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Edited by
JOHN B. WATSON AND WALTER S. HUNTER

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CONTENTS

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Acknowledgments

It is a pleasure for me to acknowledge a deeply felt indebtedness to my teachers, Professors Angell and Carr, for their instruction and inspiration.

Professor Carr kindly proposed these experiments, and patiently and helpfully criticized this presentation of their methods and results.

CONTENTS

I. INTRODUCTION

The object of these experiments, stated in general terms, was to study the kind and the degree of transfer of training in white rats which were allowed to learn a maze after they had learned, either completely or partially, one or more other mazes. Specifically, the object was to find out:

1. Whether there was transfer of training between a pair of mazes which were learned completely one after the other, and if so whether it was positive or negative. These expressions, "positive transfer" and "negative transfer," are familiar to those interested in this phase of psychological research; but it may not be useless to remark, for the sake of some chance reader, that by the former is meant that the mastery of one or more mazes renders easier the mastery of a subsequent one, while by the latter is meant that the mastery of one or more mazes renders more difficult the mastery of a subsequent one.
2. Whether, if either positive or negative transfer is present, it will persist through a series of mazes; and whether, if both present and persistent, it will also be cumulative.
3. The effect upon the learning of a maze of having partially learned a preceding maze.
4. The effect of the complete learning of a maze upon the mastery of another maze already partially learned.
5. Whether it is more advantageous to learn two mazes in succession; or to partially learn one, then completely learn the other, and finally perfect the learning of the former.
6. The effect upon the relearning of a maze of having learned four intervening mazes between the original learning of the maze and its relearning.

Diagrams of the mazes are presented in Plate I, figs. 1–5. In all the mazes except C the blind alleys were twenty

PLATE I

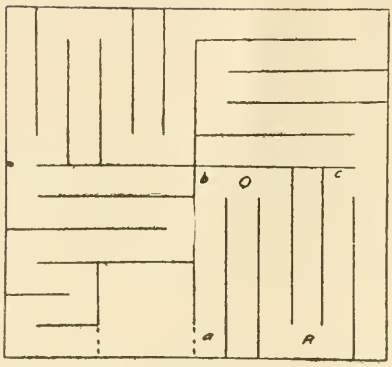

FIG. 1
MAZE A

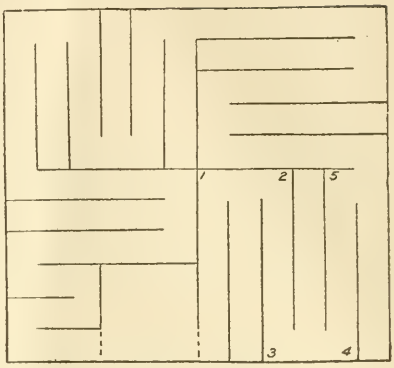

FIG. 2
MAZE B

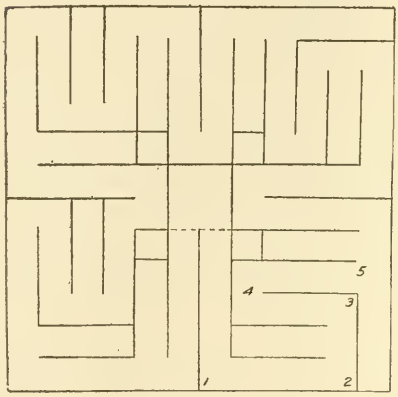

FIG. 3
MAZE C

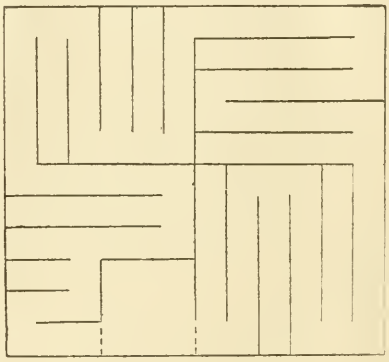

FIG. 4
MAZE D

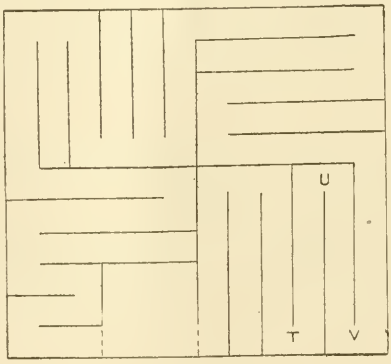

FIG. 5
MAZE E

inches long, four inches wide and five inches deep. In the C maze they were thirteen inches long, four inches wide and four inches deep. The mazes were built of half-inch boards, the partitions between the runways in each section being of metal, although the partitions between the sections themselves were of wood. By a section is here meant one of the four main divisions of the maze, in which in all the mazes except C the blind-alleys run in the same direction relative to the observer. By a runway is meant one length of the maze, such as *a*—*b* in maze A, whether it forms part of the true pathway or constitutes a blind alley. The terms, "true pathway" and "blind alley," are open to no ambiguity. The mazes were painted black without and within, and were covered with glass tops.

The rats were between two and three months of age at the beginning of the particular experiment in which they were used. About one third of them were born in the laboratory where the experiments were carried on, and the remainder were obtained elsewhere. The rats were allotted to the various groups in a thoroughly promiscuous way, so that the groups approximated unselected collections. They were fed in the food-box of the maze every day for a week before they were introduced into the maze proper. They were given one trial a day for the first five days, and afterwards two trials a day, one in the forenoon and one in the afternoon. They were fed for two minutes after the trial in the forenoon and for five minutes after the trial in the afternoon. The food was bread and milk with an occasional allowance of sunflower seed. The rats were transferred from one maze to another by groups. Those individuals in a group which learned a maze earliest were still given one trial a day upon the same maze until all had learned it.

Records were kept of the number of trials necessary to learn to run a maze four times out of five without an error, of the errors made during the course of learning and of the time required for each trial. The only errors that were counted were those made by the rat running into blind alleys while moving in the forward direction,

i.e., along the true pathway toward the food-box. These are the only errors which become fixed, and the actual task of the rat, stated in negative terms, is to overcome the tendencies to enter blind alleys while moving in the forward direction. The time was taken with a stop-watch, and was reckoned from the moment when the rat was introduced into the maze until it reached the food-box.

The groups contained the following numbers of rats and proportions of males and females:

Group 1:	8 rats—4 males, 4 females
Group 2:	10 rats—5 males, 5 females
Group 3:	10 rats—6 males, 4 females
Group 4:	9 rats—5 males, 4 females
Group 5:	10 rats—6 males, 4 females

II. TRANSFER OF TRAINING BETWEEN PAIRS OF MAZES

The Positive Nature of the Transfer

An experiment to discover whether there was transfer of training when white rats which had learned one maze were carried over to another, and whether this transfer if present was positive or negative, was performed by Webb.[1] He effected transfers between ten pairs of mazes, in five of which the first maze remained the same, while the second maze in each pair was different from all the rest; and in five of which the first maze in each pair was different from all the rest and the second maze remained the same; so that the order of the transfers was from A to B, from A to C, from A to D, from A to E, from A to F; and from B to A, from C to A, from D to A, from E to A, from F to A. He found in every case that the number of trials required, the total number of errors made per rat and the total time consumed per rat were less for a group learning a given maze as its second to be learned than for the group that learned the given maze as its first. He is of the opinion that the evidence furnished by his experiments both with rats and with humans is strongly in favor of the presence of positive transfer. There was no accounting for these savings on the ground of chance or of group-differences; and, moreover, Webb constructed his mazes with the express purpose of rendering the conditions as favorable as possible for negative transfer.

The present experiment was designed to further test this matter of transfer as between pairs of mazes, using mazes of another pattern and in a different arrangement from those of Webb's. The results of this experiment corroborate the results of Webb's with regard to the presence and the nature of the transfer. The percentages of transfer were computed on the same basis as Webb's—that of the

[1] Webb: Transfer of Training and Retroaction. *Psych. Rev. Mon. Sup.* Vol. 24 No. 3.

average number of trials required to learn the maze, of the total number of errors and the total time per rat. The percentages are given in table 1.

TABLE 1

PERCENTAGES IN SAVINGS IN TRIALS, ERRORS AND TIME IN TRANSFERS BETWEEN TWO MAZES

	Trials	Errors	Time
A to B	59	88	95
B to C	33	49	84
C to D	27	54	57
D to E	69	93	89
E to A	20	65	89
E to D	15	54	49

Although the present experimenter did not try, as did Webb, to devise mazes which would differ so much from one another that the learning of one would exert a detrimental influence upon the learning of the other, nevertheless an examination of plate I, figs. 1 to 5, will disclose that there were marked differences between certain of them. Consider for example mazes B and C, and note the differences in the number, length and arrangement of the blind-alleys. In the first section of maze B, the animal at the end of the first runway turns to the right, but in the corresponding section of C it turns to the left. In B immediately after this there is a blind alley to the right, while in C there is none either to the right or left. After the second turn in C, the animal encounters a blind alley to the left; after the second turn in B, it follows the true pathway. At the fifth turn in C, the animal faces a situation different from any to be met in B, for not only is it at this point in C far more likely to meet the true pathway at a right angle, but there is a blind alley at its left immediately as it turns into the true pathway, a similarly placed one being lacking in B. An examination of the other three sections of the mazes will multiply discrepancies of this kind.

Again, consider the differences between A and E. In the first section of the former, the true pathway consists of three runways and the connecting runways, Q and R;

in the first section of E, there are five runways in the true pathway, and there is only one connecting runway, for at T, U and V the animal passes directly from one runway into another, although instead of turning at about a right angle to do so it must turn through 180 degrees. In the first section of A, there are three blind alleys, and in the corresponding of E there is but one. In the second section of E, the true pathway turns abruptly to the left at the entrance to the section, while in A a blind alley opens at this place. In the third section of E, two blind alleys are placed side by side; in the third section of A the blind alleys alternate. In the fourth section of E, the entering animal turns into the true pathway to the left; in the corresponding section of A, there is a blind alley to the left. But there was positive transfer as between these two mazes, judged by all three criteria.

The Effect of Identical Parts

In order to discover whether the presence of identical parts would affect the kind or the degree of transfer, the first sections of mazes A and B were made alike, and also the third sections of mazes D and E. The savings in trials and errors in the transfers between these mazes with identical parts were notably greater than in the transfers between the mazes without identical parts, as may be seen by reference to table 1. The saving in time in the transfer between A and B was the largest of all the time-savings, but that between D and E was equalled by that between E and A.

If the greater positive transfer in the case of the mazes with identical parts was due to the presence of the identical parts,—and it would seem too large to dismiss as merely fortuitous,—still it is not plain that this greater transfer was brought about within the identical parts themselves. It would seem reasonable to maintain that, if the presence of the identical part in the second maze exerted a favorable influence upon the learning of the maze, the benefit would be most likely to appear in this identical part, although it is conceivable that the beneficial effect might appear in some other part of the maze. For the purpose

of finding out whether there was a greater saving in this identical part of maze B than in the other sections, the distribution of errors within the four sections of maze B made by the control-group and by the trial-group may be compared. The average number of errors per rat made by the control-group, group 2, in the four sections of B, and the average number made by the trial-group, group 1, which had already learned maze A, are given in table 2, together with the percentages of savings made by group 1.

TABLE 2

THE AVERAGE NUMBER OF ERRORS PER RAT MADE BY GROUPS 2 AND 1 IN THE SECTIONS OF MAZE B, AND THE PERCENTAGES OF SAVINGS

	Sec. 1	Sec. 2	Sec. 3	Sec. 4
Group 2	16.5	9.4	13.9	5.5
Group 1	1.7	.9	.8	3.8
Savings by Group 1	89	90	94	31

While group 1 effected a saving in the first section of 89 per cent, the savings in the second and third sections were still larger. It cannot be argued on the *prima-facie* evidence, therefore, that the saving in the identical part was due to the fact of this identity, when the savings in sections dissimilar from the corresponding sections of maze A were even larger. It might be expected that much confusion would arise at the entrance of the second section, inasmuch as the animal had gained undoubtedly as much momentum in the first section of the second maze as in the corresponding section of the first maze, and at the entrance to the second section of the maze it encounters quite a different pattern. Contrary to any preconception, however, the group effected as great a saving in the second section as in the first. In connection with this fact, it may be noted—as has been shown by Webb[2] and is shown also in one of the experiments now being reported[3]—that an animal brings over from the learning of one maze to the learning of another some factors making for positive transfer and some making for negative. There is, accord-

[2] Webb: *op. cit.* p. 52.
[3] *Infra*, p. 18, ff.

ing to the view adopted here as a result of the observations made in the course of these experiments, a practise in error-elimination which is useful and which an animal passing from one maze-learning to another enjoys, so that this animal may be expected to display a greater facility in the the dropping of errors in the second maze than an animal learning this maze as its first. But among the specific habits, including entrance into some runways and the avoidance of others, there will be some that aid the learning and some that deter it; and an instance of the latter may be found in the transfer now under consideration. The group trained in the first maze had learned to pass a blind alley on its left upon entering the fourth section and then to turn into the next runway, which formed a part of the true pathway. When transferred to the second maze, there was no blind alley at the left immediately on entering this section, so that no difficulty was experienced here; but instead of the adjoining runway being a part of the true pathway it was a blind alley, and as a consequence the trial-group made 53 per cent of the total number of errors in this section, where the control-group made but 14 per cent.

It is impossible to predict, with regard to the factors making for positive and for negative transfer, how they will interact in a given situation. It would seem that, in the second of the two mazes involved in the present comparison, the tendency to turn into the blind alley in the fourth section is so deeply implanted, as a result of the learning of the former maze, that any general habit of error-elimination is nearly if not completely suppressed; while on the contrary there are no specific habits in the second and third sections so strongly formed as to counteract the working of the general elimination activity, and the results of this activity were so great that it effected in these sections savings larger than in the identical part.

Turning to the other mazes which contained identical parts, these mazes being the D and E and the parts the third section, we find that positive transfer was evident in the learning of the E maze by the group which had first learned the D maze, and that the greatest saving was effected in the identical part, although the saving in

the first section was nearly as great. The distribution of errors in the various sections of the E maze, and the percentages of savings are given in table 3.

TABLE 3

THE AVERAGE NUMBER OF ERRORS PER RAT MADE BY GROUPS 5 AND 4 IN THE SECTIONS OF MAZE E, AND THE PERCENTAGES OF SAVINGS

	Sec. 1	Sec. 2	Sec. 3	Sec. 4
Group 5 (Control)	11.1	11.7	8.7	.4
Group 4 (Trial)	.33	1.7	.11	.11
Savings by Group 4	97	85	99	72

The situation in maze E differs from the situation in B, in that the identical part is not encountered in the former until the animal has run through two sections which differ from the first two of the maze which he has already learned; so that in the situation presented in the B maze the question was not only as to whether the animal would retain the habit acquired in the first section of the maze in which it was first run, but also as to whether there would be any disconcerting effect from meeting the strange second section after travelling the familiar first one; while in the situation presented in the E maze the transition was from a pathway unfamiliar at the beginning and through half of its whole length to a section which had been learned before. Although the saving in the third section was 99 per cent, this was but little more than the saving in the first section. There would seem to be no ground for the assertion that, if the presence of the identical part in the two mazes results in the more expeditious learning of the second maze, this is due to the saving of errors in the identical part.

It might be contended that the comparison ought to be made between the average number of errors and percentage of saving in the identical part and the average errors and savings of the other three sections taken together, instead of being considered severally as above. When this method is followed, it is found that the average number of errors per rat made in the dissimilar sections of maze B was 1.8 as compared with the average of 1.7 in the identical part, and that the average saving of the

dissimilar sections was 71.7 per cent as compared with 89 in the identical part. The same method applied to maze E discloses that the average number of errors in the dissimilar sections was .71 and the average saving 85 per cent as compared with .11 and 99 in the identical part. It may be remarked that the smaller average savings for the three dissimilar sections were due in the case of both mazes principally to the low records of the fourth section; to which a defender of this method might reply that the low gains in the fourth sections may have resulted from the same cause as the high gains in the identical parts: namely, the presence of the identical part, which exerted more of a beneficial effect in the learning of other sections than it did in the learning of the fourth. But we have seen reason to believe that the smaller gain in the fourth section of the B maze was due to a peculiarity of its pattern in connection with the maze-habit acquired in A; and the smaller gain in the fourth section of E as compared with D may be explicable according to the same principle.

The Dependence of Transfer upon the Relative Difficulty of the Two Mazes

The query is a logical one, whether as between mazes of different degrees of difficulty it matters from the point of view of savings if the more difficult or the less difficult is learned first.

Two of the transfers in this experiment were from the harder to the easier maze, judging by the records of the control-groups; and four were from the easier to the harder. In the case of one of the transfers from the harder to the easier, the saving in errors was less than in any of the transfers from an easier to a harder maze, the saving in trials was less than in two of these transfers, and the saving in time was also less than in two of these transfers, the computations being on both the basis of the average total number of errors and the average total time per rat and the basis of the average errors and the average time per trial. In the case of the other transfer from a harder to an easier maze, the savings in trials and in errors were greater than in any of the transfers from an easier to a

harder maze, judging both by the average total errors and the average total time per rat and by the average number of errors and the average time per trial; and the saving in time was less than the saving in one of the transfers from an easier to a harder maze, according to the average total errors and average total time per rat, and less than the saving in two of these transfers, according to the average number of errors and the average time per trial.

