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LEARNING OF A DIFFERENTIAL RESPONSE AS A FUNCTION OF  
STIMULUS-RESPONSE ASYNCHRONISM

A THESIS  
FOR THE DEGREE OF MASTER OF ARTS

1948

BY  
ROBERT WILLIAM GOY

THESIS

This is to certify that the  
thesis entitled  
Learning of a differential  
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**LEARNING OF A DIFFERENTIAL RESPONSE AS A FUNCTION OF  
STIMULUS-RESPONSE ASYNCHRONISM**

**by**

**Robert William Goy**

**A THESIS**

**Submitted to the Graduate School of Michigan  
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# TABLE OF CONTENTS

|                        | Page |
|------------------------|------|
| Introduction           | 1    |
| Theoretical Background | 3    |
| Experimental Technique | 14   |
| I. Apparatus           | 14   |
| II. Subjects           | 17   |
| III. Procedure         | 18   |
| Results                | 22   |
| Table I                | 23   |
| Fig. 1                 | 24   |
| Table II               | 26   |
| Figure 2               | 27   |
| Figure 3               | 27   |
| Table III              | 29   |
| Figure 4               | 30   |
| Figure 5               | 32   |
| Discussion             | 34   |
| Table IV               | 35   |
| Figure 6               | 36   |
| Figure 7               | 36   |
| Table V                | 40   |
| CONCLUSIONS            |      |
| Summary                | 44   |
| Reference              | 46   |
| Appendix               | 47   |

## INTRODUCTION

The present study is based on an account of the temporal aspects of learning in a reinforcement situation as presented by Hull (3) in his book, "Principles of Behavior". The variable of time enters into Hull's description of learning in essentially three ways: one, the delay of reward; two, frequency of the trials; three, stimulus response asynchronism.

The present investigation is concerned with the latter role of the time variable, its former two functions in this learning situation being held relatively constant.

The subject of trace conditioning has never been fully exploited in a systematic manner within any of the existing psychological systems, although concepts such as stimulus trace, perseveration, and mediational events in general have long been incorporated into most systems as necessary concepts for an adequate representation of various behavioral phenomena. More comprehensive work is felt to be immediately necessary in order to correct and properly extend current uses of this type of concept.

Evidence for the application of stimulus trace to learning processes usually considered to be on a higher level than simple conditioning is particularly lacking, and those systems utilizing the concept in a description of this kind of behavior have been rebuked for being too molecular, unnecessarily complicated, or speculative. Those systems distrusting the concept in this usage have generally

preferred labels of symbolic functions, representative factors or association spans. The present paper was therefore designed to test the role of stimulus trace in differential response learning as this concept has been formulated by one of the major current behavior theorists.

## THEORETICAL BACKGROUND

Probably the most thorough going and testable formulations of stimulus trace in the field today is that advanced by Hull. The concept itself enters his theory early in his first postulate, although at this time its relationship to learning is not stated nor is its mathematical formulation in this particular capacity given until the fourth postulate.

Hull states that both the limit of habit strength and the rate of acquisition of habit strength are a function of the magnitude of the stimulus trace at the time of occurrence of the response, other variables such as the delay of reinforcement being equal. He states,

"Numerous experiments have shown that the gradient of reinforcement remaining constant the most favorable temporal arrangement for the delivery of the conditioned and unconditioned stimuli is to have the latter follow the former by something less than a half second. But as the asynchronism of the onset of the two stimuli deviates from this optimal relationship in either direction, there is a falling off in the habit strength which will result from a given quality and number ~~and~~ reinforcements, the rate of decline in each direction probably being simple decay function of the nature and extent of stimulus asynchronism". (Hull, 3, p. 176).

The fourth postulate shows more clearly perhaps than the foregoing paragraph the true role of stimulus trace in a reinforcement situation as well as its relation to other variables. This postulate is as follows:

"Whenever an effector activity ( $r-R$ ) and a receptor activity ( $S-s$ ) occur in close temporal contiguity ( $s^Cr$ ) and this  $s^Cr$  is closely and consistently associated with the diminution of need ( $G$ ) there will result an increment to a tendency ( $s^Hr$ ) for that afferent impulse on later occasions to evoke that reaction. The increments from successive reinforcements summate in a manner which yields a combined

habit strength (SHR) which is a simple positive growth function of the number of reinforcements (N). The upper limit (M) of this curve of habit growth is the product of (1) a positive growth function of the magnitude of need reduction which is involved in primary or associated with secondary, reinforcement; (2) a negative function of the delay (t) in reinforcement; and (3) (a) a negative growth function of the degree of asynchronism (t') of S and R when both are of brief duration, or (b) in case the action of S is prolonged so as to overlap the beginning of R, a negative growth function of the duration (t") of the continuous action of S on the receptor when R begins."

The relationships given in the above postulate are expressed mathematically in the following manner:

$$S_{HR} : M(1-e^{-kG})e^{-jt}e^{-ut'}(1-e^{-iN})$$

where,

M : The absolute physiological limit of habit strength attainable under optimal conditions of learning with unlimited reinforcement.

e : 10, the base of common logarithms

G : the amount of need reduction as measured by objective criteria such as size of reward

t : the delay in reinforcement

T<sub>R</sub> : the time of occurrence of R

T<sub>S</sub> : the time of onset of S

t' : T<sub>R</sub>-T<sub>S</sub>-.44, where S and R are of brief duration (.44 has been empirically determined as the time of maximum recruitment).

N : number of reinforcements

k, i, u, and j : empirical constants.

In this particular problem, the size of reward is kept constant for all experimental groups and thus affects all the acquisition curves in the same manner; the delay in reinforcement is assumed to be zero so that this term in the equation (e-jt) remains optimal and constant, and since

for any measure of direct comparison that may be employed the number of reinforcements will be kept constant for all groups, this term in the equation also has a constant expression in the determination of the measures involved. The fourth term in the equation ( $e^{-ut}$ ) is the one with which we are directly concerned, and the major variable of the present study. The empirical constant ( $u$ ) is determined from the curve fitted to the data and in this manner expresses the operation of the other variables.

The original formulation of stimulus trace has been extended to include the effects of conditions such as the frequency of presentation of S and the ordinal position of S in a given series, (Reynolds, 5, p. 17), but these factors are also uniform for the groups involved.

It may be well to give a verbal definition of the concepts expressed in the above formulation which are important to us. For this purpose Hilgard supplies a very good definition of stimulus trace as follows:

"Stimuli impinging upon a receptor give rise to afferent neural impulses which rise quickly to a maximum intensity and then diminish gradually. After the termination of the stimulus, the activity of the afferent neural impulse continues in the central nervous tissue for some seconds." (Hilgard, 2, p. 81).

In conjunction with the above, Hull's imposed condition for the generation of trace conditioned responses is that S be of brief duration. This is defined by Hull as an amount of time less than the amount of time required for maximum receptor discharge. The time for maximum receptor discharge has been determined behaviorally by recent investigators and found to be about 450 msc. Thus, operationally,

a brief stimulus is one whose duration is less than 450 msc.

The decided parallel, if not covariation, of intra-neural phenomena and the empirical results of trace types of conditioning, insofar as temporal factors were concerned, led Hull to hypothesize a neurological basis for stimulus trace. This hypothesis states: Other things equal, the increment to the strength of a receptor-effector connection resulting from a reinforcement is an increasing function of the frequency of the associated receptor discharge, or the intensity of the resulting afferent impulse.

A fairly recent study by Kimble (4) however disclaims the neurological basis of stimulus trace but asserts the correctness of the mathematical treatment of the concept. The neurological basis of this concept is however completely unnecessary insofar as its descriptive use in behavior is concerned. Kimble investigated time intervals of 100, 200, 225, 250, 300 and 400 msc. using an eye-wink reflex elicitable by an unconditioned stimulus of a puff of air and a conditioned stimulus of a light source of .53 millilamberts and a duration of 1500 msc. The time intervals were measured from the onset of the conditioned stimulus. Periodic test trials were given during the conditioning process so that the latency of the response in question would not obscure the data on acquisition. The results of the study clearly show that the 400 msc. interval was the optimal of those used. These results are in essential agreement with

the previous study of Wolfle (9) in which she conditioned finger withdrawal response originally elicited by an electric shock to a conditioned stimulus of a sharp click. Of the time intervals investigated an interval of 500 msc. yielded optimal results. However from an extrapolation from these data Hull places the optimal interval at 440 msc.

Another study by Reynolds (5), using the eye-wink reflex to a puff of air and a conditioned stimulus of a click of 50 msc. duration, investigated intervals of 250, 450, 1150 and 2250 msc also placed the optimal interval around 450 msc. The Reynold's study also investigated the effect of massing the training trials and gives clear-cut evidence as to the deleterious effect of this. Under conditions of massed presentation; with only 10 to 20 records between trials, both the rate of acquisition and the maximum level of conditioning attainable under the 90 reinforced trials given were considerably reduced.

The results of conditioning data in general then would tend to confirm Hull's hypothesis of an anterior and posterior stimulus asynchronism gradient both of which are simple decay functions of an optimal interval of stimulus asynchronism around 440 msc. for conditioning. The investigations also confirm the hypothesis that the limit of fall of this gradient is substantially above 0 (around 20%) in the case of both visual and auditory receptors.

