immediate reward group and the 0.5 second delay group, the animals that were trained with the differential secondary cues that were identical to the negative stimulus not only learned the maze, but no significant difference was found in trials to criterion and error scores of these animals as compared with control animals that were not trained under conflicting
secondary cues. In Phase III, the 1.3 second delay group, both the control and the experimental group reached the criterion of learning; however there was a significant difference between the mean trial and error scores for the two groups.

The present experiment is comparable to Grice's experiment in certain respects. Grice, it is recalled, trained rats in a visual discrimination apparatus under 0, .5, 1.2, 2, 5, and 10 second delays. In so far as a comparison is possible the present experiment shows a rate of learning with increase in delay that is comparable to the rate of learning in Grice's experiment. Grice compared the five second delay group that ran to neutral gray delay chambers and food boxes with a five second delay group that ran to a neutral gray delay chamber, but a goal box that was the same color as the stimulus to which the response was just made. Grice found that the secondary reinforcing properties of the white and black goal boxes afforded immediate reinforcement of the positive stimulus alley. This was evidenced by the fact that the group of animals that were trained on the maze with white and black goal boxes learned the maze in significantly fewer trials. In the present experiment, a comparison between the experimental groups, wherein the goal boxes provided secondary cues that were identical with the negative stimulus alley, and the control group, that ran to goal boxes that secondarily reinforced the positive alley,
RATE OF LEARNING AS A FUNCTION OF DELAY

FIGURE 6
showed no significant difference in two of the three experimental situations. In the third experimental condition, where there was a delay of 1.3 seconds between the stimulus alley and goal box, a significant difference was obtained between the control and experimental condition.

Smith (24) in a study investigating the stimulus trace gradient in visual discrimination learning found that when animals were required to learn a turning response to the right or to the left depending upon whether they just previously ran through a white or black alley learning was extremely unstable. Although Smith compared his results with the rate of learning that Grice obtained, it is doubtful if such a comparison is warranted. Since, as it has already been suggested, Smith was working with a delay response and not a delayed reward situation, this would account for the instability of learning which was found by Smith, but which was not evident in the present experiment.

Although the rate of learning with an increase in delay is in agreement with the data from other experiments, the prediction based on differential secondary reinforcement as hypothesized by Spence, Grice, and Riesen is not verified. However, it is possible to reconcile these experiments if consideration is given to the nature of the response in discrimination learning. Both Spence (25) and Niesen (14, 15) maintain that the response in a typical discrimination learning situation is an orientation and approach toward the
stimulus containing the positive cue rather than approaching the stimulus containing the negative cue. Gulliksen and Wolfe (8) have held the position that the subject learns to turn left to one spatial arrangement of the stimulus cues and to turn right to some other spatial arrangement. The Gulliksen-Wolfe interpretation assumes that the subject responds to all aspects of the stimulus situation, while Niesen and Spence contend that the subject responds to one part of the stimulus complex without regard to the other.

Weise and Bitterman (32) in a recent article posed the problem of how, according to Niesen's and Spence's interpretation of discrimination learning, could learning occur in what they call a successive discrimination problem. In a successive discrimination problem, only one of the cues is present at any one time. In the case of an alley maze, both paths are either black or white, and the animal learns to turn left when one of the cues is present and right when the other is present.

Spence (26) has replied to Weise and Bitterman by reference to the concept of stimulus patterning or stimulus compounds. Stimulus patterning for Spence is an admittance that if no one cue member in a discrimination problem is consistently reinforced the subject will respond on the basis of a patterning of stimuli present in the situation. Concerning these stimulus compounds, Spence writes,

There is nothing new, of course, in this conception of stimulus compounds and their differentiation for, as will be
recalled, Pavlov demonstrated that one can set up differential conditioned responses to stimulus compounds involving the same elements in different order. Undoubtedly Hull would interpret these different compounds in terms of his afferent interaction hypothesis...