TABLE 4

PERCENTAGES OF SAVINGS IN TRANSFERS FROM LESS DIFFICULT TO MORE DIFFICULT AND FROM MORE DIFFICULT TO LESS DIFFICULT MAZES, ON THE BASIS OF THE AVERAGE TOTAL ERRORS AND AVERAGE TOTAL TIME PER RAT

From the Less to the More Difficult				From the More to the Less Difficult			
	Trials	Errors	Time		Trials	Errors	Time
From A to B...	59	88	95	From B to C....	33	49	84
From C to D...	27	54	57	From D to E...	69	93	89
From E to A...	20	65	89				
From E to D...	15	54	49				

TABLE 5

PERCENTAGES OF SAVINGS IN TRANSFERS FROM LESS DIFFICULT TO MORE DIFFICULT AND FROM MORE DIFFICULT TO LESS DIFFICULT MAZES, ON THE BASIS OF THE AVERAGE NUMBER OF ERRORS AND THE AVERAGE TIME PER TRIAL

From the Less to the More Difficult				From the More to the Less Difficult			
	Trials	Errors	Time		Trials	Errors	Time
From A to B...	59	70	88	From B to C....	33	33	78
From C to D...	27	37	41	From D to E...	65	77	69
From E to A...	20	53	86				
From E to D...	15	46	40				

It will be seen from the figures in tables 4 and 5 that, although the average savings are higher when the transfer is from the harder to the easier maze, there is no ground for the statement that these savings are in every instance higher than when the transfer is from the easier to the harder. The transfer from the easier to the harder may be greater, as we may note by comparing the transfer between A and B with that between B and C.

III. TRANSFER OF TRAINING THROUGH SERIES OF MAZES

The Persistence of the Transfer

If we accept the statement that there is positive transfer of training when rats are carried over from one maze completely learned to another which is then also completely learned, the question arises as to whether the transfer of training will persist and retain its positive character if the learning is continued through a series of mazes. It might be presupposed with some plausibility that habits acquired in situations which present marked peculiarities in the midst of general resemblances, as do the situations in the various mazes, would conflict with one another in such a way that the transfer would cease to be positive. On the other hand, it might be presupposed with perhaps equal plausibility that in these situations practise tends toward perfection, and the ability which an animal has to thread the maze may consequently be expected to improve in proportion to the number of mazes it learns to run.

It was to throw light upon this question that the present experiment was undertaken. The five groups of rats were allowed to continue their learning through series of mazes, each group learning one series. The series were composed of the same five mazes, but the mazes were learned in a different order by each group, according to the scheme presented in table 6, in which the letters represent mazes and the numbers groups of rats.

TABLE 6

THE ORDER IN WHICH VARIOUS SERIES OF MAZES WERE LEARNED BY VARIOUS GROUPS

Mazes	A	B	C	D	E	A	B	C	D
Group	1	1	1	1	1	..	..	..	..
	..	2	2	2	2	2	..	..	..
	..	..	3	3	3	3	3	..	..
	..	..	..	4	4	4	4	4	..
	..	..	..	..	5	5	5	5	5

In pursuance of this method, there were twenty-five maze-learnings, in twenty of which evidence might be sought as to whether the positive transfer persists. Attention is drawn to the fact that the first group to learn a given maze constituted a control-group for that maze. The records of the groups upon these series of mazes are given in tables 7 to 16. The average number of trials necessary to learn a maze is given, and in connection with it the mean variation of the individual rats from this average; then the percentages of transfer for each maze are given, these being computed by comparing the record of the trial-group with that of the control-group in this particular maze. The same method is followed with respect to errors and time, and these are reckoned both on the basis of the average total per rat and on that of the average per trial. The percentages of transfer are shown graphically in figures 6, 7, and 8.

TABLE 7

THE AVERAGE NUMBER OF TRIALS PER RAT IN THE LEARNING OF A SERIES OF MAZES

	Group 1	Group 2	Group 3	Group 4	Group 5
Maze A..	26.62± 6.87	.....	.....	.....	.....
Maze B..	11.62± 5.28	28.70± 6.66	.....	.....	.....
Maze C..	9.75± 3.31	12.20± 4.14	16.20±7.24	.....	.....
Maze D..	25.56±12.67	27.60±10.93	18.00±8.03	24.67±7.24	.....
Maze E..	4.00	4.40± .56	7.30± .49	7.11±3.88	23.10±7.10
Maze A..	6.62± 3.56	6.40± 1.92	6.50±2.32	6.89±3.23	21.40±8.95
Maze B..	.....	7.50± 3.91	13.20± .67	11.44±3.06	19.00±4.91
Maze C..	.....	.....	6.20±1.84	9.00±2.64	7.00±1.51
Maze D..	.....	.....	.....	8.89±3.96	22.10±4.87
Maze E..	.....	.....	.....	.....	5.00± .83

TABLE 8

THE PERCENTAGES OF TRANSFER OF TRAINING IN TRIALS THROUGH A SERIES OF MAZES

	Group 1	Group 2	Group 3	Group 4	Group 5
Maze B..	59	....	....	....	....
Maze C..	39	33	....	....	....
Maze D..	—3.58	—12	27	....	....
Maze E..	83	81	68	69	....
Maze A..	75	76	75	74	20
Maze B..	....	74	54	60	34
Maze C..	....	....	62	44	57
Maze D..	....	....	....	64	4.33
Maze E..	....	....	....	....	78

TABLE 9

THE AVERAGE TOTAL NUMBER OF ERRORS PER RAT IN THE LEARNING OF A SERIES OF MAZES

	Group 1	Group 2	Group 3	Group 4	Group 5
Maze A..	48.45±13.52	.....	.....	.....	.....
Maze B..	8.15± 2.52	68.88±36.52	.....	.....	.....
Maze C..	6.82± 2.42	14.50± 6.20	28.35±8.72	.....	.....
Maze D..	26.58±13.27	22.36±10.61	21.42±9.38	46.63±14.96	.....
Maze E..	0	.31± .12	1.31± .95	2.20± 1.26	31.88±12.27
Maze A..	1.31± .91	1.22± .70	1.75±1.20	2.07± .92	16.69± 6.56
Maze B..	.....	3.97± 1.30	6.74±3.29	9.27± 3.55	18.05± 5.99
Maze C..	.....	.....	1.92± .82	7.29± 4.45	3.64± 1.29
Maze D..	.....	.....	.....	4.53± 2.21	23.87± 8.45
Maze E..	.....	.....	.....	.....	.90± .72

TABLE 10

THE PERCENTAGES OF TRANSFER OF TRAINING, ON THE BASIS OF THE AVERAGE TOTAL NUMBER OF ERRORS PER RAT, IN THE LEARNING OF A SERIES OF MAZES

	Group 1	Group 2	Group 3	Group 4	Group 5
Maze A..	..	..	..	..	..
Maze B..	88	..	..	..	..
Maze C..	76	49	..	..	..
Maze D..	43	52	54	..	..
Maze E..	100	99	96	93	..
Maze A..	97	97	96	96	65
Maze B..	..	94	90	87	74
Maze C..	..	..	93	74	87
Maze D..	..	..	..	90	49
Maze E..	..	..	..	..	97

TABLE 11

THE AVERAGE TOTAL TIME PER RAT IN THE LEARNING OF A SERIES OF MAZES

	Group 1	Group 2	Group 3	Group 4	Group 5
Maze A..	50.05±29.74	.....	.....	.....	.....
Maze B..	4.65± 2.27	93.85±49.36	.....	.....	.....
Maze C..	5.75± 3.30	12.71± 9.17	77.92±39.49	.....	.....
Maze D..	9.20± 4.42	15.46± 8.41	16.20± 7.17	37.50±19.45	.....
Maze E..	1.56± .38	1.53± .34	3.36± 1.57	3.27± 1.79	30.72±16.20
Maze A..	1.39± .81	1.60± 1.02	2.01± .80	1.93± .90	5.56± 1.48
Maze B..	.....	2.02± 1.51	4.22± 1.23	3.09± 1.04	4.75± 1.44
Maze C..	.....	.....	7.56± 4.81	17.73±10.37	4.55± 1.38
Maze D..	.....	.....	.....	6.49± 5.98	5.52± 2.13
Maze E..	.....	.....	.....	.....	2.15± 1.05

TABLE 12

THE PERCENTAGES OF TRANSFER OF TRAINING, ON THE BASIS OF THE AVERAGE TOTAL TIME PER RAT, IN THE LEARNING OF A SERIES OF MAZES

	Group 1	Group 2	Group 3	Group 4	Group 5
Maze A. .	..	..	..	..	..
Maze B. .	95	..	..	..	..
Maze C. .	93	84	..	..	..
Maze D. .	75	59	57	..	..
Maze E. .	95	94	89	89	..
Maze A. .	97	97	97	96	89
Maze B. .	..	96	96	97	96
Maze C. .	..	..	90	77	94
Maze D. .	..	..	..	83	84
Maze E. .	..	..	..	..	93

TABLE 13

THE AVERAGE NUMBER OF ERRORS PER TRIAL IN THE LEARNING OF A SERIES OF MAZES

	Group 1	Group 2	Group 3	Group 4	Group 5
Maze A. .	1.82±.33	.....	.....	.....	.....
Maze B. .	.71±.30	2.40±.40	.....	.....	.....
Maze C. .	.70±.35	1.18±.54	1.75±.40	.....	.....
Maze D. .	1.04±.34	.81±.23	1.19±.26	1.89±.37	.....
Maze E. .	0	.07±.04	.18±.21	.31±.17	1.38±.32
Maze A. .	.17±.16	.19±.01	.27±.17	.30±.24	.78±.24
Maze B. .	.....	.53±.39	.51±.28	.81±.13	.95±.21
Maze C. .	.....	.....	.31±.21	.81±.34	.52±.25
Maze D. .	.....	.....	.....	.51±.26	1.08±.30
Maze E. .	.....	.....	.....	.....	.18±.08

TABLE 14

THE PERCENTAGES OF TRANSFER OF TRAINING, ON THE BASIS OF THE AVERAGE NUMBER OF ERRORS PER TRIAL, IN THE LEARNING OF A SERIES OF MAZES

	Group 1	Group 2	Group 3	Group 4	Group 5
Maze A. .	..	..	..	..	..
Maze B. .	70	..	..	..	..
Maze C. .	59	33	..	..	..
Maze D. .	45	58	37	..	..
Maze E. .	100	95	87	77	..
Maze A. .	91	90	80	84	53
Maze B. .	..	78	79	65	60
Maze C. .	..	..	82	54	71
Maze D. .	..	..	..	76	43
Maze E. .	..	..	..	..	87

TABLE 15

THE AVERAGE TIME PER TRIAL IN THE LEARNING OF A SERIES OF MAZES

	Group 1	Group 2	Group 3	Group 4	Group 5
Maze A..	1.88±1.23	.....	.....	.....	.....
Maze B..	.40± .12	3.27±2.12	.....	.....	.....
Maze C..	.59± .13	1.05± .68	4.81±1.77	.....	.....
Maze D..	.36± .16	.56± .40	.90± .41	1.52± .77	.....
Maze E..	.39±. 10	.37± .09	.46± .14	.46± .19	1.33 ±.68
Maze A..	.21± .04	.25± .12	.31± .06	.28± .08	.26±.03
Maze B..	.....	.27± .05	.32± .06	.27± .05	.25±.02
Maze C..	.....	.....	1.38± .97	1.97±1.62	.65±.12
Maze D..	.....	.....	.....	.73± .67	.25±.06
Maze E..	.....	.....	.....	.....	.43±.13

TABLE 16

THE PERCENTAGES OF TRANSFER OF TRAINING, ON THE BASIS OF THE AVERAGE TIME PER TRIAL, IN THE LEARNING OF A SERIES OF MAZES

	Group 1	Group 2	Group 3	Group 4	Group 5
Maze A..	..	..	..	..	..
Maze B..	88	..	..	..	..
Maze C..	88	78	..	..	..
Maze D..	76	45	41	..	..
Maze E..	71	73	65	65	..
Maze A..	89	86	30	85	86
Maze B..	..	92	90	92	90
Maze C..	..	..	70	59	54
Maze D..	..	..	..	52	83
Maze E..	..	..	..	..	68

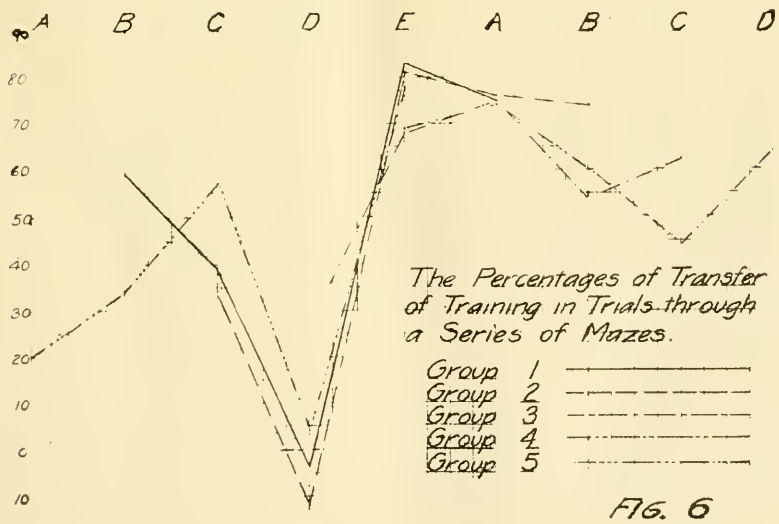

FIG. 6

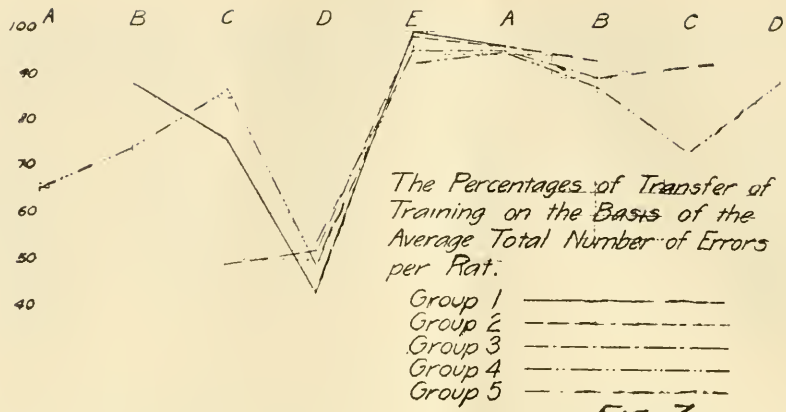

FIG. 7

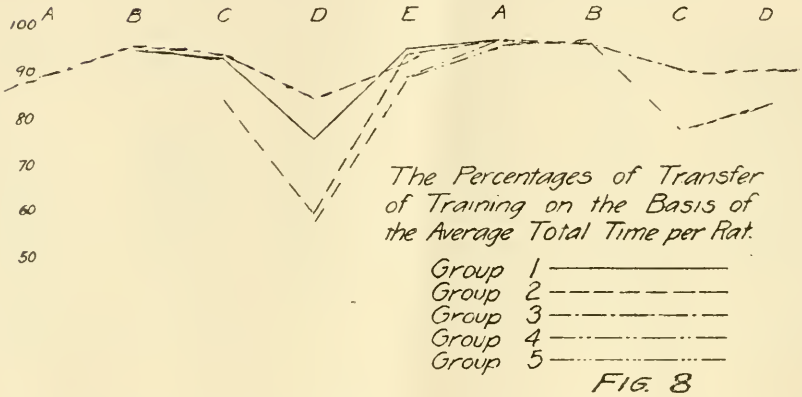

FIG. 8

An examination of tables 7 to 16 will reveal the fact that there was positive transfer manifest throughout the various series of maze-learnings with the exception of the learning of maze D by groups 1 and 2, as judged by the criterion of trials, the former group requiring an average of 3.58 per cent more trials than did the control-group upon this maze, and the latter requiring 12 per cent more (Tables 7 and 8).

In examining the records made by groups 1 and 2 in maze D for the purpose of explaining these occurrences of negative transfer, the outstanding fact brought to light is that it is the number and persistence of errors made in the first blind alley of maze D which account for the nega-

tive transfer. This fact comes out upon a comparison of the records of the control-groups and trial-groups concerned. Out of 420 errors made by the control-group in learning the maze, 102 were made in the first blind alley, and the rest were distributed among the other blind alleys. Out of a total of 223 errors made by group 2 in this maze, 166 were made in the first blind alley; and out of a total of 212 made by group 1, 126 were made in the first blind alley. It was the large number of trials necessary to eliminate these errors made in the first blind alley which resulted in the negative transfer, as may be seen from an examination of tables 17 to 20, and figure 9, in which respectively the number of errors and the percentage of errors made in each blind alley by each group are shown.