Of those studies investigating stimulus trace in a trial-and-error situation, the studies of Warner (7) and

Wilson (8) are most prominent. Warner's study with white rats consisted of a response of jumping a low fence formerly elicited by an electric shock becoming conditioned to a cue-stimulus of a buzzer which lasted for one second. Warner used intervals of one second, 10 seconds, 20 seconds, and 30 seconds between the cue-stimulus and the shock. The time between trials was one minute for the one second group, one minute and 20 seconds for the 10 second group, one minute and 40 seconds for the 20 second group, 2 minutes and 10 seconds for the 30 second group. The animals jumped a low fence in the middle of a box from one half of the floor which was charged with an electric current to the other half which was not charged, but which became charged on the next trial. The animals were given 50 trials a day. Warner found learning in at least a few animals in all of the groups except the one with an interval of 30 seconds. It is significant however, that the number of trials required by the few animals in the 20 second group that did meet the criterion is not significantly larger than the number of trials required by the animals, in either the 1 sec. or 10 sec. groups. Furthermore, it is conceivable that the criterion of six consecutive crossings could have been met purely on the bases of chance behavior when the nature of the apparatus is considered, especially in the 20 second group where such a large number of trials was given. And in fact, an examination of the data Warner presents shows very little of the gradual accumulation of a response tend-

ency so characteristic of learning in any except the I second group. In addition, none of the animals, in any of the groups other than the I sec. group, repeated the correct response after the criterion had been met in any consistent manner, but instead showed equally strong tendencies to other kinds of escape and extraneous behavior patterns. Hull attributes whatever learning may be said to have been generated to a type of conditioning called "cyclic-phase" conditioning. Because of the exactness of the time intervals between trials which Warner maintained, and the relatively constant rate of return equilibrium of body tissues affected by shock, it is conceivable that the animals under study were responding to some point on the gradient of return to equilibrium rather than to the buzzer itself. This hypothesis is in fact supported by the results of Warner's test trials. On the day after the animals had reached the criterion, they were again placed in the box and all operations that had previously been performed by the experimenter were repeated, and all conditions of the experiment repeated with the exception that both the buzzer and the shock were omitted. In no case, under these conditions, were the animals observed to cross the fence.

Warner attributes this to the absence of the buzzer. However, such results are equally as predictable on the basis of cyclic phase conditioning as may be seen in the following analysis.

The data show that many of the animals could have attained the criterion of six consecutive crossing purely on the basis

of chance, and further more, in those cases where the frequency of correct responses was such as to indicate learning, none of the animals ever responded on a particular day until they had received at least one electric shock indicating that the shock and the gradual return to equilibrium may well have been the stimulus evoking the response. Thus Warner's own test trials tend to validate Hull's explanation.

The Wilson study, called, "Symbolic Behavior in the White Rat", (8), was presumably investigating delayed response. However, the familiar experiments in delayed response never take place during the learning of the response as Wilson's study does, but always investigate the effects of delaying an already learned response to a given stimulus. To introduce varying time intervals between the cue-stimuli and the differential response, Wilson used runways of three different lengths; an 8 inch alley, a 24 inch alley and a 60 inch alley. He does not record any average times for traversing those distances, although 500 msc., 1500 msc and 4000 msc. would seem to be adequate approximations. The cue-stimuli consisted of (a) a forced right turn or (b) a forced left turn in a portion of an H-shaped maze designated as the stimulus chamber. The differently lengthed alleys were introduced as the cross bar of the H between the stimulus chamber and the other arm of the H was designated as the response chamber. The animal was required to learn a right turning response in the response chamber following a forced right turning response in the stimulus chamber with one of the above mentioned time intervals intervening between stimulus and response period. The animals were reinforced on each correct response with "a

small nibble of food". The criterion of mastery was 32 correct choices in 40 consecutive trials, 20 trials per day being given. A chance sequence of the forced turning responses was used. The goal boxes were placed at the ends of both wings of the response chamber, but on the occasions when all animals made the wrong response the door to the goal-box was locked and early in training the animal was given a shock instead of food ( a practice soon discontinued because of its disruptive effects ). Acquisition curves are not presented in the paper, but it is stated that animals were given as many as 1000 trials in which to meet the criterion. The average for the 500 msc. group was 716 trials, 792 for the 1500 msc group and 874 for the 4000 msc. group. However, in the latter group only two animals out of 11 used reached the criterion. This is equivalent to 20% mastery whereas, in the 1500 msc. group 60% mastery was reached, and in the 500 msc group 100% mastery was reached in considerably less trials. The difficulty with the data presented in this way is that they do not show the percentage of mastery after a given number of reinforcements which is a determinant of considerable importance in the approach utilised by the present paper. Doubtless had this been done, a true gradient falling as low as 10% for the 4,000 msc. group would have been obtained. Even as presented however, the results offer no disturbing departure from those obtained in trace conditioning, although it must be remembered that the relationship is here represented by data from only three groups with considerable overlap from group to group. The actual limits for the posterior asynchronism gradient are not determinate,

because several factors entered into the situation operating in such a way as to reduce both the rate and maximum of learning markedly. These factors were; 1) massing of trials, 2) the presence of the disruption due to shock in the initial trials, 3) a delay in reinforcement due to the construction of the apparatus that may have been as long as two seconds, 4) the fact that reinforcement occurred on incorrect as well as correct responses due to the fact that the arms of the H containing the goal chambers were identically constructed, (see Denny, 1). Moreover, the data in the 4,000 msc. group are particularly obscured by the use of a runway 60 inches long as a means of introducing the delay. At the beginning of learning, the time in which this distance is traversed may be greater than ten seconds, especially since no goal association had been built up by a period of preliminary training. With these unfavorable conditions for learning, a very large number of reinforcements are required to bring the response to the observable level - above threshold. According to this concept, a habit must develop to a certain degree of strength called the response threshold in order to overcome slight fluctuations in strength which reduce the response tendency to the degree where the habit does not make an empirical showing, (Hull, 3).

It may be argued that on the basis of conditioning data the posterior asynchronism gradient reaches its lower limit or fall at about three seconds, and that time intervals longer than this do not yield appreciable differences. It

is this very argument, however, which this paper attempts to show may not be a valid form of argument in so far as trace learning is concerned. The fact<sup>is</sup> that the asynchronism gradients have never<sup>been</sup> adequately worked out for differential response learning.

## EXPERIMENTAL TECHNIQUE

### I. Apparatus.

The apparatus used in this experiment is best divided in two parts for the purpose of a clear presentation. The first part of the apparatus to be discussed is that of the simple T-Maze. This part of the apparatus was built in four sections.

#### A. The Simple T-Maze.

##### 1. The Starting Box.

The starting box was 9" long, 6" wide with walls and floor of  $3/4$ " ply-wood painted white. The box had a hinged top made of  $1/8$ " ply-wood 6" wide, 7" long for the distal portion of the cover. That portion of the cover, proximal to the exit door of the starting box consisted of 2" of  $1/4$ " mesh hardware cloth so that the rat's behavior in the starting box could be observed. The cover to the starting box also supported the stimuli, i.e. the lights (three, 3 watt, G. E. Neon Lamps), and a buzzer obtained from a small commercial electric scalp vibrator. This type of buzzer was used because of the moderate intensity of the buzzer.

The exit door of the starting box was 3" wide, 4" high and attached by a spring to the top of the starting box directly above. The door was held in a closed position by a latch which was opened electrically by a 2 lb. solenoid. Thus when the latch was removed the exit door was raised by the spring and allowed the rat to enter the second portion of the maze.



## 2. The choice point of the maze.

This portion of the maze was built of  $3/4$ " ply-wood. The interior of it was painted a uniform gray with an apparent brightness approximately half way between the contrasting brightnesses of the two end boxes. At either end of the choice point section gray woolen curtains were attached to the sides of the choice box and suspended from a cross bar one inch from either end of the choice point. The first three inches above the floor was the first point of attachment of the curtains to the side walls of the alley so that the animal could gain entrance to the end box by lifting the free flap of the curtain with his nose. The walls of the choice box (and similarly the two curtains) were nine inches high, and the whole thing was covered by a removable piece of hardware cloth of  $1/4$ " mesh.

## 3. The Negative End Box.

The negative end box was an alley 5" wide and 18" long with walls and floor composed of  $3/4$ " ply-wood, and having its entire interior painted with flat black house paint. The top of the negative end box was covered with removable  $1/4$ " mesh hardware cloth. The entrance to the box, i.e. the end proximal to the curtain in the choice point contained a vertical sliding door, one side of which (that side that might possibly have been visible to the rat inside the choice point) was painted gray, and the other side of which



(the side visible from the inside of the negative end box when the door was closed) was painted black. This door was always open at the beginning of each trial, and closed immediately after the animal entered the box.

#### 4. The Positive End Box.

The positive end box or goal box had dimensions identical with that of the negative end box, but the internal appearance of the box was made completely different. The walls of this box were painted flat white. The floor of the box was covered with a  $\frac{1}{2}$ " thickness of standard soundproofing material, the first 9" of which had been sanded to form an uphill grade. At the distal end of the box a small crystal food dish similar to a common furniture coaster was placed. The top of this box was left uncovered. The proximal end of the box contained a vertical sliding door identical with the door in the negative box with the exception that the internal surface was painted white.