Hull (13) has given special consideration to what he calls the patterning of stimulus compounds. Hull distinguishes between two forms of stimulus patterning. One is a simultaneous stimulus patterning when the onset of several stimulus energies take place at the same time; the second is a temporal stimulus patterning wherein the stimulus energies occur successively. For the purpose of this discussion the successive stimulus patterning is of considerable importance.

Hull offers as an example of successive stimulus patterning a study described by Pavlov. In this experiment, a dog was to discriminate between a sequence of three stimuli, a light, a cutaneous stimulus, and the sound of bubbling water presented in that order, from the same stimuli presented in the reverse order. The obvious similarity between successive stimulus patterning and the experimental conditions in the present experiment is undeniable.

The principles upon which the patterning of stimulus compounds is based is fairly complex, for the purpose of this discussion it will be necessary to consider several of Hull's theoretical formulations. According to Hull, temporal stimulus patterning depends namely upon the principle of afferent neural interaction and the generalization of excitation. The neural interaction, in the case of temporal
stimulus patterning, takes place between the afferent impulses arising from the second stimulation and the perseverative stimulus traces from the stimulation occurring earlier in time. Hull's neural interaction postulate takes into consideration the progressive diminution in the intensity of the stimulus trace with the passage of time, applying this principle to the concept of temporal stimulus compounding Hull formulates a minor corollary as follows:

VIII Other things equal, in the patterning of a temporal stimulus compound, the greater the lapse of time between the termination of one stimulus and the beginning of the next, the greater will be the number of differential reinforcements required to attain a given degree of patterning.

In view of the foregoing discussion of stimulus patterning, it is possible to reconcile the results of the present experiment with the results of the experiment by Grice. In the present experiment, the response is being made to a temporal stimulus compound. The animal is orienting toward and approaching a white or a black alley which in the case of the experimental group is a stimulus compound consisting of gray, black and white stimuli. If the black stimulus alley happens to be the positive cue the animal learns that gray, leading to black, leading to white is reinforced; whereas gray leading to white, leading to black, is not reinforced. The perseverative trace of the positive cue is sufficiently strong that through the process of neural interaction and the generalization of excitation a discrimination situation requiring stimulus patterning is not
significantly more difficult to learn than a discrimination situation that does not require stimulus patterning to be learned.

Thus, in Phase I and Phase II of the present experiment there was no significant difference in learning between the control and experimental groups. In Phase III, where a significant difference was found between the control and experimental groups, it can be assumed that the stimulus trace of the first cue was sufficiently diminished in intensity that little stimulus patterning could occur.

In the experiment by Grice animals comprising a five second control group ran to a gray delay chamber and a gray food box and were then compared with a five second delay group that ran to a gray delay chamber and then to a black or white goal box. The difference in learning between the two groups can be accounted for in terms of an increase in the opportunity for differential stimulus patterning with the added black and white goal boxes. That is to say, the stimulus pattern black-gray-black is more unlike white-gray-white than black-gray-gray is unlike white-gray-gray.

Analyzed in these terms the present experiment is quite unlike the experiment by Grice in that there was no differential change in the stimulus patterning but, rather, a diminution of the stimulus trace on the basis of which the patterning occurred. Thus, black-white is a stimulus pattern that is different from white-black and can be learned as
readily as white-white paired with black-black. With the diminution of the stimulus trace, however, black-white paired with white-black cannot be learned as readily as white-white paired with black-black; a difference therefore is found in the rate of learning between the control and experimental groups in Phase III.

On the basis of the patterning of stimulus compounds it is possible to reconcile the data from this experiment with the data from Grice’s experiment. Although the differential secondary reinforcement hypothesis is adequate to explain the results of the experiments by Grice (6), Perkins (18), Wolfe (33), and Riesen (19), the results could just as readily be explained in terms of Hull’s (13) patterning of stimulus compounds.
CHAPTER VI