TABLE 17

THE ERRORS MADE BY GROUP 4 (CONTROL) IN MAZE D, ARRANGED ACCORDING TO BLIND ALLEYS AND TRIALS

Blind Alleys	1	2	3	4	5	6	7	8	9	10	11
Trial 1	5	2	2	4	1	1	2	1	2	2	2
2	5	2	1	3	1	1	2	2	1		
3	4	1	2	5	1	1	2	3	4		2
4	6	1	5	4	3			3	4		
5	5	2	5	3	2		1		3		
6	4	2	4	1	2		2	1	4		2
7	4	2	2	1	3	1	1	2	1		
8	5	3	3	3	1		2	1	3		
9	3	2	3	4	4	1	2	4	3		
10	6	4	2	4	2	1	3		3		
11	5	2	3	3	2		1	2	4		
12	7	4	1	2	3		3	2	3		
13	5	3	2	2	3		4		2		
14	3	2		3	1		1		3		
15	3	3		3	1		2		1		1
16	4	1			1		1		3		
17	2	2		3	1		1		2		2
18	2	3		2	1				1		1
19	5	2		1							
20	3	1							1		
21	4	2		3			1		1		
22	1	1	2	4	1				1		
23	3			1							
24	1	1		3							
25	2			1			1				
26	1			1							
27	1			1							
28		1		2							
29	1		1	2							
30				3							
31	1	1		1							
32		1		1							
33	1										

TABLE 18

THE ERRORS MADE BY GROUP 3 IN MAZE D, ARRANGED ACCORDING TO BLIND ALLEYS AND TRIALS

Blind Alleys	1	2	3	4	5	6	7	8	9	10	11
Trial 1	14	2	4	2		3	2	1		1	1
2	14	1	1	1	1						
3	7		1	4							
4	6	1	1	2	1		1		2		2
5	4		2	2			2				1
6	4		1	1	1				1	1	1
7	4						1		4		
8	7			1			2		3		
9	5	1					3	1	1		
10	4						3		2		
11	3										
12	5			4			2		2		
13	4						2				
14	4						2				
15	4	1		1							
16	3	1									
17	3			1							
18	2										
19	2			1							
20	1								1		
21	1						1				
22	1			1							
23	1			1							
24											
25	1										
26	1										
27	1										
28	1										
29	1										
30	1										
31	1										
32	1										
33	1										

TABLE 19

THE ERRORS MADE BY GROUP 2 IN MAZE D, ARRANGED ACCORDING TO BLIND ALLEYS AND TRIALS

Blind Alleys	1	2	3	4	5	6	7	8	9	10	11
Trial 1	4				1	2		1	4	6	1
2	6	1		3					2	3	1
3	8			1			2		1		
4	8			1			2		1		1
5	8			1			1		1		
6	8			1			2		1		1
7	7								1		
8	8								1		1
9	6			1			1				
10	9		1	1			1		1		
11	4	1									
12			1	1							
13	7			1							
14	6			1							
15	6	1									
16	5										
17	4										
18	4										
19	5										
20	3										
21	3										
22	5										
23	4										
24	2										
25	3										
26	1										
27	2										
28	3										
29	2										
30	3										
31	1										
32	2										
33	2										
34	2										
35	1										
36	2										
37	2										
38	2										
39	2										
40	2										
41	2										
42	1										
43	0										
44	1										

TABLE 20

THE ERRORS MADE BY GROUP 1 IN MAZE D, ACCORDING TO BLIND ALLEYS AND TRIALS

Blind Alleys	1	2	3	4	5	6	7	8	9	10	11
Trial 1	9	3			1		2	1	7	2	1
2	9	2		1			2	2	5	2	3
3	5	1					4		4		
4	5	1					2		4		
5	2	1					1		3		
6	6	1			1				3		
7	5		1	1	1		2		2		
8	5		2		1						
9	4						1		1		2
10	5			1			1		2		
11	4			1					3		
12	5			1			1		1		
13	4								1		
14	4										
15	2								1		
16	2										
17	2										
18	2										
19	3										
20	2										
21	2										
22	1										
23	3										
24	1										
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37	1										
38	1										
39	1										
40	1										
41	1										
42	1										
43	1										
44	1										
45	1										
46	1										
47	1										
48	1										
49	1										
50	1										
51											
52	1										
53	1										

TABLE 20—(*Continued*)

Blind Alleys	1	2	3	4	5	6	7	8	9	10	11
Trial 54											
55	1										
56	1										
57	1										
58											
59	1										

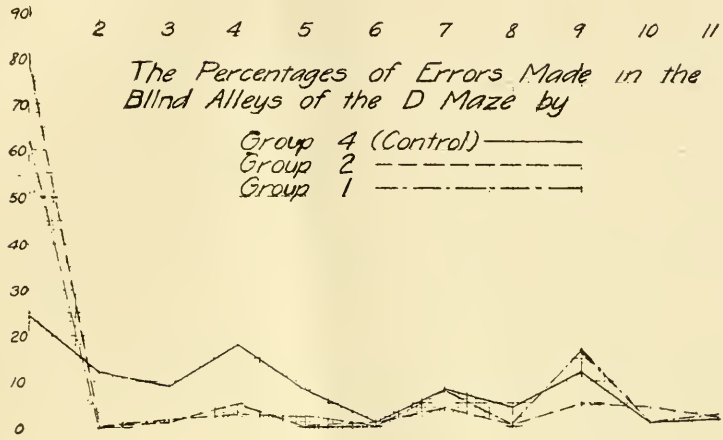


FIG 9

It is apparent that these instances of negative transfer cannot be treated as if the transfer in question were simply that between the C maze and the D maze. The groups exhibiting this negative transfer had learned—one the A and B mazes before the C, and the other the B maze before the C. The fact that, as between the C and the D mazes when no other maze had been learned before C, there was 27 per cent of positive transfer, while the transfer was negative when maze B or mazes A and B were learned before C, would suggest that the final element of the explanation is to be sought in the learning prior to that of the C maze.

The increase of more than 100 per cent in the errors made by group 3 in blind alley 1 of the D maze, as compared with the errors made by the control-group, would seem to have been due to the facts that group 3 came to the maze with the habit already formed of traversing a runway of similar construction to those confronting it on

entering D, and that the behavior of the animals on being placed within the entrance of D accounts for their frequent entrances into blind alley 1. The former of these facts needs no special comment, for the connection between running forward through a series of runways and obtaining food at the end of the journey must be implanted in the animal's neural mechanism by the close of the first maze-learning. Why the animals entered the blind alley so frequently, however, is not to be explained solely on the ground of the dispositions which they brought with them to the maze, but also on the ground of their behavior within the maze itself. It was the almost invariable behavior of the rats,—invariable both as respects the number of rats concerned and the number of trials through which it continued,—to turn immediately on being introduced into the maze and sniff at the door. This brought their bodies into a position in which the likelihood of their entering blind alley 1 was much greater than that of their entering the true pathway, as may be seen by referring to the diagram of the maze, Plate I, figure 4. When they were in this position, it required movement through only a few degrees to the right in order to bring their heads into line with the blind alley or even into the blind alley. In any case, it was a situation similar to that which in the C maze called forth the first of the motor habits eventuating in the animals' obtaining food, and the animals plunged into the blind alley with great speed and great force. After sniffing at the door, it was necessary for them, if they were to enter the true pathway, either to pass close to the blind alley by turning to the right, without being overcome by its solicitation; or else by turning to the left pass through an arc of more than 180 degrees. It is plain that, once the animals turned to the door, their chance random movements would favor decidedly the selection of the blind alley.

The question remains to be dealt with, why this tendency to enter the blind alley should have been so greatly exaggerated in the cases of groups 1 and 2—so greatly, in fact, as to be the cause of the negative transfer. If 52.8 per cent of the errors made by group 3 were made in blind

alley 1, 60 per cent of those made by group 1 and 74 per cent of those made by group 2 were made in the same blind alley. All the conditions under which the three groups learned the maze were the same, and the only difference among the groups was in the number of mazes they had learned before being placed in D. Group 3 had learned one maze, group 2 had learned two mazes, and group 1 had learned three. It would seem therefore that the difference in the records of group 3 on the one hand and of groups 1 and 2 on the other must have been due to some factor or factors acquired prior to the learning of the C maze. Reference to the patterns of the mazes concerned will furnish a clue as to the nature of this factor. In maze C the true pathway proceeds directly from the entrance without necessitating any change in the orientation of an animal that was introduced straight through the entrance; but in mazes A and B the true pathway turns to the left, demanding a turn to the left in an animal so introduced. The marked tendency of the rats in groups 1 and 2 to turn into blind alley 1 in maze D would seem accordingly to come from a habit brought to maze C, leading them to seek the true pathway in the same position which the blind alley occupies in maze D.

It would be reasonable to affirm that, on the basis of the principles adduced to explain the cases of negative transfer, we should look for negative transfer in the group which learned mazes E, A, B and C before learning the E maze, for in the E maze as well as in mazes A and B the true pathway lies to the left of the entrance. It would seem equally reasonable to expect that the tendency to take the first runway to the left of the entrance in maze D would be more pronounced in group 1 than in group 2, and more pronounced in group 5 than in either 1 or 2, since group 5 learned three mazes in which the true pathway takes this course, group 1 learned two, and group 2 learned one. Contrary to these assumptions, we find that the transfer of group 5 on maze D is positive. But it is the least of all the positive transfers, being only 4.33 per cent; and when we examine the distribution of errors according to the blind alleys and the trials, we see the same tendencies

at work as in the case of groups 1 and 2. Of the 239 errors made by the group, 137 were made in the first blind alley, or 56.9 per cent of the total number; and the errors persisted there as with the other groups. In the case of this group, however, the tendencies were not quite sufficient to turn the tide of positive transfer. This reversal of such justifiable expectations as those above might be due to an increase in the number of deviations from the rule of turning to sniff at the door as the rats learned an increasing number of mazes. That there was an increase in these exceptions cannot be asserted, for no record of the number of sniffings was kept; but it would seem probable that the futility of such behavior would lead to its becoming less frequent. It would not take many deviations of this sort from the usual behavior to account for the difference between the 3.58 per cent of negative transfer shown by group 1 and the 4.33 per cent of positive transfer shown by group 5.

The negative instances dealt with above indicate certainly that, when three mazes are learned in succession, the transfer is not a function of the last two mazes alone, but of all three; and they probably indicate that, when four or five are learned in succession, the transfer is not a function of the last two alone, but of all the mazes involved. They also prove—it needs hardly to be remarked—that, although transfer is generally positive, there may be a particular kinaesthetic habit occurring in a particular maze-situation so as to produce negative transfer.

The Question as to Whether the Transfer is Cumulative

The experiment demonstrates that the transfer as between the first and second mazes of a series is positive, and that the transfer as between any other two contiguous mazes of the series is also positive, judging by all the three criteria employed, except in the two negative results in trials. The query which next presents itself is whether this generally persistent positive transfer increases with each additional maze-learning, or in other words whether it is cumulative.

There was no series in which the transfer as estimated by

any one of the criteria was cumulative throughout the series, but there were some instances where there was cumulation for three maze-learnings and one where there was cumulation for four. These are given in table 21.

TABLE 21

CUMULATIVE SAVINGS IN AVERAGE TRIALS, IN AVERAGE ERRORS PER TRIAL AND IN AVERAGE TIME PER TRIAL

Group	Mazes	Percentages of Transfer in Mazes Named
	Savings in Trials	
3	C to D, D to E, E to A	27, 68, 75
5	E to A, A to B, B to C	20, 34, 57
	Savings in Errors	
2	B to C, C to D, D to E	33, 58, 95
5	E to A, A to B, B to C	53, 60, 71
	Savings in Time	
2	C to D, D to E, E to A, A to B	45, 73, 86, 92
4	D to E, E to A, A to B	65, 85, 92

Over against these five instances of cumulation for three mazes and one of cumulation for four, there were eight instances in which the transfer decreased in amount through three maze-learnings. Three of these were in trials, four in errors and one in time. They are presented in table 22.

TABLE 22

SUCCESSIVE DECREASES IN TRANSFER OF TRAINING

Group	Mazes	Percentages of Transfer in Mazes Named
	According to Average Trials	
1	A to B, B to C, C to D	59, 39, —3.58
2	D to E, E to A, A to B	81, 76, 74
4	E to A, A to B, B to C	74, 60, 44
	According to Average Errors per Trial	
1	A to B, B to C, C to D	70, 59, 45
2	D to E, E to A, A to B	95, 90, 78
3	D to E, E to A, A to B	87, 80, 79
4	E to A, A to B, B to C	84, 65, 54
	According to Average Time per Trial	
1	B to C, C to D, D to E	88, 76, 71

When the errors and the time were computed on the basis of the average total per rat, there were six instances in errors and time taken together where the transfer was cumulative for three maze-learnings, and six where it decreased for three maze-learnings in succession. In the case of the errors, the mazes upon which these cumulations and decreases occurred were the same, whether the errors were computed according to one or the other method, except that according to the average per trial there was one more series than according to the other method. But in the case of time, cumulation appeared upon the same two series of three mazes as it did according to the average time per trial and also upon two additional series of three mazes. There was no coincidence in the decreases in time as reckoned by the two methods.

There is no evidence therefore that this generally positive and persistent transfer is also cumulative invariably and continuously; nor, it may be added, that there is a regular and continuous decrease.

The Effect of Preceding Maze-Learnings upon the Learning of a Particular Maze

In the foregoing discussion, the data are treated from the point of view of the different groups as they proceed to learn the series of mazes, and we have followed the various groups and examined their records to see whether these records show a persistence and a cumulation of positive transfer. But the same data can be considered from another point of view—that of a particular maze, where we can take our position and inquire if this maze can be learned more readily by a group that has had two previous learnings than by a group that has had but one, and if by a group that has had three more readily than by a group that has had two, and so on. The number of trials required by the various groups to learn the various mazes is given in table 23, and figure 10. Disregarding the designations of the groups, which can be obtained by reference to table 6, p. 13, they are treated merely as the groups which were the first, second, third, fourth or fifth to learn a certain maze.

TABLE 23

THE AVERAGE NUMBER OF TRIALS PER RAT REQUIRED IN LEARNING A MAZE BY GROUPS HAVING PREVIOUSLY LEARNED ONE, TWO, THREE, OR FOUR MAZES

	Maze A	Maze B	Maze C	Maze D	Maze E
Group having learned *one* preceding maze	21.40	11.62	12.20	18.00	7.11
Group having learned *two* preceding mazes	6.89	19.00	9.75	27.60	7.30
Group having learned *three* preceding mazes	6.50	11.44	7.00	25.56	4.40
Group having learned *four* preceding mazes	6.40	13.20	9.00	22.10	4.00

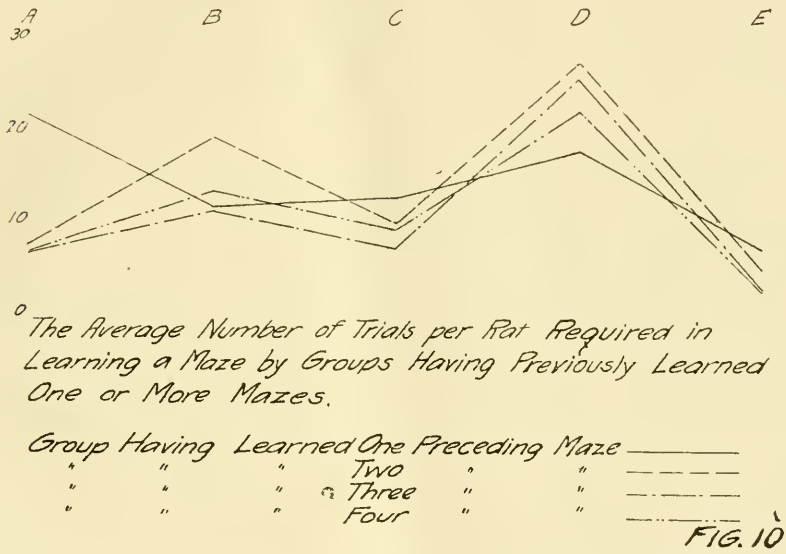


FIG. 10

The figures in table 23 show that the groups which have learned more than one maze before attacking another do not necessarily and invariably enjoy any advantage in the learning of the new maze, as compared with the trial-record of the group that came to the maze with but one prior maze-learning. The groups learning maze A showed a nominal increase of savings with the increase in the number of previous maze-learnings, but the group that had had four maze-learnings saved but .1 of a trial as compared with the one having had three, and the one that had had three saved but .4 of a trial as compared with the one having had two. If the group with two previous maze-

learnings showed a large saving relative to the group with one, this is deprived of any significance by the fact that, in the case of the other four mazes, two of them proved easier for the group with one prior learning than for the group with two. A comparison of the groups with three prior learnings and the groups with four discloses the fact that in two instances—namely, in mazes B and C, the groups with three prior learnings learned the maze more readily than the groups with four; and, if there were three instances where the groups with four prior learnings did better than those with three, one of these was but .1 of a trial better. This table might accordingly be brought forward in support of the statement that three maze-learnings are as good as four, measured by the beneficial effect upon the learning of a subsequent maze according to the standard of trials. But the actual differences in these figures representing the number of trials necessary to learn the third and fourth mazes are not large enough to give much weight to such a statement.

The D maze presents the least evidence of any beneficial effect accruing from the learning of preceding mazes, and the principle which is to be invoked in explanation is the one used with reference to the negative figure representing the transfer in trials, as may be seen on pp. 18 ff. The number of trials needed by the groups coming to this maze with two and with three prior learnings was greater than the number made by the control-group, and the number needed by the group coming with four learnings was also high. These figures were all greater than any in the A and B mazes, the control-figures of which show them to be some-

TABLE 24

THE RANKINGS OF THE GROUPS UPON THE MAZES, ACCORDING TO THE AVERAGE NUMBER OF TRIALS PER RAT

	Maze A	Maze B	Maze C	Maze D	Maze E	Av. Rank
Group having learned *four* preceding mazes	1	3	2	2	1	1.8
Group having learned *three* preceding mazes	2	1	1	3	2	1.8
Group having learned *two* preceding mazes	3	4	3	4	4	3.6
Group having learned *one* preceding maze.	4	2	4	1	3	2.8

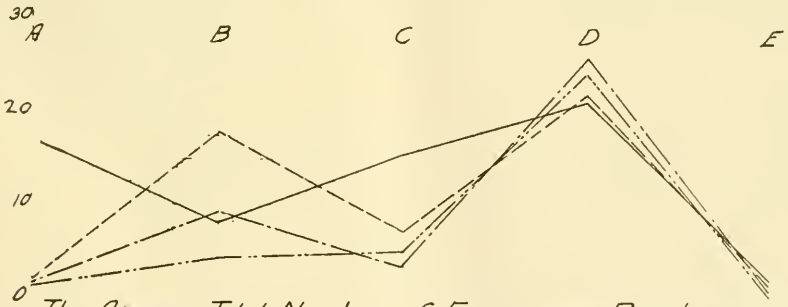
what more difficult mazes. It is the position of blind alley 1 which accounts for this. When the animals came from the C maze, they found themselves in a situation which in the maze or mazes before C had called forth the habit of turning into a runway to the left on entering the maze; and this position in the D maze being occupied by a blind alley which called forth this habit, the learning of the maze was consequently retarded.

The evidence that the average total number of errors per rat tends to decrease as the number of prior maze-learnings increases is more convincing than any figures furnished by the trial criterion in favor of a similar benefit from the latter point of view, as may be seen from an examination of table 25 and figure 11.