#### B. Electrical Synchronization; the second part of the apparatus.

The second part of the apparatus consists of the electrical wiring of the stimuli and their synchronization with the electrical solenoid which opened the exit door of the starting box. Two electrodes, spaced about one inch apart measured vertically and of the same length, were held stationary in such ~~a~~ way that the surface of an ordinary piece of graph paper stretched tightly over a revolving drum on an

electrically driven kymograph moved beneath them. At regular intervals a shot was cut in the paper so that one or both (as the case might be) of the electrodes made contact with the metal surface of the drum which was charged with an electric current. The upper of the two electrodes (on the vertical axis) was wired to a double knife edge switch and carried the current from the drum through the switch to either the buzzer or the lights as the case might be. The lower of the two electrodes was connected to the solenoid and made contact with the drum either concurrently with the stimulus electrode, 250, 1,250, 2,000 or 4,000 msec. after contact was made by the upper electrode. The time intervals were carefully controlled by spacing the slots along the horizontal axis of the graph paper. In the case of the simultaneous contact with the drum, the upper and lower electrodes used the same slot. The slot for the stimulus electrode was  $\frac{1}{4}$  of an inch long, a linear distance equal to 250 msec. according to the speed of revolution of the drum. Thus both the light and the buzzer had a duration of 250 msec., an amount of time considerably lower than the empirically determined maximum recruitment time as it is defined behaviorally.

## II. Subjects.

The subjects for the experiment were 27 male albino rats from the new colony of the department of psychology



of Michigan State College. They ranged between the ages of 80 to 110 days. They were divided into five groups in the following manner:

Group I, a simultaneous group, contained six animals. Group II, with a time interval of 250 msec. was composed of five animals at the outset of the experiment although one animal of this group died in the training process. Group III, with an Sc-Su interval of 1,250 msec. contained six animals. Group IV, with a time interval of 2,000 msec. contained four animals. And Group V, with a time interval of 4,000 msec. contained six animals.\*

Control in the selection of animals was accomplished in the following manner. Any animals that in the course of preliminary training failed to accomplish the task within a range of from .6 seconds to 1.8 seconds (a range of plus and minus one standard deviation around the mean time for accomplishing the task) were discarded.

### III. Procedure.

Each subject was given twenty preliminary training trials at the rate of four trials per day, with ten minutes between individual trials. The apparatus used for the preliminary training consisted of the starting box of the T-Maze placed in juxtaposition with the positive end box. The

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\* It should be noted at this time however that to be consistent with the preceding formulation of the Sc-Su interval, the 250 msec. group should be considered a simultaneous group since R occurred simultaneously with the offset of Sc. All following groups should have their time values decreased by 250 msec. This will be done later in the discussion.

animals were placed in the starting box and the door opened so that the animal might run to the distal end of the goal box where he received  $\frac{1}{2}$  gram Standard Purina Dog Chow as reinforcement. The purpose of this preliminary training was twofold: (1) To condition the animal to respond immediately to the opening of the exit door in the starting box, so that in the actual problem the door would play a role equivalent to that of an unconditioned stimulus (Su). (2) To build up secondary reinforcement in the goal box.

The major experimental groups were then divided into two sub-groups, each of which contained half of the animals in the original group. One of the sub-groups was run in the morning or early afternoon and the other was run in the evening between the hours of seven and nine P. M. Further, for one of the sub-groups the goal box formed the right arm of the T on trials in which the buzzer was used as the cue stimulus, and the left arm of the T for the other. The experimental procedure was then the same for all animals with the exception of the interpelation of varying degrees of time between the onset of the cue stimuli and the opening of the door of the starting box. The rats were required to respond consistently to the right (or left depending on the sub-group) when the buzzer went off concurrently with or slightly before the opening of the exit door of the starting box. When the



light was used the response demanded was opposite to that demanded when a buzzer trial was given. The rats were given six trials a day, three with the buzzer and three with the light, following the order of presentation provided for by the following table:

| First Week |          |          |          |          |          |          |   |           |
|------------|----------|----------|----------|----------|----------|----------|---|-----------|
|            | <u>M</u> | <u>T</u> | <u>W</u> | <u>T</u> | <u>F</u> | <u>S</u> |   |           |
|            | <u>S</u> | B        | L        | B        | B        | L        | L | <u>M</u>  |
|            | <u>F</u> | L        | B        | B        | L        | B        | L | <u>T</u>  |
| Fourth     | <u>T</u> | L        | L        | B        | B        | L        | B | <u>W'</u> |
| Week       | <u>W</u> | L        | B        | L        | L        | B        | B | <u>T</u>  |
|            | <u>T</u> | B        | B        | L        | L        | B        | L | <u>F</u>  |
|            | <u>M</u> | B        | L        | L        | B        | L        | B | <u>S</u>  |
|            | <u>S</u> | <u>F</u> | <u>T</u> | <u>W</u> | <u>T</u> | <u>M</u> |   |           |
| Third Week |          |          |          |          |          |          |   |           |

The animals received 1/3 gram Purina dog food as reinforcement for correct responses. When the animal made an incorrect response and entered the negative end box, he was retained there for 20 seconds, a period of time approximately equal to the amount of time required by the animals to consume 1/3 gram of food. The criterion of response used was the animal's (with his nose) pushing against one of the curtains in the choice point. This criterion was adopted before training because it was realized that after a certain

amount of training, the animals would refuse to enter the negative end box. In the case of an incorrect response, as soon as the animal had nosed the wrong curtain, the vertical sliding doors to the starting box and the positive end box were closed, thus eliminating the use of a correction technique. In such a case, if the animal refused to enter the negative end box within thirty seconds after leaving the starting box, he was removed from the choice point and an incorrect trial scored.

For the ten minutes between trials, the animals were kept in small wooden carrying cages. The purpose of this was to remove any delayed effects of secondary reinforcement that the home cage might have provided, and alternation due to reactive inhibition.

The amount of time that animals remained in the starting box before the presentation of either stimulus varied randomly within a small range of from two to ten seconds depending for the most part upon how quickly the animal oriented itself toward the exit door. At the end of the experimental period, the animals were removed to their home cage and fed a standard amount of the same food they had received for reward in no greater quantity than 9 grams and no less than 8 grams.

The order in which the animals were run was varied constantly so that no animal followed the same animal it had followed on the previous trial. This was done to eliminate the possibility of tracking.

## RESULTS

The conventional form of acquisition curve for all five of the experimental groups is given in Fig.1, the data for these curves being in concise form in Table I. It will be observed that, for the most part, all the curves plotted are negatively accelerated and indicate a simple positive growth function. However, the curves for all groups except the simultaneous group show a positive acceleration at the beginning of learning and tend to be S-shaped or ogival in appearance. It will also be noted that the greater the time interval interpolated between  $S_c$  and  $S_u$ , the greater the slanting of the S-shaped curves. This fact we may interpret as indicating the relatively slow accumulation of habit strength in the groups with the longer time intervals. This seems to be the most valid explanation because of the fact that fluctuations in the strength of a habit in the beginning of habit strength generation cause the habit in question to be obscured from observation. (For the theoretical formulation of behavioral oscillation see Hull,3, p. 289).

An examination of Table I, reading down the vertical columns, clearly indicates the general trend to a lower empirical probability of response evocation, within the limits of an equivalent number of trials, as the time interval increases from zero to 4,000 msc. This observation is illustrated graphically in Fig. 2 derived



TABLE I. AVERAGE NUMBER OF CORRECT RESPONSES  
IN 18 CONSECUTIVE TRIALS

AVERAGE % CORRECT IN 18 CONSECUTIVE  
TRIALS

|           |      |      |      |      |      |      |      |      |      |      |      |      |      |     |
|-----------|------|------|------|------|------|------|------|------|------|------|------|------|------|-----|
| GROUP I   | 10.2 | 13.0 | 15.2 | 17.5 | 18.0 | 56.7 | 72.2 | 89.4 | 97.2 | 100  |      |      |      |     |
| GROUP II  | 9.5  | 11.3 | 13.8 | 16.8 | 18.0 | 52.8 | 62.6 | 76.5 | 91.5 | 100  |      |      |      |     |
| GROUP III | 9.5  | 10.7 | 13.3 | 16.0 | 17.5 | 52.8 | 59.5 | 73.8 | 89.0 | 97.3 | 100  |      |      |     |
| GROUP IV  | 9.75 | 10.8 | 12.8 | 15.0 | 17.3 | 54.1 | 59.7 | 70.7 | 83.4 | 95.8 | 100  |      |      |     |
| GROUP V   | 9.5  | 10.2 | 11.0 | 13.6 | 15.2 | 17.5 | 18.0 | 52.7 | 56.7 | 61.1 | 75.6 | 84.4 | 97.2 | 100 |

The above table is most profitably read down the vertical columns. In this manner it is a relatively crude index of habit strength for each group after 18, 36, 54, etc. consecutive trials, although it carries the erroneous implication that Groups I and II, and Groups III and IV reached the criterion in the same number of trials. This is because of the grouping of the data.