SUMMARY AND CONCLUSIONS

One hundred and twenty-eight albino rats were trained on a visual discrimination problem involving a contradictory secondary reinforcing cue. The experiment involved three experimental conditions or phases, each consisting of a control-experimental group. In Phase I the control group was trained in a Y-maze on a black-white discrimination problem. The experimental group was trained on a discrimination problem involving a contradiction between the secondary reinforcing cue and the discrimination cue. The maze for the experimental group was constructed in two sections. The white stimulus alley was followed by a black section; while the black stimulus alley was followed by a white alley. Phases II and III were identical to Phase I except a gray section was placed between the stimulus alley and the second section of the maze; the gray section was 18" long in Phase II and 36" long in Phase III. The animals were given five trials a day until they reached the criterion of 18 out of 20 correct responses. On the basis of the differential secondary reinforcement of Spence, it was predicted that the contradictory cues should make learning virtually impossible.
An analysis of the trials to reach criterion and error scores revealed no significant difference in learning between the control groups and experimental groups in Phase I or II. In Phase III, a significant difference ($P = .02$) was obtained between the control and experimental groups.

It was concluded that a differential secondary reinforcement hypothesis is adequate to explain many experiments involving discrimination learning with delay in reward but entirely inadequate in predicting the results of the present experiment. It was suggested that Hull's concept of the patterning of stimulus compounds is more in agreement with the experimental data in that it handles the results of the present experiment as well as the results from other experiments involving discrimination learning with a delay in reward.
BIBLIOGRAPHY


34. Wolfe, J. B. "Effectiveness of Token-Rewards for Chimpanzees." *Comp. Psychol. Monog.*, 1936, 12, No. 5.

Table II

<table>
<thead>
<tr>
<th>(hkl)</th>
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<th>TIO</th>
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<tr>
<td></td>
<td>2θ</td>
<td>I/I₀</td>
<td>qₜₖ</td>
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<td>5</td>
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A plot of lattice parameter versus $\sin^2 \theta$ (Fig. 4) gives values of the lattice parameters, after extrapolation to $\sin^2 \theta = 1$, of 4.238 and of 4.178 Å for TIN and TIO, respectively. These agree very closely with values reported for the pure compounds.

The relative intensities of reflections from a given (hkl) give an indication of the thickness of the nitride layer. The calculated mass absorption coefficient of TIN is 161 for copper $K_\alpha$ radiation. Values of $I_1/I_0$ are tabulated in Table III for various thicknesses of TIN, employing a value of 5.4 gm/cm² for the density of the nitride. A value of $I_1/I_0 = 0.03$ would be sufficient to reduce the...
Table III

THE ABSORPTION OF TiO REFLECTIONS BY THE NITRIDE LAYER FOR VARIOUS THICKNESSES OF THE NITRIDE

<table>
<thead>
<tr>
<th>Thickness (mm)</th>
<th>$I_1/I_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>0.419</td>
</tr>
<tr>
<td>0.02</td>
<td>0.194</td>
</tr>
<tr>
<td>0.03</td>
<td>0.0735</td>
</tr>
<tr>
<td>0.04</td>
<td>0.0308</td>
</tr>
<tr>
<td>0.05</td>
<td>0.0129</td>
</tr>
<tr>
<td>0.10</td>
<td>0.00017</td>
</tr>
</tbody>
</table>

$I_1$ = intensity of a given TiO reflection through the indicated thickness of TiN.

$I_0$ = intensity of a given reflection from TiO in the absence of a nitride layer.

intensity of a given reflection from the substrate of TiO through the nitride layer to the background level of the spectrometer. This fraction corresponds to a value of 0.04 mm or about 0.0016 inch of nitride. In other words, if the nitride layer is thicker than 0.04 mm, no TiO reflections are observed.

The composition of the TiO from which the nitride formed may be determined from Rostoker's plot of the lattice parameter of TiO versus oxygen content as shown in Figure 5. A value of 47 atomic per cent oxygen is obtained and indicates that a metal-excess compound exists, which,
LATTICE PARAMETER, $A^* = 4.160$

ATOMIC % OXYGEN

FIG. 5 LATTICE PARAMETER–COMPOSITION RELATION OF THE TiO PHASE