TABLE 25

THE AVERAGE TOTAL NUMBER OF ERRORS PER RAT BY GROUPS HAVING PREVIOUSLY LEARNED ONE OR MORE MAZES

	Maze A	Maze B	Maze C	Maze D	Maze E
Group having learned *one* preceding maze	16.69	8.25	15.40	21.42	2.20
Group having learned *two* preceding mazes	2.07	18.05	6.82	22.36	1.31
Group having learned *three* preceding mazes	1.75	9.27	3.64	26.58	.31
Group having learned *four* preceding mazes	1.22	6.73	7.29	23.87	00



The Average Total Number of Errors per Rat by Groups Having Previously Learned One or More Mazes.

Group Having Learned One Preceding Maze ———
" " " Two " " - - - - -
" " " Three " " —·—·—
" " " Four " " —··—··—

FIG. 11

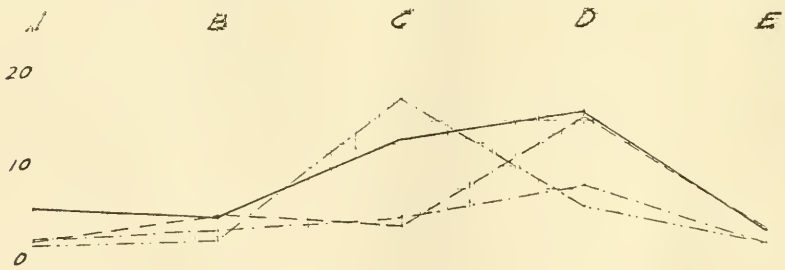
In two mazes, A and E, the average total number of errors per rat decreased with the increase in the number of mazes previously learned, and these decreases were not slight ones, proportionately speaking. If the various groups are ranked upon the mazes according to the average total errors made by the rats of the group, it will be found that the average ranking of the groups having had four prior learnings is highest, the average total errors of the rats in these groups taken together being least; and the groups having had three, two and one prior learnings follow in order. This may be seen in table 26.

TABLE 26

THE RANKINGS OF THE GROUPS UPON THE MAZES, ACCORDING TO THE AVERAGE TOTAL NUMBER OF ERRORS PER RAT

	Maze A	Maze B	Maze C	Maze D	Maze E	Av. Rank
Group having learned *four* preceding mazes	1	1	3	3	1	1.8
Group having learned *three* preceding mazes	2	2	1	4	2	2.2
Group having learned *two* preceding mazes	3	4	2	2	3	2.8
Group having learned *one* preceding maze.	4	3	4	1	4	3.2

According to the average total time per rat, there was only one maze in which this time decreased with the increase in the number of previous maze learnings by groups



The Average Total Time per Rat by Groups Having Previously Learned One or More Mazes.

Group Having Learned One Preceding Maze ———
" " " Two " " - - - - -
" " " Three " " —·—·—
" " " Four " " —··—··—

coming to the maze—maze A. When the groups were ranked upon the various mazes, the groups with four and those with three previous learnings had the same average ranking, these having required the least total time per rat; and the groups with two and with one previous learning followed. In tables 27 and 28 are given respectively the average total time per rat and the rankings on this basis. The records of the different groups are shown graphically in figure 12.

TABLE 27

THE AVERAGE TOTAL TIME PER RAT BY GROUPS HAVING PREVIOUSLY LEARNED ONE OR MORE MAZES

	Maze A	Maze B	Maze C	Maze D	Maze E
Group having learned *one* preceding maze	5.56	4.65	12.81	16.20	3.27
Group having learned *two* preceding mazes	1.93	4.75	3.51	15.46	3.36
Group having learned *three* preceding mazes	2.01	3.09	4.55	8.20	1.63
Group having learned *four* preceding mazes	1.60	4.22	17.73	5.52	1.56

TABLE 28

THE RANKINGS OF THE GROUPS UPON THE MAZES, ACCORDING TO THE AVERAGE TOTAL TIME PER RAT

	Maze A	Maze B	Maze C	Maze D	Maze E	Av. Rank
Group having learned *four* preceding mazes	1	2	3	3	1	2.0
Group having learned *three* preceding mazes	2	1	1	4	2	2.0
Group having learned *two* preceding mazes	3	4	2	2	3	2.8
Group having learned *one* preceding maze.	4	3	4	1	4	3.2

The rankings according to the average errors per trial and the average time per trial are given in tables 29 and 31.

TABLE 29

THE RANKINGS OF THE GROUPS UPON THE MAZES, ACCORDING TO THE AVERAGE ERRORS PER TRIAL

	Maze A	Maze B	Maze C	Maze D	Maze E	Av. Rank
Group having learned *four* preceding mazes	1	1	3	3	1	1.8
Group having learned *three* preceding mazes	2	3	1	2	2	2.0
Group having learned *two* preceding mazes	3	4	2	1	3	2.6
Group having learned *one* preceding maze.	4	2	4	4	4	3.6

TABLE 30

THE RANKING OF THE GROUPS UPON THE MAZES, ACCORDING TO THE AVERAGE TIME PER TRIAL

	Maze A	Maze B	Maze C	Maze D	Maze E	Av. Rank
Group having learned *four* preceding mazes	1	3	4	1	2	2.2
Group having learned *three* preceding mazes	4	2	2	2	1	2.2
Group having learned *two* preceding mazes	3	1	1	3	3	2.2
Group having learned *one* preceding maze.	2	4	3	4	3	3.2

It is apparent from tables 26 to 30 that, as in the case of trials so in that of errors and time, an increase in the number of preceding maze-learnings does not necessarily and invariably result in a decrease in errors or in time. But that there is a tendency for the errors to decrease with the increase in the number of maze-learnings may be seen from the average rankings.

The Theory of Transfer

The foregoing paragraphs show that the degree of transfer is not a function of the serial position of the maze. It appears to be a function of the maze to which the transfer is made, irrespective of the position of this maze. Thus maze E, whatever its position, tends to be the one in which according to all the criteria the greatest savings are effected. The degree of transfer may be a function also of the maze or mazes from which the transfer is made. This became apparent in our search for the causes underlying the instances of negative transfer in trials on maze D. The transfer is not a function of the difficulty of the maze, for the E maze—to use it again as an example—was not the least difficult maze, as measured by the records of original mastery; and the B maze, which was the most difficult with respect to original mastery does not appear as the one in which the least savings were made.

In attempting an explanation of the presence and persistence of positive transfer, we may assume that the animal having learned one or more mazes and being introduced into a new one is to be looked upon as an organism

which has acquired some tendencies making for positive transfer and some making for negative. The kind and the degree of transfer may be viewed as the result of the interaction of these tendencies with the new situation.

When the hungry animal is introduced into the maze, its behavior indicates that it is controlled by the instincts of curiosity and timidity, the former being undoubtedly quickened by hunger. The instinct of curiosity accounts for the explorations of the animal, in the course of which it sooner or later reaches the food-box; and the instinct of timidity accounts in the main for the retreating movements, which are so frequent in the early stages of the learning. It would be baseless to say that there is never a retreating movement due to curiosity, or that curiosity never enters as a factor into the induction of such movements; nevertheless, the behavior of the animal when advancing through the maze in the earlier stages of the learning would seem explicable only on the ground that it is under the control of a combination of curosity and timidity, with curiosity in the ascendency. Its change of behavior into that of retreating is so precipitate and its movements back toward the food-box are so direct and rapid that it would seem due to timidity's gaining the upper hand over curiosity and coming to dominate the animal. The early cessation of these retreating movements in the course of the maze-learning would seem to indicate that the instinct of timidity soon recedes far into the background and becomes almost if not quite inactive. That this recession of the instinct of timidity carries over from one maze to another is apparent from the fewer retreating movements and their prompter cessation in a second maze than in the first. This recession of the instinct of timidity is a factor making for positive transfer.

Included among the kinaesthetic habits which the animal brings to the new maze, there are some tending to lead it into the true pathway and some tending to lead it into blind alleys. Since it is generally the errors made during the first few trials which become fixed and constitute the hindrance to be overcome in order to learn the maze,

it is the tendencies driving the animals into these blind alleys which are to be looked upon as the chief factor accounting for negative transfer. Conversely, the kinaesthetic habits acquired while traversing the true pathway under the influence of the exploring instinct of curiosity constitute one of the factors making for positive transfer.

The association which is formed between the animal's running through the maze to the end of the true pathway and its gaining access to the food-box is also a factor making for positive transfer. The only purpose for which the animals are taken from the cage before they begin their trials in the maze is to feed them, and before their first trial they have been taken out daily for a week and fed in the food-box of the maze. When they are placed in the maze for the first time, their behavior denotes the frustration of their food-securing movements and helplessness to deal with the new situation; but they need to pass through the maze only a few time and to gain ingress to the food-box every time before they will eagerly attack the problem presented to them by the maze, which is that of reaching its end and the food there as rapidly and easily as possible. What at first was a mere m-pediment to their obtaining food becomes consequently a part of the process of obtaining food, which begins with their being taken from the cage and ends with their entering the food-box. This association is no doubt formed by the end of the first maze-learning, and must affect favorably the promptness and persistence with which they attack the next maze, irrespective of the elements which affect unfavorably the learning of the second maze.

The practise in error-elimination which an animal has had while learning one maze would seem to exert a beneficial influence upon the learning of another. The blind-alley situation is one that is repeated in maze after maze, and calls for the same reaction in every instance, which is an about-face and retreat. This situation is the one unambiguous situation between the entrance and the exit of the maze, and the uniformity and repetition of response would seem to constitute what may properly be called practise in error-elimination; and we have encountered

evidence that uniformity of response would tend to appear in a uniform situation, in whatever maze this situation might occur.

The tendency to turn into blind-alleys which have been eliminated remains after the animal's last entrance into them, for not only do the animals occasionally reenter these alleys once or twice after they have been apparently avoided for good, but the swaying inward of their bodies as they pass certain blind-alleys into which they once regularly entered, sometimes bringing their bodies into contact with the far corner of the alley, would point to the same conclusion. The successful running of the maze must therefore include the overcoming of these tendencies to enter blind alleys, and this practise in error-elimination with its attendant resistance to the blind alleys once frequently entered cannot but leave its impress upon the reactions of the organism in any similar situation. In other words, the animal comes from its first maze-learning with a maze-habit formed, an integral part of which is this error-elimination activity including the habitual resistance to certain runways once frequently entered.

In seeking an explanation of the positive transfer of training, it would seem necessary to take into account this practise in error-elimination, while at the same time being careful not to read into the expression, "error-elimination," more than is implied in the discussion above. The rat which is learning its second maze forms habits under the combined influence of its instinctive reactions and the environment in which they are made, just as was the case in its first maze-learning; and under the spell of its exploring instinct it forms in the same manner habits of running into blind alleys. Its problem, from our point of view and little as the rat itself may realize it, is to eliminate these blind alleys, so as to reach the food-box as speedily as possible. The advantage which the rat that has learned at least one maze enjoys as compared with a rat that is attacking the same problem without having learned another maze beforehand is several-fold. The retarding influence of the instinct of timidity is not felt as strongly nor does it continue as long, the best evi-

dence for this fact being furnished by the large saving in the group's time of learning the second maze, as compared with the time of the control-group. In addition to this, the association between running the maze and the procurement of food is firmly fixed at the beginning of the maze-learning in the case of the rat that has learned a preceding maze, while this connection has to be formed by the inexperienced group in the course of the learning. Still again, and perhaps most important of all, is the practise in error-elimination. This does not secure the animal against entering blind alleys nor forming habits of doing so, neither does it assist the animal in finding the true pathway; but it enables the animal that has had this practise to eliminate more promptly its entrances into blind alleys.

The Correlations among the Records of Transfer through a Series of Mazes

It was found that a positive correlation existed among the savings in trials and errors, in trials and time, and in errors and time, effected by the various groups as they learned the various series of mazes; the savings being estimated on the basis of the average number of trials, the average total errors and the average total time per rat. A positive correlation existed among the savings when they were estimated on the basis of the average errors and the average time per trial, except in the case of that between trials and errors in the third group and that between trials and time, and errors and time, in the fifth group, in which cases it was negative. On this basis of estimation there were also two cases of zero correlation, those of errors and time in the second and in the third groups. The method of rank-differences was used in determining these correlations, and the two sets of figures are given in tables 31 and 32.

TABLE 31

THE CORRELATIONS AMONG THE RECORDS OF TRANSFER THROUGH A SERIES OF MAZES, ON THE BASIS OF THE AVERAGE TOTAL ERRORS AND AVERAGE TOTAL TIME PER RAT

Group	Series Learned	Trials and Errors	Trials and Time	Errors and Time
1	A to B, B to C, C to D, D to E	1.00	.70	.70
2	B to C, C to D, D to E, E to A	.80	.80	.60
3	C to D, D to E, E to A, A to B	.70	.80	.50
4	D to E, E to A, A to B, B to C	1.00	.40	.40
5	E to A, A to B, B to C, C to D	1.00	.80	.80

TABLE 32

THE CORRELATIONS AMONG THE RECORDS OF TRANSFER THROUGH A SERIES OF MAZES, ON THE BASIS OF THE AVERAGE ERRORS AND THE AVERAGE TIME PER TRIAL

Group	Trials and Errors	Trials and Time	Errors and Time
1	1.00	.40	.40
2	.80	.40	00
3	.80	—.40	00
4	1.00	.40	.40
5	1.00	—.20	—.20

IV. TRANSFER OF TRAINING BETWEEN A MAZE PARTIALLY LEARNED AND ONE COMPLETELY LEARNED

We have seen that there is always transfer of training when both mazes of a pair are completely learned, and that the transfer is positive. The inquiry may be made as to whether there is transfer of training when the first maze of the pair is only partially learned and the second completely learned.

In order to answer this inquiry, groups of rats were transferred from one maze to another after two, four, eight, or sixteen trials in the first of the two mazes, and also after the complete mastery of the first maze. The groups consisted of from seven to twelve rats, with an average of nine. The mazes used were the ones in which the greatest degree and the least of positive transfer of training had occurred in the last experiment considering the average of all the groups—mazes E and D respectively. The results are presented in tables 33 to 38, and graphically in figures 13 and 14.

TABLE 33

THE RECORDS OF GROUPS LEARNING THE D MAZE AFTER THE PARTIAL LEARNING OF THE E MAZE

	After 2 trials in E	After 4 trials	After 8 trials	After 16 trials	After complete mastery
Av. Trials....	25.29±2.90	28.43±6.20	26.10±7.46	16.20±7.46	20.86±4.00
Av. Errors per Trial.....	2.09± .31	1.94± .77	2.64± .63	1.07± .40	1.03± .35
Av. Time per Trial.....	.38± .08	.32± .06	.31± .03	.41± .17	.91± .25

TABLE 34

THE PERCENTAGES OF TRANSFER OF TRAINING IN GROUPS LEARNING THE D MAZE AFTER THE PARTIAL LEARNING OF THE E MAZE, ON THE BASIS OF THE AVERAGE ERRORS AND THE AVERAGE TIME PER TRIAL

	After 2 trials in E	After 4 trials	After 8 trials	After 16 trials	After complete mastery
Trials.....	— 3.73	—15.24	— 5.81	34.63	15.44
Errors.....	—10.60	— 2.65	—39.84	43.50	44.97
Time.....	75.11	78.76	79.62	72.82	40.13

TABLE 35

THE PERCENTAGES OF TRANSFER OF TRAINING IN GROUPS LEARNING THE D MAZE AFTER THE PARTIAL LEARNING OF THE E MAZE, ON THE BASIS OF THE AVERAGE TOTAL NUMBER OF ERRORS AND THE AVERAGE TOTAL TIME PER RAT

	After 2 trials in E	After 4 trials	After 8 trials	After 16 trials	After complete learning
Errors.....	13.36	—18.27	—48.18	63.01	53.83
Time.....	74.37	75.73	78.40	82.37	93.07

TABLE 36

THE RECORDS OF GROUPS LEARNING THE E MAZE AFTER THE PARTIAL LEARNING OF THE D MAZE

	After 2 trials in D	After 4 trials	After 8 trials	After 16 trials	After complete learning
Av. Trials....	28.33±6.80	23.86±4.98	23.80±6.06	12.20±6.60	7.11±3.81
Av. Errors per Trial.....	2.05± .90	1.35± .44	1.99± .81	.68± .27	.31± .17
Av. Time per Trial.....	.33± .05	.28± .03	.33± .06	.38± .14	.46± .1

TABLE 37

THE PERCENTAGES OF TRANSFER OF TRAINING IN GROUPS LEARNING THE E MAZE AFTER THE PARTIAL LEARNING OF THE D MAZE, ON THE BASIS OF THE AVERAGE ERRORS AND THE AVERAGE TIME PER TRIAL

	After 2 trials in D	After 4 trials	After 8 trials	After 16 trials	After complete learning
Trials.....	—22.51	—11.72	— 3.03	47.19	69.22
Errors.....	—48.55	— 2.17	—44.19	51.01	77.69
Time.....	75.11	78.95	75.11	71.36	65.41

TABLE 38

THE PERCENTAGES OF TRANSFER OF TRAINING IN GROUPS LEARNING THE E MAZE AFTER THE PARTIAL LEARNING OF THE D MAZE, ON THE BASIS OF THE AVERAGE TOTAL NUMBER OF ERRORS AND THE AVERAGE TOTAL TIME PER RAT

	After 2 trials in D	After 4 trials	After 8 trials	After 16 trials	After complete learning
Errors.....	79.02	— 1.07	—44.36	73.96	93.09
Time.....	69.56	77.93	76.56	84.89	89.36

The most notable fact disclosed in tables 33 to 38 is that the transfer of training is negative, according to the trial and error-criteria in all the changes from one maze to another previous to the change after 16 trials. This is in accord with our study of the factors affecting transfer

(see pp. 34 ff.). As was there pointed out, it is the errors made in the blind alleys during the first few trials which become fixed and constitute the chief obstacle which the animal has to overcome in order to learn the maze. The transfer is negative prior to the change of mazes after the sixteenth trial for the reason that the factors making for positive transfer, and particularly the practise in error-

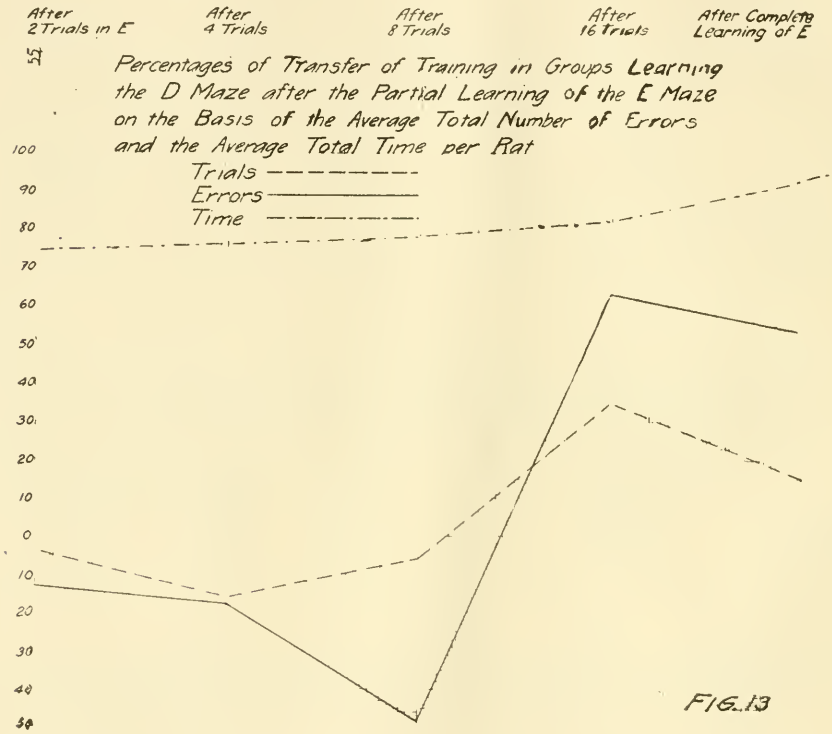


FIG. 13

elimination, do not gain the ascendency over the negative tendencies until the latter stage of the learning process. Concerning the factors making for positive transfer, we may assert with confidence that the kinaesthetic habits tending to impel the animal into the blind alleys are formed at the beginning of the learning-process, and that the practise in error-elimination does not exert its beneficent effect until the latter part of the process; but we cannot

affirm with equal confidence at what part of the process the overcoming of fear and the association between running to the end of the maze and obtaining food begin to tell.