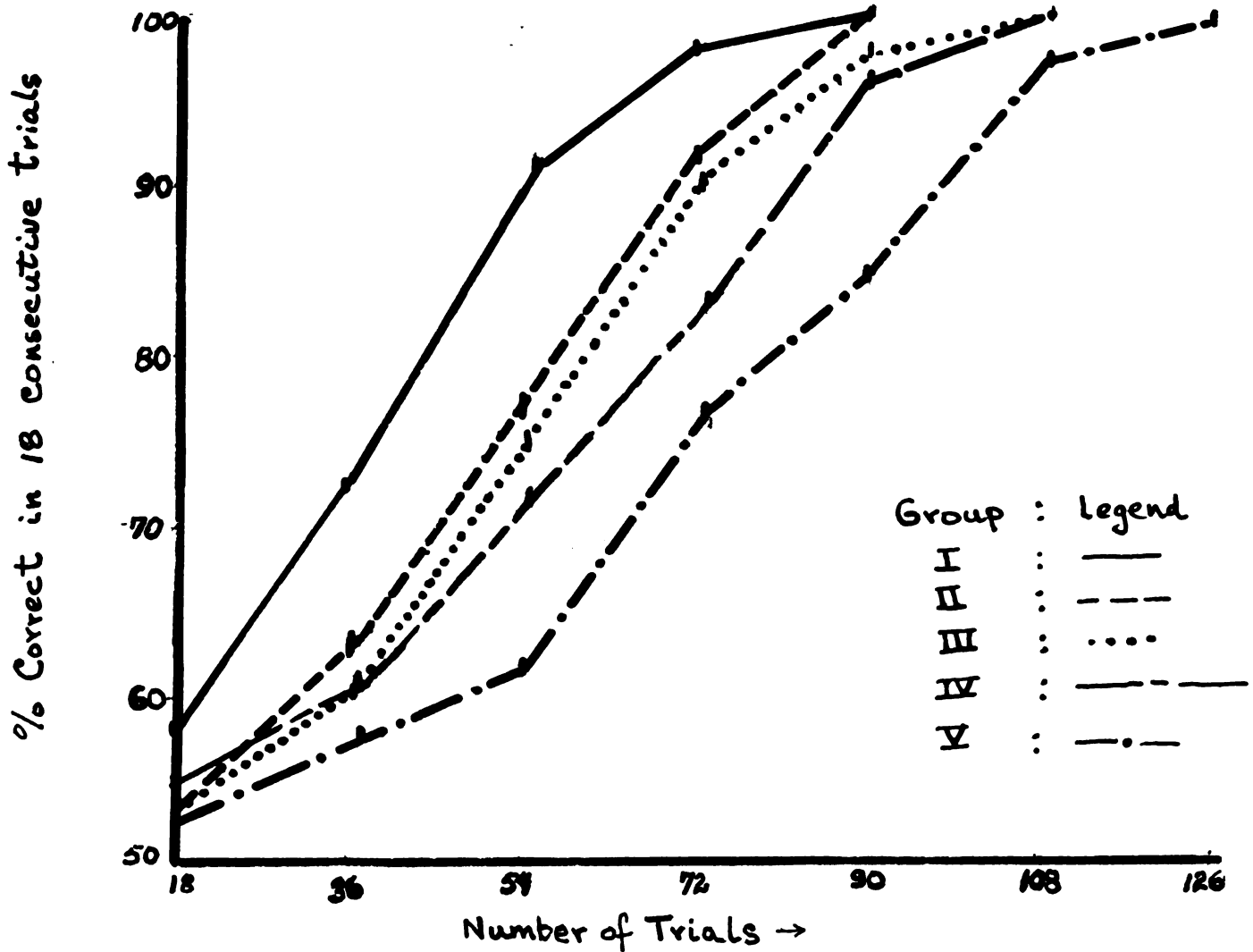


Figure 1, above, is plotted from values obtained in Table I, and has for its ordinate values the %correct responses in a block of 18 consecutive trials.

from values obtained in the eleventh column of Table I.

The above method of presentation of the data, however, is not entirely consistent with a reinforcement theory of learning in which the number of reinforcements is considered a more important determinate of learning than the number of trials. With this in mind, the data have been re-arranged in Table II. There it may be observed that the same general relationships hold true. It will be recalled that in the section of this paper dealing with the theoretical formulation of stimulus trace, it was stated that the effects of the time intervals are most clearly observed when the number of reinforcements is the same, other factors such as size and delay of reward being equal. For the purpose of demonstrating this principal, the probabilities of response for the five groups after forty-eight reinforcements were used as the ordinate values in Fig. 3, and were plotted against the appropriate time intervals. In Fig. 3 we clearly see the effects of increasing the Sc-Su interval upon the amount of habit strength attainable with a given number of reinforcements. For the 4,000 msc. group, the strength of the habit provides a probability of response of .764, or 26.4% above the level of chance expectancy. Whereas, Group I has already attained the level of 100% performance.

TABLE II. AVERAGE NUMBER OF TRIALS REQUIRED  
TO GAIN 12 REINFORCEMENTS

AVERAGE PROBABILITY OF RESPONSES AFTER  
EACH 12 REINFORCEMENTS

|           |      |      |      |      |      |      |      |      |      |      |      |      |
|-----------|------|------|------|------|------|------|------|------|------|------|------|------|
| GROUP I   | 20.5 | 16.0 | 15.3 | 12.0 |      | .585 | .750 | .783 | 1.00 |      |      |      |
| GROUP II  | 22.2 | 17.8 | 16.2 | 12.6 | 12.0 | .540 | .675 | .740 | .950 | 1.00 |      |      |
| GROUP III | 22.7 | 19.8 | 14.9 | 13.5 | 12.0 | .528 | .606 | .805 | .890 | 1.00 |      |      |
| GROUP IV  | 21.3 | 20.1 | 18.5 | 14.8 | 12.0 | .562 | .600 | .649 | .811 | 1.00 |      |      |
| GROUP V   | 22.0 | 20.8 | 17.2 | 15.7 | 13.1 | 12.0 | .545 | .576 | .698 | .764 | .916 | 1.00 |

The above table represents a more refined measure of the acquisition of habit strength using smaller groupings based upon successive (not consecutive) reinforcements. It may be read in the same manner as Table I.

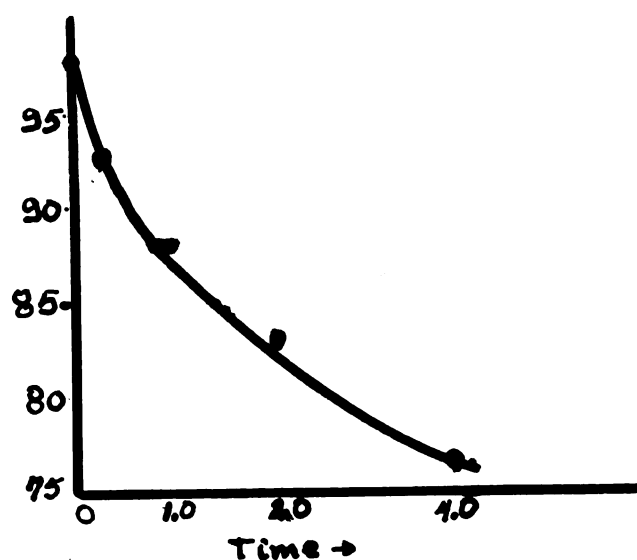


Fig.2 has as its ordinate values, percentages taken from column 11 in Table I.

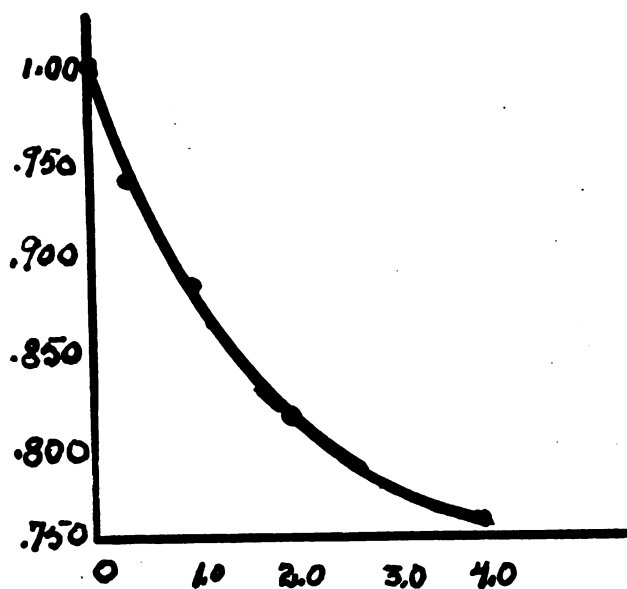


Fig. 3 is drawn from the average probabilities of response provided in Table II, column 10.

Hull's formulation of habit strength generation under conditions of stimulus trace also asserts that the rate of generation will be reduced as the time interval becomes longer, having its limit appreciably above zero. For the purpose of showing the effect of the time intervals upon the rates of learning, the curves in Fig. 4 were drawn. These curves were based upon the cumulative data for each group shown in Table III. From the values listed in the table, it may be easily observed that the rate of increase of any given curve constantly decreases in a manner resembling a simple positive growth function, the increment to the cumulative percentage constantly decreasing as a function of the number of reinforcements attained. However, at any given number of reinforcements the increases in the cumulative percentages of the various groups is less as the time interval of the group is larger. For example, at forty-eight reinforcements, Group I has a cumulative percentage increase of 2.7% over the cumulative percentage recorded for thirty-six reinforcements. For Group Y however, the difference between the percentages reached at the same number of reinforcements is only 1.9%. It must be remembered however that these reinforcement values for Group V occur relatively near the beginning of learning where the rate of acquisition is nearly maximal, whereas the same numbers of reinforcements place Group I near the end of learning where the rate is normally low.