With regard to the transfer-effect according to the time-criterion, it will be observed that the degree of transfer did not increase regularly with the increase in the number of trials in the first maze of the pair, except in the average

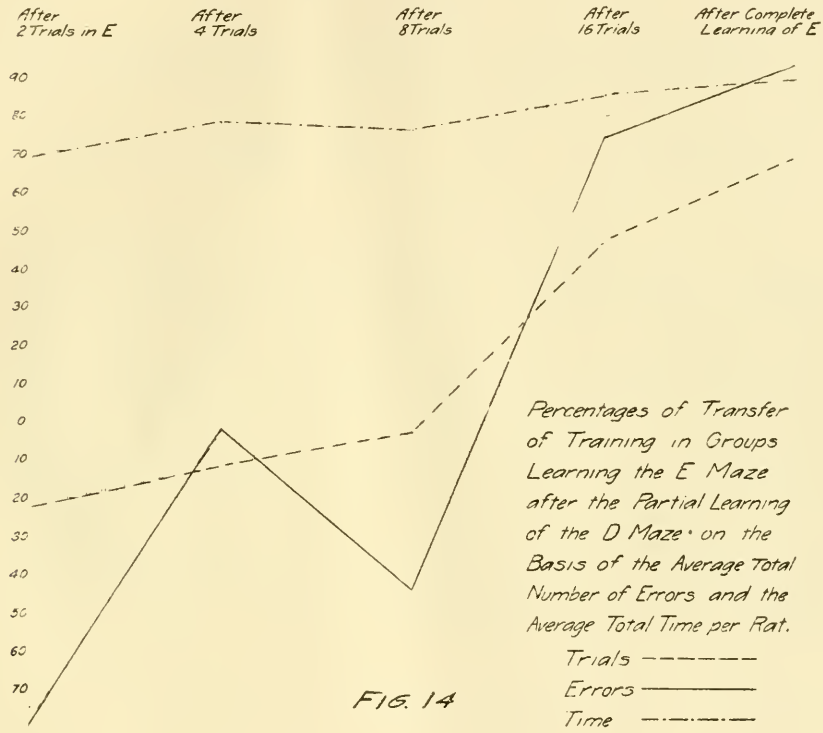


FIG. 14

total time per rat of the group carried over from E to D. But a regular increase of this kind was brought to light when the transfer was reckoned on the basis of the average surplus time required by the rats to run the mazes. This surplus time was obtained by subtracting from the average time per trial within a group the average time of the last trial made by the rats of the group that completely learned the same maze.

TABLE 39

THE PERCENTAGES OF TRANSFER OF TRAINING AS MEASURED BY THE SAVINGS IN SURPLUS TIME BY GROUPS LEARNING THE D MAZE AFTER THE PARTIAL LEARNING OF THE E MAZE

After 2 trials on E.....	81	After 8 trials on E.....	86
After 4 trials on E.....	85	After 16 trials on E.....	88
After learning E.....	93		

TABLE 40

THE PERCENTAGES OF TRANSFER OF TRAINING AS MEASURED BY THE SAVINGS IN SURPLUS TIME BY GROUPS LEARNING THE E MAZE AFTER THE PARTIAL LEARNING OF THE D MAZE

After 2 trials on D.....	76	After 8 trials on D.....	80.7
After 4 trials on D.....	80.6	After 16 trials on D.....	92
After learning D.....	96		

It is not surprising that the transfer in time should be positive throughout the entire series of transfers, for the first two trials are almost without exception the greatest time-consumers. The animals during these trials, and especially during the first, proceed very slowly and with every sign of extreme timidity. It rarely takes more than one or two successful passages of the maze for the animals' behavior in this respect to radically change, so that they proceed to their task with much greater speed. It is probably this increase in speed which, continuing through the four-trial partial learning and the eight-trial, secures slight increases in transfer of training.

V. TRANSFER OF TRAINING BETWEEN A MAZE COMPLETELY LEARNED AND ONE ALREADY PARTIALLY LEARNED

We have just considered the transfer of training as between a maze partially learned and a maze in which the rat has never run and which is completely mastered. Now we shall consider transfer of training as between a maze completely mastered and one which has been partially learned before the transfer is effected. The plan was to give two, four, eight or sixteen trials on D, then master E, and then return to D and complete its learning. A similar process was carried through beginning with E, then mastering D, and then completing the learning of E.

In the absence of any such data as are presented in the experiments herein described and by other experiments in the same general field, it might have been contended with some reason that the learning of the new maze would blot out the effects of the partial learning of the old, so that the animals would have to rebegin it. But, considering the evidence set forth above which is strongly in support of the positive transfer of training, the contrary presupposition might be formed, that the effect of such an interpolated maze-learning would prove beneficial. It might seem accordingly, on the one hand, a serious hindrance to the acquirement of a habit to break off the formation of that habit at a certain point in order to acquire completely a different habit before resuming practise upon the former. On the other hand, we have found ample evidence to believe that the beneficial effects of learning one maze can be carried over to the learning of another, and consequently we should expect that the animal will return to the learning of the original maze with some results of his training in the new maze which will prove available in the old. It becomes therefore a question of relative advantage and disadvantage, so that it may be asked with regard to the completion of the learn-

ing of the maze already partially learned: Does the advantage of the experience in the new maze, consisting in the formation of the association between the running of the maze and the satisfaction of hunger and in practise in error-elimination, counterbalance the disadvantage of bringing in another habit to confuse a habit in process of formation, especially when as in this case the habit which is being formed is the first maze-habit of the organism?

The groups which were used in the foregoing experiment in transfer after partial learning were carried back, after they had learned the second maze, to the mazes in which they had had two, four, eight and sixteen trials respectively, and were allowed to complete the learning. This furnished eight groups of rats, four groups of which while learning D were interrupted at these various points and taught E, after which they were returned to D and continued their learning of it; and four groups of which were trained according to the same plan, except that they began in E, were taught D, and then returned to E.

The effect from the point of view of trials was beneficial in all the transfers, except that in which sixteen trials were given in the first maze. This may be explained on the ground that in the last-named instance the habit was nearly formed, and much of the benefit of the sixteen trials were stored up—so to speak—in it; and when the new maze-learning was effected the disadvantage which it brought by inculcating particular kinaesthetic habits which conflicted with the nearly perfected maze-habit outweighed the advantage gained through the additional practise afforded by the new maze-learning in those activities which are beneficial in a general way irrespective of the design of the particular maze. The work which the group had done—to express it somewhat differently—by means of its sixteen trials was to a large extent undone by the new habit, and it took a number of trials to bring the group up to the efficiency it had attained before the interruption. While the new habit afforded exercise for the factors making for positive transfer, still not enough trials were saved as a consequence of this additional practise to make up for the trials lost through the conflict

of the habit completely formed in the second maze with the habit nearly formed in the first maze. Where the transfer was made after two, four or eight trials, the formation of the maze-habit had not progressed nearly so far, and a larger number of errors were being made than were being made by the sixteen-trial group when it was transferred. The consequence was that with these groups any interference with the imperfect maze-habit would not render futile, to all intents and purposes, many of the trials which had already been made, and that furthermore any interference with the imperfect habit, including a relatively large number of errors, would be not unlikely to correct an error instead of diverting the animal from the true pathway.

Table 41 presents the number of trials necessary to learn the maze—the trials before the interruption plus the trials after the interruption, and also the percentages of savings and losses. The savings and losses were computed by comparing the records thus obtained with the records of the control-group for the particular maze, and besides being shown in the table just named, they are presented graphically in figs. 15 and 16. Accordingly, the total number of trials in D before and after the learning of E were compared with the number of trials in D before

TABLE 41

THE AVERAGE NUMBER OF TRIALS REQUIRED IN A MAZE PARTIALLY LEARNED BEFORE THE COMPLETE LEARNING OF A SECOND MAZE AND COMPLETELY LEARNED AFTER THE LEARNING OF THE SECOND MAZE; AND THE PERCENTAGES OF TRANSFER OF TRAINING

Maze D		Maze E	
Trials	Percentages of Transfer	Trials	Percentages of Transfer
(Two Trials in Partial Learning)			
17. 9± 7.8	27.36	8.43±2.20	63.51
(Four Trials in Partial Learning)			
16.43± 4.61	33.39	15.70± .42	32.06
(Eight Trials in Partial Learning)			
23.00± 5.23	6.77	14.40±2.24	37.66
(Sixteen Trials in Partial Learning)			
29 .1± 4.70	—17.91	24.00±4.00	— 3.90
(Control-groups: Group 4 for D, Group 5 for E)			
24.67±12.67		23.10±7.10	

TABLE 42

THE AVERAGE TOTAL NUMBER OF ERRORS PER RAT MADE IN A MAZE PARTIALLY LEARNED BEFORE THE COMPLETE LEARNING OF A SECOND MAZE AND COMPLETELY LEARNED AFTER THE LEARNING OF THE SECOND MAZE; AND THE PERCENTAGES OF TRANSFER OF TRAINING

Maze D		Maze E	
Errors	Percentages of Transfer	Errors	Percentages of Transfer
	(Two Trials in Partial Learning)		
33.11	29.24	5.81	81.71
	(Four Trials in Partial Learning)		
37.62	12.89	24.81	—22.18
	(Eight Trials in Partial Learning)		
80.27	—72.14	29.81	6.18
	(Sixteen Trials in Partial Learning)		
80.61	—72.88	36.00	—12.92
	(Control-groups: Group 4 for D, Group 5 for E)		
46.63		31.88	

TABLE 43

THE AVERAGE TOTAL TIME PER RAT MADE IN A MAZE PARTIALLY LEARNED BEFORE THE COMPLETE LEARNING OF A SECOND MAZE AND COMPLETELY LEARNED AFTER THE LEARNING OF THE SECOND MAZE; AND THE PERCENTAGES OF TRANSFER OF TRAINING

Maze D		Maze E	
Time	Percentages of Transfer	Time	Percentages of Transfer
	(Two Trials in Partial Learning)		
22.91	44.24	32.52	— 5.86
	(Four Trials in Partial Learning		
19.55	50.55	51.32	—67.06
	(Eight Trials in Partial Learning)		
30.36	19.04	56.16	—82.81
	(Sixteen Trials in Partial Learning)		
20.08	46.46	30.49	.75
	(Control-groups: Group 4 for D, Group 5 for E)		
37.50		30.72	

and after the learning of E were compared with the number made by the control-group for D, which was group 4; and the same method was followed with respect to errors and time.

We cannot make, from the point of view of time, as broad a statement concerning the beneficial effect upon a maze-learning of interrupting it in order to learn another maze as was made concerning the same matter from the point of view of trials. The transfer in the E maze, with

The Percentages of Transfer of Training in the D Maze Partially Learned before the Complete Learning of the E Maze and Completely Learned after the Learning of the Second Maze.

Trials ———————
Errors ————————
Time —·—·—·—

FIG. 15

respect to time, was negative in three of the four changes from D to E. But there is nothing in this negative transfer to invalidate the findings of the experiments reported here and those reported elsewhere as to the generally positive nature of transfer, for this negative transfer was due to the fact that the animals made large time-records in the trials before the interruption, and then on being returned to the maze completed the learning in comparatively few

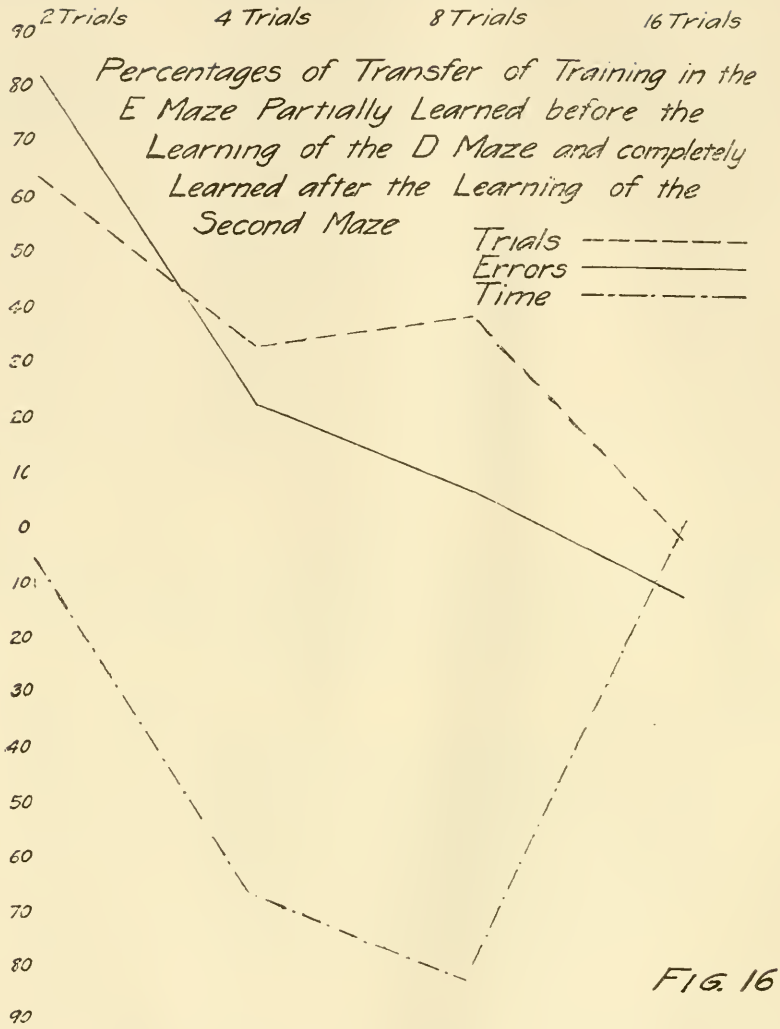


FIG. 16

trials, relative to the records of the control-group. The result was that, although the time-records of the trials following the return to the partially learned maze was low, still they were too few to counteract the high records made in the trials before the interruption; a large time-total therefore had to be divided by a small number of trials. For example, the average time per trial made by the group that was taken from the E maze after two trials

and brought back to E after having learned D was for the two trials 13.32 minutes, and for the remaining trials necessary to learn E but .28 of a minute; but the average number of trials necessary to complete the learning of E was but 6.43.

The negative transfer in errors after sixteen trials would seem to be due to the fact that a nearly perfect habit is interrupted in order to learn another maze; and the disconcerting nature of such a proceeding is denoted by the increased number of trials necessary to learn the maze, as compared with the control-group and by the increased number of errors per trial. It would seem that this principle is to be invoked to explain the negative transfer also when the partial learning consisted of eight trials.

The only criterion logically applicable here, when the two entire group-performances are compared with each other, is the trial-criterion, for as has been just indicated the favorable effect of practise as it is seen in the error and time-records of the group in the trials following its return to the maze whose learning has been interrupted is swamped by the high average made during the trials preceding the interruption. Accordingly, when we compare the records of the control-group with regard to errors and time with the records of the group whose learning is interrupted, we are not bringing together two learning processes which are analogous in these respects. The transfer in errors and in time, however, may be estimated by bringing into comparison the performances of the rats in the trial-group upon their return to the first maze after having learned the second with the performances of the rats in the control-group for the first maze, beginning with that trial of the control-group which corresponded with the first trial made by the trial-group upon its return. Thus in the case of the interruption after four trials, the first trial of the returning group after having learned the intervening maze would be its fifth trial upon the former maze; and the transfer which it has effected from the maze learned during the interruption may be estimated with reference to the record of the control-group beginning with its fifth trial and continuing to the end of the learning. In table 46

these records of the trial-group and of the control-group are placed side by side.

TABLE 44

THE RECORDS MADE UPON THE PARTIALLY LEARNED MAZE AFTER THE RESUMPTION OF LEARNING, COMPARED WITH RECORDS OF CONTROL-GROUP FOR SAME PART OF LEARNING

	Maze D		Maze E	
	Trial-Group	Control-Group	Trial-Group	Control-Group
	(Two Trials in Partial Learning)			
Trials....	15.92±6.06	22.67 .09	..... 6.43±2.20	21.10±7.14
Errors....	1.35± .48	1.66 .40	..... .36± .31	1.32± .32
Time.....	.22± .03	.71 .48	..... .28± .04	.43± .17
	(Four Trials in Partial Learning)			
Trials....	12.43± .56	20.67 7.09	.....11.71±6.10	19.10±7.06
Errors....	1.31± .29	1.43 .42	..... .61± .22	1.14± .30
Time.....	.24± .02	.38 .18	..... .26± .04	.32± .06
	(Eight Trials in Partial Learning)			
Trials....	15.00±6.75	16.67±7.26	..... 6.40±3.16	15.10±6.98
Errors....	1.55± .64	1.10± .64	..... .20± .32	.89± .22
Time.....	.24± .05	.44± .26	..... .25± .03	.30± .04
	(Sixteen Trials in Partial Learning)			
Trials....	13.10±4.70	8.67±6.14	..... 8.00±4.00	7.10±6.70
Errors....	1.06± .51	.65± .23	..... .30± .02	.40± .23
Time.....	.21± .02	.38± .18	..... .20± .01	.23± .03

All the records of the groups whose learning was interrupted showed a saving in that part of the learning which followed the return to the maze already partially learned, except the error-record of the group whose learning was broken into after the eighth trial in the D maze, the trial and error-records of the group whose learning was interrupted after the sixteenth in the D maze, and the trial-record of the group whose learning was interrupted after the sixteenth trial in the E maze.

The figures in table 44 help to bring out the fact, which has been already stated, that the negative result in the case of time, when the learning of the maze before and after the interruption is compared with the record of the control-group, is due to the small time-records made in the part of the maze-learning succeeding the interruption not being numerous enough to counterbalance the large time-records for the trials before the interruption.

These figures make plain the basis for the similar observa-

tion concerning the error-records, although in this case there are two exceptions. In the record of the group whose learning of the D maze was interrupted after the sixteenth trial, the negative transfer in errors in the part of the learning succeeding the interruption is to be ascribed to the same cause which produced the negative transfer in trials. In the part of the learning of the E maze that followed the interruption after the sixteenth trial, there was a small negative transfer in trials, but the causes producing it did not suffice to produce negative transfer in errors, although they did bring about the closest approach between the average errors of the trial and control-groups for any of the interrupted learnings in the E maze.

As a part of the present inquiry, the average error and time-records of the trial-group for the first three trials after its return to the maze already partially learned were compared with the records of the control-group for the corresponding trials. For example, the records for these first three trials after the resumption of learning by the group whose learning of the maze had been interrupted after the second trial were compared with the records of the control-group for the third, fourth and fifth trials upon the same maze. The figures setting forth this comparison are presented in table 45.

TABLE 45

THE AVERAGE ERRORS AND THE AVERAGE TIME PER TRIAL FOR THE FIRST THREE TRIALS AFTER THE RETURN TO THE MAZE ALREADY PARTIALLY LEARNED, COMPARED WITH THE CORRESPONDING RECORDS OF THE CONTROL-GROUP

	Maze D		Maze E	
	Trial-Group	Control-Group	Trial-Group	Control-Group
(Two Trials in Partial Learning)				
Errors....	2.89	3.29	.67	2.30
Time.....	.26	1.30	.34	1.01
(Four Trials in Partial Learning)				
Errors....	2.52	2.52	.81	2.00
Time.....	.27	.89	.30	.39
(Eight Trials in Partial Learning)				
Errors....	2.90	2.00	.41	1.57
Time.....	.28	.50	.28	.37
(Sixteen Trials in Partial Learning)				
Errors....	2.10	.86	.50	1.10
Time.....	.25	.52	.23	.29

The trial-groups all effected a large saving in the first three trials upon the resumption of the E maze. It may be said, in other words, that while they were learning the D maze following their two, four, eight or sixteen trials on E, they were continuing the learning of E, for on their return they showed both an improvement upon their earlier performances in E and a marked saving as compared with the control-group. Even more, some of the rats on their return to E ran that maze four times in succession without an error. Of those whose learning had been interrupted after two trials, three out of the seven rats composing the group made a perfect score upon their return to E, and none of these three had made an errorless run on either of their two former trials in E. Of those whose learning had been interrupted after four trials, one rat out of seven made a perfect score, so far as errors were concerned, and another made but one error in five trials; and neither of these had made an errorless run in its four previous trials. Of those whose learning had been interrupted after eight trials, six out of ten made a perfect score, and one made a single error in five trials; and among these was one rat which had made one errorless run, which was its first trial, and another which had made two errorless runs, on its fifth and sixth trials respectively. Of those interrupted after the sixteenth trial, two out of eight made a perfect score, one of these having made one errorless run, on its second trial, and the other no errorless runs.

If the general statement is justified that, while the rats of all four groups were learning D after having begun to learn E, they were continuing their learning of E at the same time they were learning D, there is equal justification for the statement that certain of these rats while being taught D completed their learning of E. It would be tempting to believe that these rats making errorless runs on their return to E had learned to recognize a blind alley at sight, if both their behavior in the maze and also the results of the experiments which have been made upon the rats' sensory control in the maze did not preclude such a belief. The present experiment does not furnish

the data for the solution of the problem, and any attempt at an explanation here would be but the advancement of conjecture.

The first three trials of the groups returning to the D maze after they have learned the E maze do not all show positive transfer, as is the case in the E maze after having learned the D. The group that had had two preliminary trials in D showed a saving both in errors and in time; but the group with four preliminary trials showed the same average number of errors as did the control-group, while those with eight and sixteen preliminary trials respectively made more errors than the control-group. With all four groups there was a constant saving in time.

VI. THE LEARNING OF TWO MAZES WHEN THEY ARE LEARNED ONE AFTER ANOTHER COMPARED WITH THE LEARNING OF THE SAME MAZES WHEN ONE IS PARTIALLY LEARNED, THEN THE OTHER COMPLETELY LEARNED, AND FINALLY THE LEARNING OF THE FORMER COMPLETED

After the learning of the first maze had been completed, as described in the last section, records were at hand giving the total number of trials, of errors and the time required for the mastery of the two mazes. These records enable us to compare the records of learning two mazes when these mazes are learned one after the other with the records

TABLE 46

THE LEARNING OF MAZES D AND E TOGETHER: THE AVERAGE TRIALS, AND THE AVERAGE ERRORS AND THE AVERAGE TIME PER TRIAL

1. Learning E and then D (Control) Total for E and D

Trials	43.72±3.17
Errors	1.78± .20
Time	1.19± .26

2. Learning D and then E (Control) Total for D and E

Trials	31.78±5.57
Errors	1.52 ±.32
Time	1.22± .48

3. Learning E after 2 trials on D, then completing the learning of D

Trials	46.23±9.46
Errors	2.03± .58
Time	1.17± .64

4. Learning D after 2 trials on E, then completing the learning of E

Trials	33.72±3.59
Errors	1.39± .73
Time	1.17± .32

5. Learning E after 4 trials on D, then completing the learning of D

Trials	40.29±4.64
Errors	2.25±1.37
Time	1.14± .61

6. Learning D after 4 trials on E, then completing the learning of E

Trials	44.13±4.71
Errors	1.19± .32
Time	1.17±1.32

7. Learning E after 8 trials on D, then completing the learning of D

Trials	46.80±8.33
Errors	2.96± .40
Time	.79± .35

8. Learning D after 8 trials on E, then completing the learning of E

Trials	40.50±7.33
Errors	2.53± .44
Time	1.73± .66

9. Learning E after 16 trials on D, then completing the learning of D

Trials	41.30±8.30
Errors	2.12± .27
Time	.66± .31

10. Learning D after 16 trials on E, then completing the learning of E

Trials	40.12±3.75
Errors	1.55± .25
Time	.96± .49

when one is partially learned, then the other completely learned and finally the learning of the former completed. The group which after learning the D maze as its first was carried over to the E maze in the course of the first experiment described above, having to do with the persistence and cumulation of transfer of training, served as the control-group for these mazes in this order. A special group of seven rats was trained in E and then transferred to D, giving a control for the learning of these mazes in this order.

The figures of the control-group are given in table 46, and after them the figures of the other groups learning the mazes according to the method indicated in connection with each group.

From the control-figures—those numbered 1 and 2 above—it will be apparent that the two mazes were mastered with less effort when the more difficult maze, judging according to the degree of transfer, which was D, was learned first. But the advantage of learning the more difficult maze first was counteracted if before learning it four trials were made upon the easier maze, to which the transfer was to be made. Moreover, when the order: sixteen trials in a maze, the learning of another maze, the completion of the learning of the maze in which the sixteen trials were made,—when this order was followed it mattered little whether the trials began in the more difficult or less difficult maze. The sixteen trials when made upon the more difficult maze resulted in a large saving in the easier maze, but this saving was counterbalanced by the comparatively great number of trials needed upon the return to the harder maze in order to carry its learning to completion. When the sixteen trials were made in the easier maze, the beneficial effect upon the learning of the second maze was far less marked, but this disadvantage was fully compensated for by the less effort needed to complete the easier maze.

If the series numbered 2, 4, 6, 8, 10 is viewed as one in which the order of the learning is from the D maze to the E maze, except that after the first maze-learning of the series the order is modified by the giving of a certain num-

ber of trials in the second maze, E, before the first is learned, then it will be observed that no maze-learning in this series subsequent to the first equalled the first, as far as the trial-criterion was concerned, while learnings 4 and 6 bettered it judging by the error-criterion, and 6 and 10 bettered it by the time-criterion. If the series 1, 3, 5, 7, 9 is viewed in the same way, as if the order E to D were the fundamental one and the learnings subsequent to it but modifications of it, we find that learnings 5 and 9 excel the first as judged by the trial-criterion; and that, although none of the after learnings equal the first from the point of view of errors, all surpass it from the point of view of time. It may be said therefore that there is no one method among all the arrangements, taking the D-to-E series and the E-to-D together, which enjoys signal preeminence. If it is said that the learning of the harder maze before the easier without any previous trials in the easier results in the best record according to trials, the learning numbered 4 is a very close second to it, and there are better arrangements according to the error and time-criteria. Nevertheless, there is an average advantage in learning the harder maze before learning the easier, from the point of view of trials and errors, as may be seen through the series in which the learning of D and then of E. is viewed as fundamental. When the time-criterion is applied, the series in which the passage from the easier to the harder maze is viewed as fundamental enjoys a striking advantage. These facts may be seen in table 47.

TABLE 47

THE AVERAGE RECORDS OF THE D-TO-E AND OF THE E-TO-D SERIES

	D-to-E Series		E-to-D Series
Trials	37.77±4.01	.....	43.60±2.25
Errors	1.64± .21	.....	2.03± .41
Time	1.44± .20	.....	.81± .21

VII. RELEARNING A MAZE AFTER HAVING LEARNED FOUR INTERVENING MAZES

It was possible, by carrying the groups of rats which had learned a series of mazes back to the first maze learned, to ascertain whether any beneficial effect of the first maze-learning appeared in the relearning of that maze after four intervening maze-learnings. Thus group 1, which learned the series from A to E, was brought back and retaught A; and group 2, which learned the series from B to A, was brought back and retaught B. It was considered that, if any beneficial effect of the original learning remained, the maze relearned would be mastered with less effort than any maze of equal or greater difficulty among the intervening four. If, conversely, one or more mazes of at least equal difficulty were learned more readily than the first maze was relearned, this would be accepted as evidence that the first maze, now being relearned, was practically speaking a new maze to the rats. The records of the relearnings may be found in tables 7, 9, 11, pp. 14 ff.

Looking at the relearnings from the trial point of view, we see that the A maze was relearned by its group more easily than any one of the intervening mazes was learned, except the E maze. This E maze, however, was an easier maze, according to the records of the control-group; although the ease of its mastery by group 1, as compared with the relearning of A was proportionately much greater than the difference in the difficulty attending the original mastery of the two mazes by the control-groups. The E maze was but 13 per cent easier as judged by the trial-criterion of the groups last named, but in the series of learnings which we are now considering the E maze was learned with 40 per cent less effort, by the same criterion. The group relearning the A maze saved 75 per cent as compared with the record of original mastery, but this same group learned E with a saving of 83 per cent as com-

pared with the control-group. This fact would seem to render unsafe the statement that the first group enjoyed any advantage in the relearning of A over and above the other mazes.

The B maze was relearned by the second group with an average of 7.5 trials, but the E and A mazes were learned with an average of 4.4 and 6.4 trials respectively. These mazes were less difficult than the B maze, which was the most difficult of all from the point of view of original mastery; but in these instances, as in the one just considered, the saving in the learning of the mazes as compared with the relearning of B was much greater than the records of the control-groups in these mazes as compared with the control-group in B. The A maze was 7.0 per cent easier according to the records of the control-group, but 15 per cent as shown by the group learning it in the series now being considered when this group's records in A and B are compared. The E maze was 20 per cent easier according to the records of original mastery, but it was 41 per cent easier in this connection. If the mazes A and E were as difficult as B, it would be defensible to say that no benefit from having learned B remained through the four intervening learnings and reappeared upon the relearning of B, since the group failed to evince any superiority in the relearning of B relative to the learning of an equally difficult maze. As it was, the group relearning B enjoyed a saving of 75 per cent as against the record of the control-group for A; and in learning E it saved 81 per cent, as compared with the control-group for E. Its saving in the B maze, as compared with its own record of original mastery, was 74 per cent. It is unwarrantable to see in the trial-record any survival of the benefit of the former learning of B.

The third group relearned the C maze in 6.2 trials. Although there was no learning of any intervening maze in fewer trials, the A maze was learned in nearly the same number—6.5 trials. The C maze was 39 per cent easier according to the control-groups, but its relearning was but 4.6 easier than the learning of A. The group relearned C with 62 per cent less effort than was needed in the original mastery, while it learned A with 76 per cent fewer trials than the control-group.

The fourth group learned the A maze, which was more difficult than the D maze, in fewer trials than were needed in the D maze, its saving in the A maze being 74 per cent and in the D maze 64. The fifth group failed to learn any of the intervening mazes in fewer trials than the relearning of the first maze called for, the nearest approach to the five trials in the relearning being the seven trials in C; but the C maze was much easier than the E. The fifth group was the only one that furnished any evidence in favor of the retention of the habit through a series of four mazes. With the other four groups, the weight of the evidence inclines to the other side.

When we consider error-records, we find that here also the weight of the evidence is against the retention of a habit through a series of this number of mazes. The third and fourth groups both learned mazes of greater difficulty than the original maze with fewer average total errors per rat than they made in the relearning of the original maze. The first group made the low average total of 1.31 errors per rat in relearning its first maze; but it made no errors in learning E. The second group made an average 3.97 per rat while relearning B, but it learned A with an average of 1.22 and E with an average of .31. It saved 94 per cent in errors as compared with its former learning of B, but it made 69 per cent fewer errors in A than in B, although A was but 29 per cent easier. It learned E with 92 per cent fewer errors than it made in A, although E was but 39 per cent easier. Coming to the fifth group, it will be found that its error-record in E was far better than its error-record in any of the other mazes of the series; and with regard to errors, as well as to trials and time, this group is the only one of the five that furnishes evidence of the retention of the beneficial effect of the original learning through four intervening learnings.

Looking at the matter from the point of view of the time-criterion, we find that the third and fourth groups learned one or more mazes of greater difficulty than the first of the series with a smaller time-average than the relearning of the first necessitated; and that the second group learned A, which was 7.8 per cent easier than B, in 37 per cent less time than was needed in B. With the first and fifth

groups, there was no maze-learning that rivalled the relearning of the first maze, as far as the time-criterion was concerned. The evidence furnished by the time-criterion, accordingly, is more favorable than that furnished by the other criteria to the continuance of beneficial effect of the first learning throughout the series.

When the records are surveyed together, it is seen that only one group showed, according to all three criteria, signs of the retention of the beneficial effects of the habit formed in the first learning of the first maze. If the first and second groups showed evidences of the retention of the beneficial effect in time, they showed no unmistakable evidence of such benefit in either trials or errors. The most that can be said therefore is that the favorable results of having learned a maze do not always appear upon the relearning of it after the learning of four intervening mazes, irrespective of the patterns and order of the intervening mazes; but that there may be such patterns and such an order as taken together will result in a saving, according to one, two or three criteria, although within the limits of the present experiment there was but one series upon which the beneficial effect was seen as judged by all three criteria. It cannot be determined on the basis of these results whether, in those cases where the maze on being relearned was, to all intents and purposes, a new one, the loss of the benefit was due to the disintegration of the benefit was due to the disintegration of the habit through the lapse of time since its original learning, or to the interference of the habits acquired since the first; or if due to both, in what proportion to each.

VIII. SUMMARY OF RESULTS

The evidence furnished by these experiments supports the position that the learning of one or more mazes is usually beneficial with respect to the learning of another following them immediately, as determined by the fewer trials required and lesser time and smaller number of errors, compared with those of the control-group. There were no instances of negative transfer in either errors or time, but there were two instances of negative transfer in trials.

When two adjacent mazes contained identical parts, the more expeditious learning of the second was not due to the saving of errors in the identical part. Whether the identical part exerted a favorable influence which was effective in the saving of errors elsewhere than in the identical part is a problem that these experiments did not attempt to solve.