TABLE III. THE RATIO OF THE CUMULATIVE TOTAL OF REINFORCEMENTS  
TO THE CUMULATIVE TOTAL OF TRIALS ( $N/T$ )

|           | $N_1$ | $N_2$ | $N_3$ | $N_4$             | $N_5$             | $N_6$             | $N_7$ | $N_8$ |
|-----------|-------|-------|-------|-------------------|-------------------|-------------------|-------|-------|
| GROUP I   | .586  | .658  | .694  | .753 <sup>‡</sup> | .792              | .820              | .842  | .860  |
| GROUP II  | .535  | .600  | .641  | .698              | .742 <sup>‡</sup> | .776              | .800  | .822  |
| GROUP III | .539  | .564  | .627  | .678              | .725              | .759 <sup>‡</sup> | .786  | .813  |
| GROUP IV  | .570  | .583  | .603  | .658              | .705              | .740              | .769  | .793  |
| GROUP V   | .545  | .562  | .600  | .634              | .675              | .712              | .744  | .768  |

The above table gives the values of the ratio of  $\hat{N}$  to  $\hat{T}$  where  $\hat{N}$  increases constantly as learning progresses in the following manner:  $N_1$  equals 12,  $\hat{N}$  equals 12;  $N_2$  equals  $N_1$  plus 12,  $\hat{N}$  equals 24 and  $\hat{T}$  represents the average cumulative total number of trials.

<sup>‡</sup> These values are close to the  $\hat{N}/\hat{T}$  ratio for the various groups at the time the criterion was reached. No values are asterisked for IV and V because they fall more accurately between the categories used than within them.

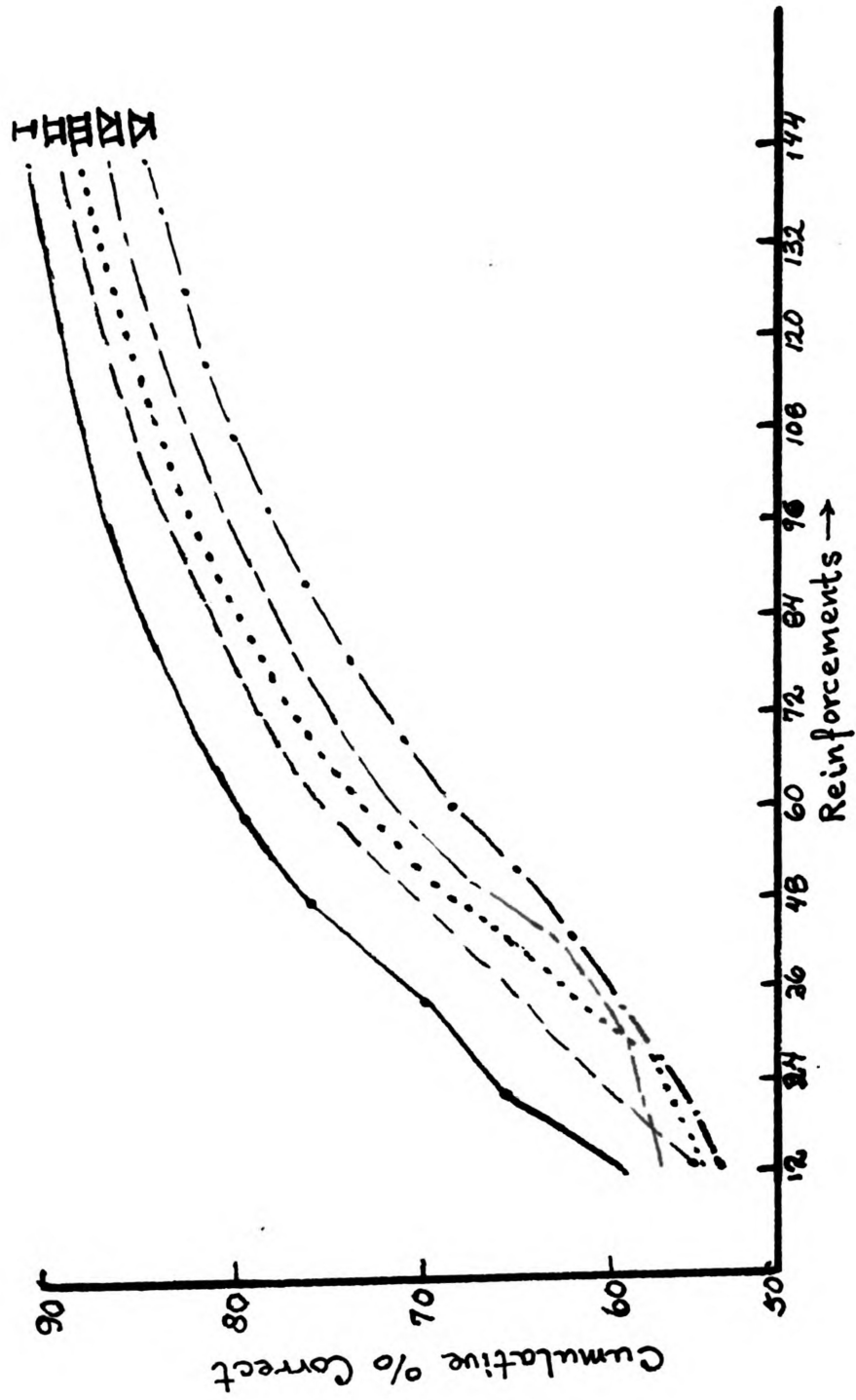


Figure 4.

The curves in Fig. 4 have a particular value in so far as they express clearly the differential effects of a time interval upon the maximum cumulative percentage attainable at any given number of reinforcements. They are of even more theoretical interest in so far as they show a differential effect of the time interval upon the cumulative percentages at the time the criterion was met, regardless of the number of reinforcements. In this respect, the following percentages were reached: Group I, 75.8%; Group II, 73.8%; Group III, 72.1%; Group IV, 71.6%; Group V, 71.2%. The reliability of these relatively small differences is attested to by the smoothness of the curves when the data are handled in the above manner. These differences are of some theoretical importance since the maximum habit strength attainable (M), that is to say the upper physiological limit is also theoretically reduced by interpolating larger time intervals, and in the absence of any direct measure of habit strength, these values may have some significance. The curves are in no way to be confused, however, with a true measure of habit strength, for to regard them as such would demand postulating that habit strength was a function of the ratio of reinforced to non-reinforced trials, which the theory underlying this study does not propose to be the case.

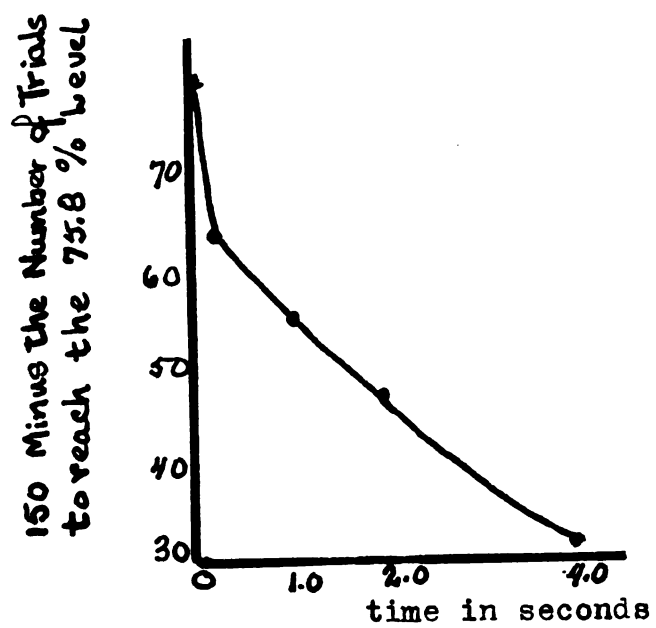


Figure 5.

Another measure of the rate of learning is seen in Fig. 5. In this method, an arbitrary value well above the maximum number of trials required by the slowest group is selected, and the average of the total number of trials to reach a given level of performance for each group is then subtracted from this value. In the present case, the largest number of trials was required by Group V, and the average of the group was found to be 111, so an arbitrary value of 150 was selected. The level of performance was 75.8% as measured by the cumulative data. This level was selected because it was the level of performance of the zero delay group at the time the criterion was reached. This curve is not based entirely upon empirically obtained data, although the assumptions upon which the extrapolations were made are reasonably tenable. In this method also Group I is seen to have the fastest rate of rise, and the other four groups slower rates in accordance with the length of the time interval.

## DISCUSSION

In the original introduction to the concept of stimulus trace, it was stated that the magnitude of the stimulus trace decreased as a simple decay function of the time interval between the offset of Sc and the occurrence of R. In the foregoing presentations of the results, the time intervals were measured from the onset of Sc. This method of presentation does not obscure the relationship expressed between groups II, III, IV, and V, since any re-arrangement of the data for these groups would simply involve a subtraction of a constant value of 250 msc. for the time axis. It may however present an untrue picture of the relationship of Group I to the other groups, and furthermore create a false impression of a serious discrepancy between the results of this investigation and the previous studies on the acquisition of trace conditioned responses. For instance, in the studies of Wolffe only small differences were observed between a simultaneous group, equivalent to this investigation's 250 msc. group, and time intervals of about .8 seconds which would correspond to the present 1,000 msc. group. The difference in character of the problem involved in the present form of simultaneous group is implied by the fact that the conventional acquisition curve for this group closely resembled a simple positive growth function, whereas the acquisition curves for Groups II, III, IV, and V were alike in being better approximated by S-shaped curves.



TABLE IV

|           | $\bar{T}$ | $\bar{N}$ |
|-----------|-----------|-----------|
| GROUP I   | 63.0      | 46.3      |
| GROUP II  | 82.3      | 63.8      |
| GROUP III | 86.0      | 66.0      |
| GROUP IV  | 96.0      | 71.5      |
| GROUP V   | 111       | 81.0      |

In the above table  $\bar{T}$  stands for the average total number of trials required by each group to reach the criterion of 18 consecutive correct responses. The symbol  $\bar{N}$  stands for the average total number of reinforcements required to reach the same criterion of performance.

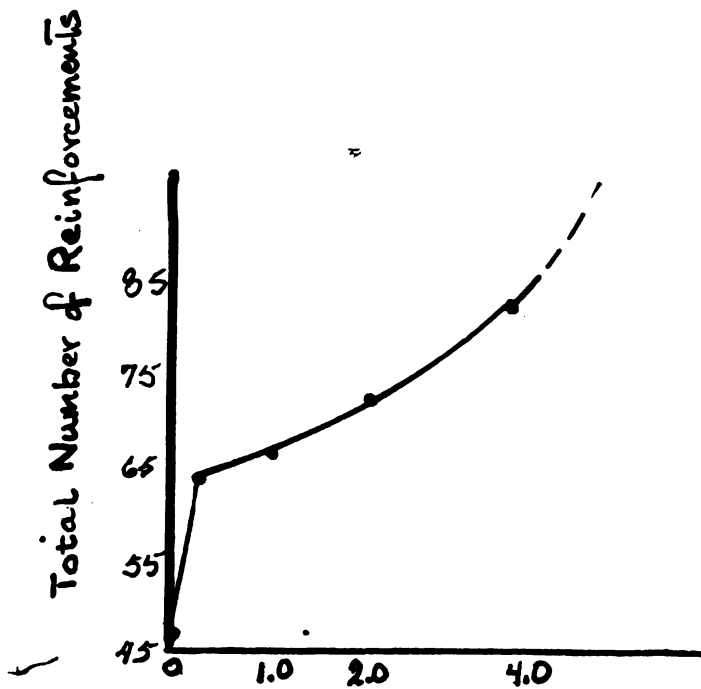


Figure 6

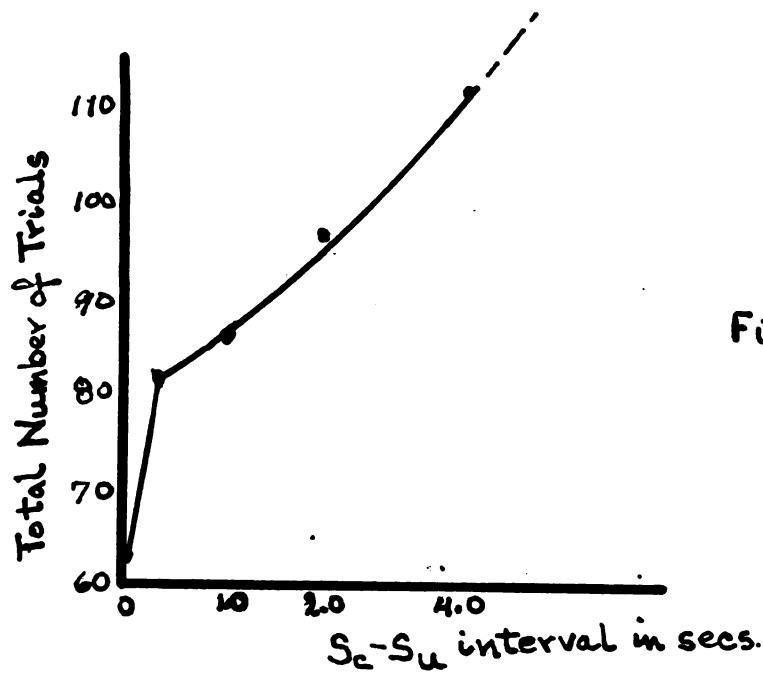


Figure 7

Figs. 5 and 7 above were designed to illustrate the marked difference (in terms of a general trend) between the zero group and the other four.

Similarly, the fact that the increase in rate of the cumulative percentage acquisition curves was not consistently greatly different for Groups II and III, as was mentioned before, is probably attributable to the facts outlined above, and does not constitute a departure from theoretical expectations. The anomalous relationship of Group I to the other groups, with respect to stimulus trace, is made quite clear in Figs. 6 and 7, as well as in Table IV.

The serious departure from conditioning data that the present study provides is the fact that groups with the time interval as long as 3,750 msc. reached a level of learning far higher than that anticipated on the basis of the conditioning data. For the most part, this difference is largely attributable to more adequate control of the relationships between drive and reinforcement. A learning situation in which reinforcement is delivered by the avoidance of a negative stimulus represents a situation of relative instability in so far as control of these factors is concerned. The fact that in a differential response situation with unlimited reinforcements, two or more responses are being learned in a unified manner is a possible factor contributing to these differences, and as such may not be completely ignored.

This study departs considerably from the results obtained by Wilson previously reviewed in this article.

Wilson obtained evidence of only 20% learning in a 4,000 msc. group, whereas in the present study, all the animals in the 4,000 msc. group reached the criterion of mastery. The most plausible explanation for this difference is the factor of inadequate control over the time interval in the Wilson study. As was pointed out in the section dealing with theoretical background, the interpolation of long runways is not comparable to the interpolation of strictly controlled time intervals because of the shortening of the time required to traverse the distance as learning progresses. For this reason, Wilson's 60 inch alley probably has an effect on learning much the same as that of a time interval of 8 seconds or more. The mean number of trials for each group in the Wilson study to reach the criterion of mastery was 716, 792, and 874 for the 500, 1500, and 4000 msc. groups respectively. This indicates that the mean number of trials for Wilson's longest group, was almost nine times as large as the mean number required by the present longest delay group. This discrepancy is attributable to the fact that the factors of size of reward, delay of reward, and massing of trials, were carefully controlled in the present study at very nearly their optimal values for learning.

Another factor contributing to the rapid speed of learning by the animals in the present study was the confinement of the operation of secondary reinforcement to only one side of the maze for a given response. Secondary reinforcement is acquired by the stimulus objects in the vicinity of the goal, and this secondary reinforcement is capable of



operating in a manner equivalent to primary reinforcement, providing that periodic primary reinforcement is provided. Thus, in the case of identical end boxes, the wrong response to a given stimulus is reinforced almost as much as the correct response to the same stimulus with the result that considerably more primary reinforcements are necessary for learning. The above explanation is supported by findings in a study by Denny (1), in which it was reported that animals learning a maze only reinforced in one particular kind of a goal box of markedly different appearance from the negative end box learned considerably faster than animals learning the same maze with the exception that both end boxes were identical thus eliminating differential secondary reinforcement.

A recent study, performed concurrently but independently of this study, reports results more in agreement with Wilson than those of this paper. This study was performed by Smith (6), at the University of Iowa, and he has kindly provided the author with a table summarising his results in regard to number of trials. The data are found here in Table V. In the Smith study, the different cue stimuli consisted of running, on one trial, through a 24 inch alley the interior of which was painted white, and on another trial, running through a 24 inch alley painted black. Thus, the stimuli involved were both mediated by the same sense organ. After the animals had run through

TABLE V

| Sc - Sj Interval | 0 msec.       |               | 600           | 750           | 2,000         | 5,000         |               |
|------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Type of Rat      | <u>Hooded</u> | <u>Albino</u> | <u>Hooded</u> | <u>Albino</u> | <u>Hooded</u> | <u>Hooded</u> | <u>Albino</u> |
|                  | 70            | 150           | 250           | 900           | 580           | 420           | 1500*         |
|                  | 120           | 70            | 330           | 900           | 200           | 1410          | 1500*         |
|                  | 150           | 100           | 190           | 610*          | 1240*         | 1480*         | 2100*         |
|                  | 40            | 220           | 380           |               | 1050          | 1400          | 2100*         |
|                  | 40            | 70            | 120           |               | 520           | 1400          | 2100*         |
|                  | 70            | 290           | 180           |               |               |               |               |
|                  | 30            | 160           | 140           |               |               |               |               |
|                  | 90            | 160           | 270           |               |               |               |               |
|                  | 70            | 160           | 140           |               |               |               |               |
|                  | 90            | 290           | 280           |               |               |               |               |
|                  | 90            |               |               |               |               |               |               |
| Median           | 70            | 160           | 220           | 900           | 580           | 1400          | 2100*         |

The above table gives the number of trials required by each animal to reach the criterion, and the median number for each experimental group.