Although the average savings are higher when the transfer is from the more difficult to the less difficult maze, there is no ground for the statement that the transfer from the harder to the easier maze is in every instance higher than from the easier to the harder. The transfer from the easier to the harder may be greater.

The transfer of training was found to be not only positive but persistent, except in two instances of negative transfer in trials, throughout the learning of five series of mazes by a different group in each series. Although it was thus persistent, it was not cumulative; that is to say, it did not increase regularly with the increase in the number of previous maze learnings. There was no case in which the transfer, as determined by any one of the three criteria, increased throughout an entire series; and if there were a number of instances in which there was an increase for three maze-learnings, there were more successive decreases for three mazes than there were successive increases for three.

Looking at the matter from the point of view of the various mazes, rather than from that of the various groups, it was found that as far as the trial-criterion is concerned increase in the number of previous maze-learnings did not always result in an increase of positive transfer. According to the error-criterion, in the case of but two mazes did the favorable effect of prior learnings increase regularly. There was no maze in which the favorable effect according to the time-criterion increased regularly with the increase in the number of prior learnings.

It was found that a positive correlation existed between the savings in trials and errors, in trials and time, and in errors and time, though a series of mazes, estimated on the basis of the average number of trials, the average total errors and the average total time per rat; and that a positive correlation existed among the savings when they were estimated on the basis of the average errors and average time per trial, except in three instances.

The transfer-effect as between two mazes when the first is only partially learned did not become positive according to all three criteria until the transfer following the sixteenth trial upon the former maze, transfers having been effected after the second, fourth, eighth and sixteenth trials. The transfer according to the time criterion was positive after the change of mazes following two trials, and remained positive throughout the series, and nearly uniform when computed on the basis of the average time per trial. But when it was computed on the basis of the average surplus time per rat, it was both positive and cumulative.

When a transfer was made from a maze completely learned to one already partially learned, and the learning of the latter then completed, the latter maze was learned with a saving in trials when the partial learning consisted of two, four or eight trials, but the transfer was negative when the partial learning consisted of sixteen trials. The transfer of training, as shown in the average total number of errors per rat, was positive when the partial learning consisted of two or four trials in D, and negative when it consisted of eight or sixteen. It was positive when it consisted of two or eight trials in E, and negative when

it consisted of four or sixteen. As shown in the average total time per rat, it was positive throughout the entire series in which the preliminary training took place in the harder maze, and negative throughout the series in which it took place in the easier maze, except that when these sixteen preliminary trials took place in the easier maze there was a positive transfer of .75 per cent.

When two mazes were learned together, the first being partially learned, then the second completely learned, and finally the first completely learned, it was found that no one of these methods enjoyed a superiority according to all three criteria. The mazes chosen for this purpose were the ones in which the greatest degree and the least degree respectively of positive transfer had appeared in the preceding experiments. When the one in which the least had appeared and the one in which the greatest had appeared were learned in this order for purposes of control, it resulted in the two being learned with fewer trials and errors than when the order was reversed; the time was slightly greater, being an average of 1.22 as against 1.19. The advantage, from the point of view of trials and from that of errors, in learning the maze first in which the least transfer-effect had appeared was manifest throughout the entire series of learnings where this may be viewed as the fundamental order. The advantage from the point of view of time resides with the other order, in which the maze manifesting the greatest transfer was learned first.

When a maze was relearned after four intervening maze-learnings, only one group showed, according to all three criteria, signs of the retention of beneficial effects from the original learning of the maze. Two groups showed signs of the retention of a beneficial effect in time, but with no unmistakable evidence of such benefit in either trials or errors.

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Edited by JOHN B. WATSON
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A Study in Retention

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THOMAS WILLIAM BROCKBANK, A. M.

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CONTENTS

INTRODUCTION

In reviewing the field of animal psychology the fact becomes evident that no special phase of retention has ever been studied to any great extent, nor has there been to date any single research devoted entirely to this subject. The need of some definite knowledge, other than what is speculative, concerning the nature or characteristics of retention has been more and more emphasized year after year as the facts of experiment point more inevitably to the conclusion that the basis and foundation of all learning is inseparably bound up with the capability of the organism to retain what has been learned. If what is learned can not be retained, there would be no advance on any line. And if what is learned can be retained, we are vitally concerned in possessing all attainable facts which will shed a clearer light on the obscurity of present knowledge on the subject. The present dearth of facts on retention is thus not to be underestimated.

Experimental literature on the present subject is so limited that the available references covering the history of experiment in retention comprise for the most part only incidental observations, supplementary to experiment which had another specific object. For the sake of comparison the following data has been summarized from these references in work on animals:

Kinnaman (1) in his work on the monkey has shown by some brief experiments that, after an absence of 50 days from the problem, perfection in point of speed, and incidentally errors, is not as marked as in the last trials of learning. The problem was one of manipulation. Allen's experiment (4) shows that the Guinea Pig retains a simple labyrinth without great loss for 63 days. Porter in his work (5) on the Vesper Sparrow, the Cowbird, the English Sparrow, and the Pigeon shows that retention was good for the first three subjects at 30 days, but there was great

loss at 120 days and 140 days, respectively, for the Cowbird and the Pigeon. Among other conclusions Rouse (6) mentions that the Pigeon retains fairly well for 6 weeks. The period of retention on a simple labyrinth is given by Hunter (11) as 28 days for the Pigeon.. Cole states (7) that the memory for a combination of 7 fastenings was far from perfect in the Raccoon at the end of approximately 5 months. With the same animal Davis (8) found that retention for simple fastenings was very good at the end of one year and even longer. Colvin and Burford tested memory in a dog and a squirrel on color discrimination. The dog exhibited no loss of discrimination for the standard color at the end of 3 weeks; after 2 months the squirrel showed no evidence of discrimination for the color, " red-red-orange." In reference to the dog, Johnson (16) notes that, after 60 days, loss in accuracy was only about 10 per cent in the retention of habits of manipulation. Thorndike observed (10) that chicks are practically perfect on a simple labyrinth after 20 days. Breed (14) made a further advance on the conclusions of Thorndike and found that 30 days was the approximate periods for retention in the chick. He states further that the chick which learns most rapidly retains the best. Casteel (13) shows that the Painted Turtle retains a simple sensory habit without loss for 2 weeks. In his work on the Canadian Porcupine, Sackett (15) shows that it retained the Hampton Court maze for 10 days with some loss. Basset (17) and Ulrich (18) have found that after a 60-day period most rats did not retain the maze perfectly. Further experimental conclusions by Ulrich seem to indicate that the effect of the distribution of effort in learning is maintained in retention within certain undefined limits; but his results on this point are inconclusive. Hubbert (21) tested rats 90 days on the Round Maze, but established nothing definite.

The foregoing summary of experiments on retention in animals clearly shows that the little already done on the subject lacks systematic study and a definite statement of results however brief. Those methods which employ only an increase or decrease of time or speed, and also

percentage of loss or gain, in explaining facts of retention have been barren of results. From this it appears that a new manner of approaching the problem along with some determining factor for retention is necessary. When the question is one in the learning of movement habit of some sort the important consideration is movement, while all else is subsidiary or of a secondary nature. This point has certainly been overlooked in the past, and as a consequence a confused mass of useless conclusions has accumulated.

It is the object of the present investigation to obtain some definite results on retention. It may have been readily gleaned years ago from experiments of long standing that the secret of retention may be found in the learning. Retention can be studied only by the effects learning has produced in the organism. As a consequence the most important thing is to compare the results obtained from the learning with those of the retention tests. This constitutes the primary factor to be considered.

APPARATUS AND METHOD FOR MAZE

The apparatus used in the present experiment comprised for the most part the Watson Circular Maze (Figs. I. & II.) somewhat modified. The paths were 12.7 cm. in width and were partitioned off by vertical sheets of aluminum 13 cm. in height, set in grooves of a circular wooden base 189 cm. in diameter. The goal was 35.5 cm. in diameter. Two semicircular sections of wire mesh covered all but the center of the maze, which was covered by two separate semicircular sections. The distance from the entrance to the center of the maze was approximately 560 cm. This enlarged pattern of the original maze was used because it allowed the animal greater freedom of movement and at the same time presented a greater difficulty in obtaining cues from the walls of the alleys.

The entrances to the alleys were located alternately in adjacent quadrants of the same arc. The radial stops in the alleys were placed diametrically opposite the entrances to the same alley, thus rendering it possible for a rat to travel only one half the circumference of the maze in any one direction from the entrance. No stop was placed in the alley around the center.

The camera lucida attachment was employed in the present experiment. This attachment consists fundamentally of two mirrors and an achromatic lens by means of which the maze and its contents are reflected in miniature on a convenient holder where the observer may plot the course of the rat's pathway through the maze. The camera lucida is described fully by Watson (20). In the present maze a further alteration from the original consisted in placing the lights higher up from the pathways, thus providing uniform illumination and avoiding shadows to a greater extent than possible in the original design.

The object in using the above attachment was to obtain a graphic record of each day's trial. It was the desire in

the present work to compare not so much the time and distance of the learning trials with the trials after the period of disuse of the habit, but to attempt to compare the movements in the two series of trials, namely, learning and redintegration. It was hoped that in this manner a more definite disclosure of essentials in retention could be thereby attained. The camera lucida attachment made possible the permanent graphic records of all gross movements and their ultimate comparison, and thus definite consideration of the degree of precision of movement was eliminated in the present work.

The rats used in this experiment were bred in our own laboratory, inbreeding being avoided by the occasional introduction of a strain from other laboratories. Young rats were used in all experimentation, except in such cases where previous training was introduced as a preliminary factor. When 30 days old, as a rule, the litter was separated from its mother; at this time it was found the young would thrive well by themselves. Before the time of experimentation had arrived, the young rats were tamed by handling them every day. Actual work commenced on the fiftieth day when the sexes were separated in cages of six or eight. The incentive to all activity during the experiment was food. The kind of food and the amount used was constant, as far as lay within the power of the experimenter. The usual food was milk-soaked bread, and after the day's experiment some additional sunflower seed and cracked corn. A hard grain biscuit was occasionally soaked with the bread in order to afford a slight change of diet. The living cages were thoroughly washed and disinfected once per week in a strong solution of " Kreso Dip" before fresh shavings were placed in them. The animals were carefully watched and treated on the appearance of any symptom of disease.

The method employed in research on the maze, with all but two groups later mentioned, was as follows: The groups were divided into those that should receive three trials per day and those to receive one trial per day. Beginning on the fourth day preceding the first actual trial of learning, the group of rats which was to begin the prob-

lem was fed every day for 30 minutes in the center of the maze, the entrance to which had been temporarily closed. The object of this procedure was to allow the rat, first, to adjust itself to the new environment, and, second, to acquire a certain association between this experimental environment and its daily food. On the first day of learning a bowl of bread and milk was placed in the center, and a rat of the group was placed by hand in the entrance box. The rat was permitted to emerge into the first alley of the maze, immediately after which the door was closed behind it and a stop watch started. The graphic record was also begun at this time and the course of the rat traced until the center was reached or a failure was recorded at the end of 30 minutes. Each rat of the group was experimented with in turn. The first day's experiment was completed for the one trial per day group at the end of the first trial.

With the three trials per day rats, the rat on reaching the center was immediately replaced in the entrance box for a new trial, and the previous procedure was repeated as also in the third trial. When the experiment for the day had been completed the group was fed in its respective cage on bread and milk, and a small ration of grain; no more food was allowed until the next day. Miss Hubbert (21) has stated that ill effects may arise from this method of feeding. In the present work this method was employed throughout all experiments and nothing detrimental was detected.

In this research the method of learning and its norm were important, inasmuch as both were to be applied in the series of trials after the retention period. No time norm was adhered to rigidly. Six seconds is usually considered the time norm for this maze, but rats were frequently found that ran the maze perfectly, although in somewhat slower time. The norm for learning, therefore, covered a period of the last fifteen trials, the first six trials of which were required to show perfect integration of all movements, and at the same time such speed as would indicate the establishment of the integrations. Less than fifteen trials, the first six of which are perfection, can not be called a norm.

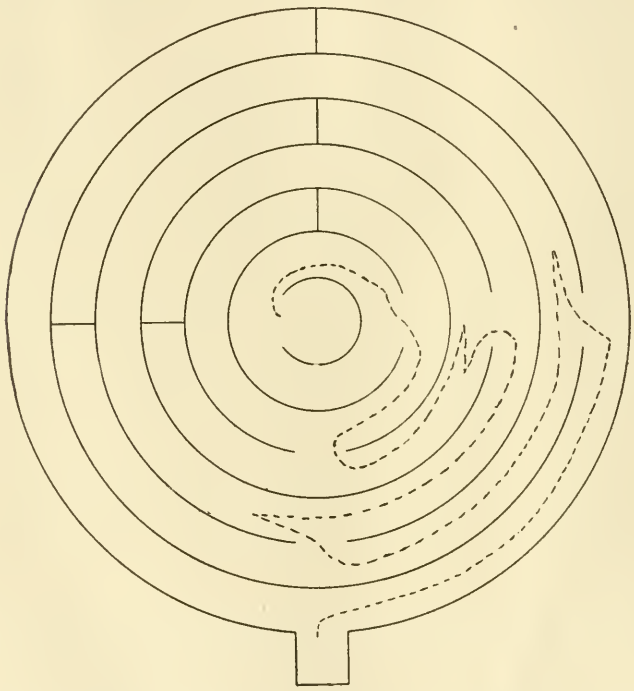
This has been established by experimentation in this work. If fewer than six perfect trials are regarded as the norm, additional trials are likely to reveal the imperfection of response. The rat thus was required to run the last nine trials, whether perfect or not. The majority of these last trials were generally perfect, according to the norm of the first six. In the foreging the word, " integrations," is to be understood as meaning an absence of so-called " errors," or imperfect movements. Thus, if a rat exhibited perfect movements in making a turn from one alley into the next these movements were considered perfectly integrated, irrespective of speed and hesitations. The employment of the camera lucida denied any further determination, as regards details of the method by which the animals learned the problem.

All criteria of learning in the maze have been based on these three—time, " error," and distance. In deciding on a norm for the present work, the time and distance criteria have both been eliminated to a certain extent because they were considered as only minor factors in aiding the pointing out of essentials in learning and retention. The learning of the maze consists in the acquirement by the rat of certain integrated movements; and the trials after the period of disuse of these movements shows the loss in integrations of movements, if any. Time and distance as primary factors can not be employed except under almost impossible conditions to show what actually takes place in the learning of the maze, but they are valuable as secondary factors. The primary criterion for us has thus resolved itself to one of movement, and therefore precision of integration is primarily concerned. " Error," therefore will not be considered except in the sense of imperfect integration.

There has never been any definite agreement as to what may be adjudged an " error." Not considering hesitation, an " error " may be said to have been made by the rat when, in the process of solving the problem, it enters a cul-de-sac or retraces its steps. Here is where distance as well as time may enter as factors, and they do so every time an " error " is made. But they are eliminated as

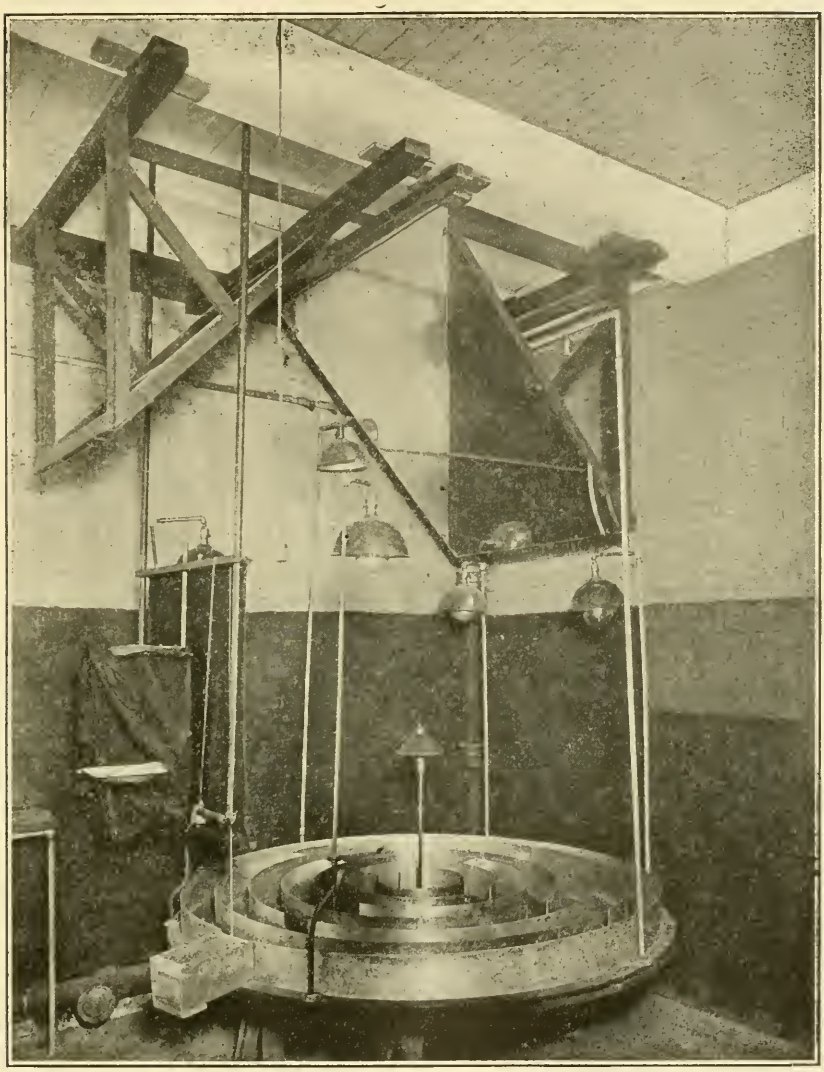
primary factors because they do not show where, how, and why the "error" was made, and this is all important. Time—that is, speed of integration—is not retained nor is distance; but precision of movement is always retained, more or less. The place of "error" in the problem must be known. To facilitate this specific location of "error" in the maze, the method was adopted of dividing the maze into areas corresponding to the turns the rat was required to make in a perfect trial to solve the problem. Thus, namely, an "error," or absence of precision of integration at the first turn (Fig. 1) was designated at turn

FIG. 1 - MAZE



1 and was qualified as minus, being to the right of the turn; at turn 2, plus, being to the left of the turn. "Error" is not to be regarded here as a positive qualifying factor in the learning.