Asterisks indicate that animal had not reached the criterion and running was discontinued at the end of the given number of trials. (From data supplied by M. Smith, University of Iowa, Iowa City, 1948 obtained in an unpublished study.)

either one or the other of the stimulus alleys, which were presented in a random order, they were confined in a neutral delay chamber for intervals of time varying in the following manner: a zero delay group, measured from the time of offset of Sc, a .75 sec. group, a 2 sec. group, and a 5 sec. group. ( These are the time intervals for the Albino subjects only, one of the Hooded groups being run under conditions of delay of .6 sec.) In this study, the zero second group required more than twice the number of trials required by the 250 msc. group of the present study which was its equivalent. Further, it required one-and-a-half times as many trials as the 4,000 msc. group of the present study. Smith found that only 80% of the animals in the 5 sec. group, and the e were all Hooded animals, could master the problem. Of the Albinos used in a similar 5 sec. group, none, or 0%, reached his criterion of 18 correct out of 20 consecutive trials. This would indicate that the limit of fall of habit strength is very low, but appreciably above zero, when the Sc-Su interval is about five seconds. These results are fairly well in line with the results obtained from conditioning experiments. However, in the present study, extrapolations of the curves based on average total number of responses and average total number of reinforcements, were made. The time interval which is to be expected to require an impossible or extremely large number of trials or reinforcements according to these extrapolations is

around ten seconds. These extrapolations were based on theoretical expectations, since the four points obtained from the present study are represented almost as well by a straight line as by a positively accelerated growth curve. The differences between the Smith data, and those of the present study, are largely attributable to two factors; one, the fact that secondary reinforcement was allowed to operate as a reinforcer of incorrect as well as for correct responses because of the identical construction of the end boxes in the Smith report, a factor previously discussed in relation to Wilson, and two, the fact that the present study employed two sense modalities for the mediation of the cue stimuli whereas the Smith study used only the visual sense. Thus, in the case where only one sense modality is employed, there is a greater possibility of stimulus generalisation which would tend to impede the accumulation of habit strength for differential responses since the Sc for one response is on the generalisation gradient of the Sc for the other response. A number of investigators have shown that the generalisation gradient for responses involving two sense modalities is remarkably steeper than the gradients for responses evoked by stimulation of only one sense modality.

Another difference between the two studies is the decided difference in the duration of the cue stimuli. It

will be recalled that stimulation as employed by Smith involved running either a black or white alley 24 inches in length. This means that the duration of the stimuli is at least 1,000 msc., or four times as long as that used in this study, and considerably above the maximum recruitment period defined behaviorally. This does not, according to Hull's original formulation, generate true trace reactions, and because of this, direct comparisons of the present report with Smith's study may involve some contradiction.

Comparison of these results with those obtained by Warner does not seem to be particularly profitable since Warner's study has already been dismissed as being representative of cyclic-phase conditioning, rather than trace conditioning. Warner's study was rather thoroughly discussed in the section of this paper dealing with the theoretical background, and the reader is referred to that discussion if further clarification is desired.

## SUMMARY AND CONCLUSIONS

1. Five groups of animals were trained in a reinforcement situation at five different Sc-Su intervals of 0, 250, 1250, 2000, and 4000 msc. respectively, primarily for the purpose of investigating the relationship between the level of learning and rate of learning and the Sc-Su interval.
2. The results indicate that, for the range of intervals used in the present study, the level of learning attainable within a given number of reinforcements is simple decay function of the magnitude of the stimulus trace at the time of occurrence of R, assuming the magnitude of stimulus trace bears a direct relationship to the amount of time that has elapsed since the occurrence of S.
3. The limit of fall of maximum learning is considerably higher in a reinforcement situation in which the role of secondary reinforcement is made optimal than in a conditioning situation.
4. In differential response learning, the limit of fall of the maximum attainable under a given number of reinforcements appears to be raised for any given time interval when two sense modalities are used.
5. When the offset of Sc is contiguous with the occurrence of R, acquisition occurs at a slightly faster rate and to a higher maximum than for intervals greater than one second.
6. When the onset of a given Sc, which has a duration less than the amount of time required for maximum recruitment,

is made contiguous with the occurrence of R, the maximum level of learning is considerably higher and is attained considerably faster than is possible for habits generated under the conditions of trace imposed by this study.

7. A cue stimulus of 250 msec. having its onset contiguous with the occurrence of R appears to bear an anomalous relationship to the data of trace generated differential response learning. That is to say, that habits generated under this condition will probably be better expressed by different functions than those formulated for trace generated habits.

8. In general, the acquisition of a differential response obeys the same general relationships provided for by Hull's present mathematical formulation of stimulus trace, and no concepts such as symbolic behavior, representative factors, or association span need be devised for an adequate account.

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## APPENDIX

# GROUP I

|            | Trials |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    | Correct |
|------------|--------|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|---------|
|            | 1      | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | Total   |
| Animal #1. | 1      | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 0  | 1  | 0  | 1  | 1  | 1  | 0  | 13      |
|            | 1      | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1  | 1  | 1  | 0  | 1  | 0  | 1  | 1  | 0  | 13      |
|            | 0      | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 16      |
|            | 1      | 1 | 1 | 1 | 1 | 1 |   |   |   |    |    |    |    |    |    |    |    |    | 6       |
| Animal #2. | 1      | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1  | 1  | 0  | 1  | 1  | 0  | 1  | 0  | 0  | 10      |
|            | 0      | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1  | 0  | 0  | 1  | 1  | 0  | 1  | 1  | 1  | 11      |
|            | 1      | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 16      |
|            | 1      | 1 | 1 | 1 | 1 | 1 |   |   |   |    |    |    |    |    |    |    |    |    | 6       |
| Animal #3. | 1      | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1  | 1  | 0  | 1  | 1  | 0  | 1  | 0  | 1  | 10      |
|            | 1      | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 15      |
|            | 1      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 18      |
| Animal #4. | 1      | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0  | 1  | 1  | 1  | 0  | 1  | 1  | 0  | 1  | 11      |
|            | 1      | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 0  | 12      |
|            | 0      | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 16      |
|            | 1      | 1 | 1 | 1 | 1 | 1 |   |   |   |    |    |    |    |    |    |    |    |    | 6       |
| Animal #5. | 0      | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0  | 1  | 0  | 1  | 1  | 0  | 1  | 1  | 0  | 9       |
|            | 1      | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 0  | 15      |
|            | 1      | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1  | 1  | 0  | 1  | 1  | 0  | 0  | 0  | 1  | 12      |
|            | 1      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 18      |
| Animal #6. | 0      | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1  | 0  | 1  | 0  | 1  | 1  | 0  | 0  | 1  | 8       |
|            | 0      | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 0  | 12      |
|            | 0      | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1  | 1  | 0  | 1  | 0  | 1  | 1  | 0  | 1  | 12      |
|            | 0      | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 15      |
|            | 1      | 1 | 1 | 1 | 1 | 1 |   |   |   |    |    |    |    |    |    |    |    |    |         |

The above tabulations represent the behavior of the animals in Group I recorded in rows of 18 consecutive trials given at the rate of six trials per day. A number "1" in the above table represents a correct response, and the "0" represents an incorrect response. The following pages contain similar tables for Groups II, III, IV and V. If the reader wishes to know the order of presentation for the stimuli, he is referred to the section in the report on experimental technique, Part III, procedure.

**GROUP II**

[illegible]

# GROUP III

|            | Trials |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    | Correct |
|------------|--------|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|---------|
|            | 1      | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | Total   |
| Animal #1. | 0      | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1  | 0  | 0  | 1  | 1  | 0  | 0  | 0  | 1  | 7       |
|            | 0      | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1  | 1  | 0  | 1  | 0  | 1  | 1  | 0  | 0  | 10      |
|            | 1      | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1  | 1  | 14      |
|            | 1      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 18      |
| Animal #2. | 0      | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1  | 0  | 1  | 1  | 1  | 0  | 1  | 1  | 0  | 11      |
|            | 0      | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1  | 1  | 1  | 0  | 0  | 1  | 1  | 1  | 0  | 11      |
|            | 0      | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1  | 0  | 1  | 1  | 0  | 1  | 1  | 1  | 0  | 12      |
|            | 0      | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1  | 0  | 1  | 0  | 0  | 1  | 1  | 1  | 1  | 13      |
|            | 1      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 18      |
| Animal #3. | 1      | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1  | 0  | 1  | 0  | 1  | 1  | 0  | 1  | 1  | 12      |
|            | 1      | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1  | 1  | 0  | 1  | 1  | 0  | 1  | 1  | 1  | 13      |
|            | 1      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1  | 1  | 1  | 0  | 0  | 1  | 1  | 1  | 1  | 15      |
|            | 1      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 18      |
| Animal #4. | 1      | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1  | 0  | 1  | 0  | 0  | 1  | 0  | 1  | 0  | 7       |
|            | 1      | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0  | 1  | 0  | 0  | 0  | 0  | 1  | 0  | 1  | 7       |
|            | 1      | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0  | 1  | 1  | 0  | 1  | 1  | 1  | 1  | 0  | 10      |
|            | 0      | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 0  | 1  | 0  | 1  | 1  | 1  | 0  | 1  | 13      |
|            | 1      | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 16      |
|            | 1      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 18      |
| Animal #5. | 1      | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1  | 1  | 0  | 0  | 1  | 1  | 1  | 1  | 0  | 10      |
|            | 1      | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 15      |
|            | 1      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1  | 0  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 16      |
|            | 1      | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1  | 1  | 16      |
|            | 1      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 18      |
| Animal #6. | 0      | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1  | 0  | 1  | 1  | 0  | 1  | 0  | 0  | 1  | 10      |
|            | 0      | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1  | 1  | 0  | 0  | 1  | 0  | 1  | 0  | 0  | 8       |
|            | 1      | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1  | 1  | 1  | 0  | 1  | 0  | 1  | 1  | 1  | 12      |
|            | 1      | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 17      |
|            | 1      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  |    |    |    |    |    |    | 12      |

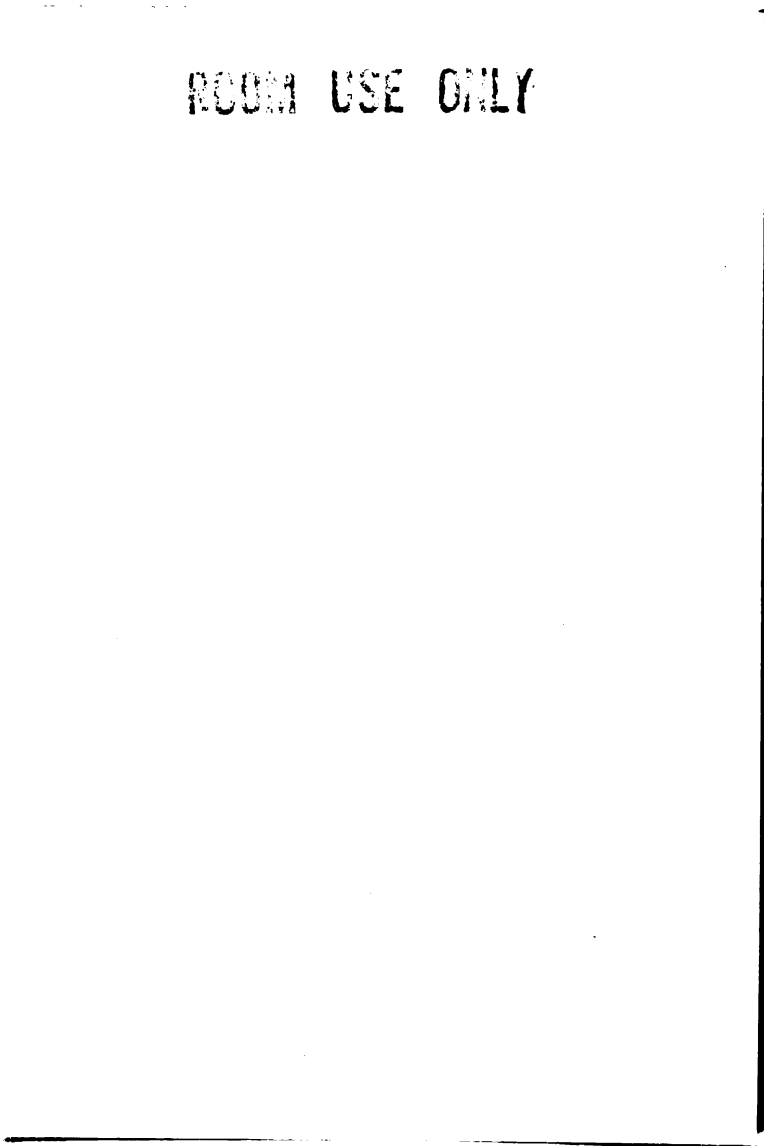
# GROUP IV

|            | Trials |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    | Correct<br>Total |
|------------|--------|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|------------------|
|            | 1      | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |                  |
| Animal #1. | 0      | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1  | 0  | 1  | 0  | 1  | 0  | 1  | 0  | 1  | 11               |
|            | 0      | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1  | 0  | 1  | 1  | 1  | 1  | 1  | 0  | 0  | 11               |
|            | 1      | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1  | 14               |
|            | 1      | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 16               |
|            | 1      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 18               |
| Animal #2. | 1      | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1  | 0  | 1  | 0  | 1  | 0  | 0  | 1  | 1  | 8                |
|            | 1      | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0  | 0  | 0  | 1  | 0  | 1  | 0  | 1  | 0  | 10               |
|            | 0      | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1  | 0  | 1  | 1  | 1  | 0  | 1  | 0  | 0  | 9                |
|            | 0      | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1  | 14               |
|            | 0      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 16               |
|            | 1      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  |    |    |    |    |    |    | 12               |
| Animal #3. | 1      | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0  | 1  | 0  | 1  | 0  | 1  | 1  | 0  | 0  | 10               |
|            | 1      | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0  | 0  | 1  | 1  | 0  | 0  | 1  | 0  | 1  | 10               |
|            | 1      | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 0  | 1  | 14               |
|            | 0      | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 0  | 1  | 1  | 1  | 1  | 0  | 1  | 14               |
|            | 1      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 18               |
| Animal #4. | 1      | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0  | 1  | 0  | 1  | 0  | 1  | 1  | 0  | 1  | 10               |
|            | 1      | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1  | 1  | 1  | 1  | 1  | 1  | 0  | 0  | 1  | 12               |
|            | 1      | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 14               |
|            | 0      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 16               |
|            | 1      | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 17               |
|            | 1      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  |    |    |    |    |    |    | 12               |

# GROUP V

|            | Trials |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    | Correct<br>Total |
|------------|--------|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|------------------|
|            | 1      | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |                  |
| Animal #1. | 0      | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0  | 1  | 0  | 0  | 1  | 0  | 1  | 1  | 0  | 9                |
|            | 1      | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1  | 1  | 0  | 0  | 1  | 0  | 0  | 1  | 1  | 9                |
|            | 1      | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1  | 1  | 0  | 0  | 1  | 0  | 1  | 1  | 0  | 8                |
|            | 0      | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1  | 0  | 1  | 1  | 1  | 1  | 1  | 1  | 0  | 14               |
|            | 1      | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 0  | 13               |
|            | 1      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 18               |
| Animal #2. | 1      | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0  | 1  | 0  | 0  | 1  | 1  | 1  | 1  | 0  | 10               |
|            | 1      | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0  | 0  | 1  | 1  | 0  | 1  | 1  | 0  | 1  | 10               |
|            | 1      | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 0  | 1  | 12               |
|            | 1      | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1  | 1  | 1  | 1  | 0  | 0  | 0  | 1  | 1  | 13               |
|            | 1      | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 0  | 1  | 1  | 1  | 1  | 1  | 1  | 16               |
|            | 1      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 18               |
| Animal #3. | 1      | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0  | 1  | 0  | 0  | 1  | 1  | 0  | 1  | 1  | 10               |
|            | 1      | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0  | 1  | 1  | 1  | 1  | 0  | 1  | 0  | 1  | 10               |
|            | 1      | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1  | 1  | 0  | 1  | 1  | 1  | 1  | 0  | 0  | 11               |
|            | 1      | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1  | 0  | 1  | 1  | 0  | 1  | 1  | 1  | 1  | 15               |
|            | 1      | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1  | 16               |
|            | 1      | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 17               |
| Animal #4. | 1      | 1 | 1 | 1 | 1 | 1 |   |   |   |    |    |    |    |    |    |    |    |    | 18               |
|            | 0      | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1  | 1  | 0  | 1  | 0  | 1  | 0  | 0  | 1  | 9                |
|            | 0      | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 1  | 0  | 1  | 1  | 1  | 0  | 0  | 1  | 0  | 10               |
|            | 0      | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0  | 1  | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 11               |
|            | 1      | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0  | 0  | 1  | 1  | 1  | 0  | 0  | 1  | 1  | 13               |
|            | 0      | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 0  | 1  | 1  | 1  | 1  | 0  | 1  | 14               |
| Animal #5. | 1      | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 17               |
|            | 1      | 1 | 1 | 1 | 1 | 1 |   |   |   |    |    |    |    |    |    |    |    |    | 6                |
|            | 0      | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0  | 1  | 0  | 1  | 1  | 1  | 0  | 0  | 1  | 9                |
|            | 0      | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0  | 1  | 1  | 0  | 0  | 1  | 1  | 0  | 1  | 9                |
|            | 1      | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1  | 1  | 0  | 0  | 1  | 1  | 1  | 0  | 1  | 11               |
|            | 1      | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 1  | 1  | 14               |
| Animal #6. | 1      | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 16               |
|            | 1      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1  | 1  | 1  |    |    |    |    |    |    | 12               |
|            | 1      | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1  | 0  | 1  | 0  | 1  | 0  | 0  | 1  | 0  | 10               |
|            | 1      | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1  | 0  | 0  | 0  | 1  | 1  | 0  | 1  | 1  | 11               |
|            | 1      | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1  | 1  | 1  | 1  | 0  | 1  | 0  | 1  | 1  | 13               |
|            | 0      | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1  | 1  | 1  | 0  | 1  | 1  | 1  | 0  | 1  | 14               |

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