The question then arose whether the trials after the



period of disuse, or the retention period, of the habit could be called " Retention " trials if the above norm of learning, namely, first six trials perfect, etc., would be applied to them. According to Watson (20), behavior has not set any fixed methods to make retention tests; nor could any other author be quoted to answer the question adequately. It was therefore decided to apply the norm. of learning to the series of trials after retention, and call this series

the " redintegration " trials. These trials were so designated because, following the norm of learning in the redintegration trials after the period of disuse of the habit, the rat did actually reestablish the integrated movements of the original learned habit. It was seen further that, by completing the redintegration trials, one could arrive at a more definite conclusion as to what movements of the habit had been lost and what retained. Retention here is to be understood as the potential perservation in the organism of those certain precise integrations of movement necessary in the habit. The word " retention " will be used in reference also to the period of disuse of the habit—the time between learning and redintegration.

After the completion of learning, all rats were held over a retention period for redintegration. During the retention period, which according to the group was respectively 70 days, 45 days, or 30 days, the rats were required to run through a runway about 900 cm. in length, which was considerably more than the exercise they received in the last few trials of learning. The amount of exercise thus given was found to be sufficient to avoid the evils that arise from allowing the rats to remain inactive during the retention period. The rats were thus kept in normal condition throughout the whole experiment, comprising the successive periods of learning, retention, and redintegration.

The first trial in the redintegration series was not preceded by any preliminary feeding in the center of the maze. On the day the redintegration trials were to begin, instead of being exercised in the runway the rat was taken directly to the entrance box of the problem and the procedure as in learning was followed. It was in this stage of the work that our opinion concerning the time norm as a secondary criterion was confirmed. More than one rat was observed to travel through the maze in relatively slow time, but without loss in integration of movements, while others, moving more quickly, a certain and definite loss. The redintegration trials followed to the end the same norm as the learning.

This is an adopted and modified system, taken from the theory which Dr. Ulrich recently advanced, that nearly all " errors " in the maze, after those in the first few trials, are consequent upon the rat's making an imperfect turn (integration), or not making a turn where one should be made.

EXPERIMENTAL RESULTS

I. Learning

As originally outlined in the general plan of research in this study of retention every group of rats, following a certain method in learning, retention, and redintegration, should total at least ten. As the work progressed, however, and unforeseen difficulties and varying circumstances presented themselves, it was found that the original plan could not be adhered to; and, furthermore, it was seen that necessity did not demand a rigid following of the set rule. Each group therefore is not uniform in number.

Throughout the learning period of all rats, a general similarity in the behavior of each group has been noticed. The " cautious treading of the pathway in the early trials," the " hesitancy on leaving an explored alley to enter a new one," the " excitement on encountering a stop," the " usual increase of activity on drawing closer to the center," and other characteristics of early learning were noted carefully. Whether this general behavior is due to " hunger," " curiosity," "fear," " some kinaesthetic sensibility," or a combination of any or all of these can not be definitely stated; but, in part, it may be said to be due to response to stimuli from environment.

That this behavior does not persist throughout the whole learning process is certain. It is to be noted that this general behavior as above stated is only the beginning of subsequent integration. After the first few trials it may be noted that integration begins to develop more definitely, finally resulting in increase of speed until the norm is reached.

This treatise is not one on learning. Be that as it may, before treating of retention and redintegration a careful perusal of learning experiments on the maze, to date, has forced us to a reconsideration of maze learning in order to analyze, briefly, for our purpose the process of the elimination of " error," and thus the acquirement of integration of movement necessary in the perfect maze habit.

Every experimenter has observed that in the early trials there is little, if any, definite integration of movement directed by the external senses toward the center; and further, that " errors " may be made in almost every spot in the problem, especially in the first few alleys. That this is true of some rats more so than of others is a matter of individual differences. But that these " errors " have an influence on subsequent behavior is not to be doubted. As the learning progresses it may be observed more clearly than in the first few trials that, as a rule, there seems to be some certain place or places in the maze where the acquirement of perfect integration is more difficult than elsewhere; and as a consequence a delay arises here in the integration of certain movements which are important links in the chain of responses constituting the habit. In every learning process, such as this in the maze, the series of successive movements in the habit may be compared to a chain which in the process of making has naturally some relatively weak and strong links. The locus of an imperfect response would indicate a weak link; and as the same imperfect response recurs continuously, or at irregular intervals, down through the whole process of learning, it is quite evident that of all the imperfect responses possible to be made in the treading of the maze, this particular response or " error " is dominant. And, therefore, there is to be observed in the process of learning what may be called the " dominant ' error '." By the dominant " error " is to be understood that imperfect integration which is made most frequently as the result of some difficulty in the problem which delays the establishment of perfect integration. The " error " which persists is nearly always the dominant " error "; in any case it is the dominant " error " in the last trials of learning which, as will be shown, has an important bearing on the subsequent trials in redintegration. In such a problem as the round maze, where each turn is a separate problem in itself, there may be expected numerous " errors " more or less dominant and equal in number to the number of separate problems.

Records 1 and 2 show the daily dominant imperfect response, or " error " records for two individual rats in the learning of the maze. These records present typical

examples of the points treated above and show quite clearly the case of the dominant "error," with the occasional recurrence of other "errors." Thus record 1 shows the plus "error" dominant at the start, the minus "error" at turn 2, the plus "error" at turn 3, etc. Turn 3 shows the minus "error" persisting, and likewise dominant in later trials. This point of dominant "error" in later trials will be treated of later. Numerous other daily records could be readily cited in full if space permitted. Suffice it to state that all other records, with very few exceptions, substantiate the two given herewith.

RECORD 1

DOMINANT IMPERFECT RESPONSES IN LEARNING

70-Day Period. 1 Trial per Day

Rat 7. "Errors" At Turns In Daily Trials

Turn	Start		1		2		3		4		5		6	
	*P	M	P	M	P	M	P	M	P	M	P	M	P	M
Trial 1			2	4	5	2		2						
2			4	10	18	4	2	9	1					
3			6	6	4	4	7	4	2					
4	1		3	1	16	4	1	8	3	2				
5	1		3	6	24	10	5	3	6	3		1		
6	1		4	4	4		2	9	8	2			2	
7		1	1	1	1		5	1	2					
8	1				1			2				1		
9				1				1			1	1		
10								2	1			1		
11			1					2	1					
12								2						
13				1				1						
14				1				1	1					
15								1	1					
16								1	1					
17					1									
18								1	1					
19	1							1						
20							1	1						
21								1						
22	1							1						
23														
24								1						
25								1	1					
26					1									
27								1						
**28								1						
Totals	6	1	24	35	75	24	23	58	29	7	1	4	2	

* P.—Plus "errors," to the left of turn.
M.—Minus "errors," to the right of turn.
** Finished in 43 trials; no "errors" after the 28th trial.

RECORD 2

DOMINANT IMPERFECT REPONSES IN LEARNING

70 Day Period. 3 Trials per Day.

Rat 6. " Errors " At Turns In Daily Trials.

Turn	Start		1		2		3		4		5		6	
Trial	P	M	P	M	P	M	P	M	P	M	P	M	P	M
1			1	3	4	1		1	2					
2	2			2		1								
3	3	1		3	3	1		5	1					
4		1	3	2	1			1	1			1	1	1
5	1			1	1	1	1	1	1	1		1	2	5
6	1			2	1			1	4	3	1	1	7	5
7	1			2	1			1	1				2	2
8	8	1		3	1			1	2				1	2
9	1			1	4		2	2						1
10	1	1		1				2	1					
11	1				1			1						
12	2			1				1	1					
13	1				1			1						
14	2			2	1			1	1					
15	1	1		1	2	1								
16	1	3	1	2		1			1					
17	2	1		1	1			1						
18	1	1			1			1						
19	1	1						1						
20	1	1		1				1						
21	1			2	1			1						
22				1	1			1						
23	1				2	2	2	1						
24	1	1				1								
25					1			1						
26	1	2	1	1										
27	1							1						
28				1				1	1					
29		1												
30		1		1										
31		1												
32		1	1	2										
33		1	2	2			1	1	1					
34		1	1	2										
35		1	2	2				1						
36		1		1										
37		1												
*39			1											
42	1	2		1										
44	1	1												
45		2												
46		1												
47			1											
49	1	1												
50			1											
51		1		1										
53			1											

* Omitted trials are free of " error."

RECORD 2 (Continued)

Turn	Start		1		2		3		4		5		6	
	P	M	P	M	P	M	P	M	P	M	P	M	P	M
Trial 54	1		1	1										
55			1											
56			1					1						
58		1												
59			1											
60			1											
62			1	1										
63								1	1					
64		1												
66			1											
67			1					1						
68			1	1					1					
69		1						1						
70				1										
71				1										
74			1											
75		1												
77			1	1										
78		1												
85		1												
90			2	1	1	1		1						
92		1			1									
93		1												
Totals	40	40	29	52	30	10	6	36	20	4	1	3	13	16

II. Redintegration

(1) *Dominant " Error "*

Records 1 and 2, showing " errors " in daily trials of two individual rats, have been cited in full to illustrate not only the dominant " error " but also the method of obtaining the total " errors " in the tables to be given.

Table I–A presents the total " errors " in both learning and redintegration for the 3 trials per day rats of the group at 70-day retention. Rats 1, 2, and 3 comprise one complete litter; rats 4, 5, and 6 are from a litter of 7, the four remaining being in the 45-day group. Rat 6 is the one cited previously in record 2. The figures running horizontally across the page and preceded by " L." and " R " are the total " errors " in learning and redintegration, respectively. The figures in perpendicular columns under " P." and " M." are totals of plus and minus " errors," respectively. All the " error " tables to follow are constructed in this manner.

It has been observed in the consideration of records 1 and 2 that of the two " errors," plus and minus, one is an established dominant " error " in almost every case. Thus, beginning at the very start of the maze and considering the learning totals, individually or collectively, the dominant " error " runs in the order plus, minus, plus, minus, etc., omitting alleys 5 and 6 for the present. E. g., in the " errors " of rat 2, plus 85 is dominant over minus 18, minus 83 over plus 12, plus 83 over minus 20, etc. The qualitative totals present a similar situation.

Coming to a consideration of the redintegration " errors," it may be seen that the dominant " errors " at the turns, with a few unimportant exceptions, follow those dominant in learning. This is notable. There are not as many " errors " in redintegration as in learning, and thus the plus, minus, plus, minus order is so decided; but that it is there is beyond question. Therefore, at the locus or place

where integration was difficult to establish in learning a similar difficulty appeared in redintegration trials after retention. In other words, the weak link in the chain of the habit, or the integration difficult to acquire, has appeared after a retention period, although the weakness apparently had disappeared after the long period of learning.

Table I–B presents " errors," tabulated as in Table I–A,

TABLE I–A

70-Day Period. 3 Trials per Day

" Errors " At Turns

Turn		Start		1		2		3		4		5		6		Total		No. of Trails
		*P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M	
Rat 1.	**L.	72	58	36	88	54	15	11	53	39	7	2	10	5	11	219	242	150
	R.	5	1	5	5	3		4	12	1	3		1	1	1	19	23	45
2.	L.	85	18	12	43	83	20	5	30	18		5	5	2	12	210	128	138
	R.			2	3		1		6	3	3				1	5	14	22
3.	L.	61	38	55	111	52	13	4	60	31	5	6	13	14	11	223	251	153
	R.	3		3	4	1	1	2	15	1	1	1	1	2	16	13	28	29
4.	L.	43	20	12	49	46	23	6	54	8		4	2	6	10	125	158	101
	R.	4	2	5	3	1	2	1	2					1	3	12	12	33
5.	L.	62	41	24	76	73	28	10	57	21	9	11	14	20	21	221	246	107
	R.	3	2	6	8	3	3	4	14	4		2	2	6	3	28	32	28
6.	L.	40	40	29	52	30	10	6	36	20	4	1	3	13	16	139	161	93
	R.	4	4	2	7	4	2	1	3	1		1			1	13	17	42
Totals																		
Qualit.	L.	363	215	168	419	338	109	42	290	137	25	29	47	60	81	1137	1186	
	R.	19	9	23	30	12	9	12	52	10	7	4	4	10	15	90	126	
Quant.	L.	578		587		447		332		162		76		141		2323		
	R.	28		53		21		64		17		8		25		216		
Aver's.	L.	96.3		97.8		74.5		55.3		27.		12.7		23.5		387.1		123.6
	R.	4.7		8.8		3.5		10.7		2.8		1.3		4.1		36.		33.1

* P.—Plus " errors," to the left of turn.
M.—Minus " errors," to the right of turn.
** L.—Learning; R.—redintegration.

but compares the total " errors " of redintegration with the " errors " of the last 35 trials of learning. It was hoped by summing these trials of learning that further light on " dominance " would be obtained. The table shows that dominance in later trials of learning, as a whole, both in reference to complete learning and also redintegration, follows closely what has already been noted. It may be seen further that in some cases " errors " not

recording the learning totals of this table appear in redintegration, and also that the number of " errors " in redintegration frequently exceed that in the learning. From this it seems that the " errors " which appeared earlier in the learning are tending to reappear in redintegration; or, in other words, a recapitulation may have taken place. The results with the individuals are not as definite here as in Table I–A, but totals follow the rule.

Table II–A presents the total " errors " in both learn-

TABLE II–A

70-Day Period. 1 Trial per Day

" Errors " At Turns

Turn		Start		1		2		3		4		5		6		Total		No. of Trials
		P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M	
Rat 1.	L.	10	3	14	28	10	4	2	19	4		1	3	2		43	57	52
	R.	2	1	1	3				4							3	8	24
2.	L.	7	7	16	20	9	4		11	14	2	2	5	1		49	49	48
	R.	4	1	2	3	1			1	1	1					8	6	17
3.	L.	25	1	33	52	29	6	4	19	16	4		1		1	107	84	43
	R.	3	1	2	7				4	4	1					9	13	17
4.	L.	15	5	7	18	30	13	2	20	22	2	1				77	58	51
	R.	26	2		8	4		3	8	7						40	18	65
5.	L.	16	6	16	12	13	4	8	18	4		2		2	1	61	41	48
	R.	3	1	4	12	3	3	2	10	2						14	26	43
6.	L.	12	1	3	26	17	6	1	33	10			1	3	1	46	67	61
	R.	3	1		2											3	3	17
7.	L.	6	1	24	35	75	24	23	58	29	7	1	4	2		160	129	43
	R.	4	3	1	7	1			13	3		1	1			10	24	29
8.	L.	8	3	3	10	5	2	3	14	4		1			1	24	30	54
	R.	4	1	5	11	4		3	9	1						17	21	28
9	L.	11	3	1	11	9	1	6	10	3	1		1	1		31	27	29
	R.	1		4	7	1	2	1	15	1		1				9	24	29
10.	L.	9	4	7	20	10	5	11	13	4	1	3	5	2		46	48	43
	R.	1	2	1	6	2				1						5	8	22
Totals Qualit.	L.	119	33	124	232	207	69	60	215	110	17	11	20	13	4	644	590	
	R.	51	13	20	66	16	5	9	64	20	2	2	1			118	151	
Quant.	L.	152		356		276		275		127		31		17		1234		
	R.	64		86		21		73		22		3				269		
Aver's.	L.	15.2		35.6		27.6		27.5		12.7		3.1		1.7		123.4		47.2
	R.	6.4		8.6		2.1		7.3		2.2		.3				26.9		29.1

ing and redintegration for the 1 trial per day rats of the 70-day group. Rats 1, 2, 3, 4, 5, 6, and 7 are from a litter

of eight, the remaining rat being in the 45-day group. Rats 8, 9, and 10 are from a litter of five, the remaining two being in the 45-day group. What was noted in Table I–A applies in like manner to the present table as far as totals and general results are concerned. But there are some few individual discrepancies, such as in rat 2, turn 9, rat 5, turn 1, etc.

Table II–B was compiled with the similar intention as was Table I–B; that is, to ascertain dominance in later trials. This table confirms the findings of table I–B. The later trials of learning beyond doubt have an important influence on the subsequent behavior in redintegration.

TABLE II–B

70-Day Period. 1 Trial per Day
"Errors" At Turns
Last 35 Trials of Learning; Complete Redintegration

Turn		Start		1		2		3		4		5		6		Total		No. of Trials
		P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M	
Rat 1.	L.	5	2		3	1			3							6	8	52
	R.	2	1	1	3				4							3	8	24
2.	L.	2	4		2	2	2		1	1			2			5	11	48
	R.	4	1	2	3	1			1	1	1					8	6	17
3.	L.	12		1	4		2		6	3	1					16	13	43
	R.	3	1	2	7				4	4	1					9	13	17
4.	L.	4	3		5	3	3	1	3	9						17	14	51
	R.	26	2		8	4		3	8	7						40	18	65
5.	L.	4	5	3	1				5	1						8	11	48
	R.	3	1	4	12	3	3	2	10	2						14	26	43
6.	L.	3		1					7	4						8	7	61
	R.	3	1		2											3	3	17
7.	L.	2		1	3	2		1	20	7		1	2			14	25	43
	R.	4	3	1	7	1			13	3		1	1			10	24	29
8.	L.	1			4	1		1	7	3					1	6	12	54
	R.	4	1	5	11	4		3	9	1						17	21	28
9.	L.	11	3	1	11	9	1	6	10	3	1		1	1		31	27	29
	R.	1		4	7	1	2	1	15	1		1				9	24	29
10.	L.	5	3		7	2	4	2		1	1		1	2		12	16	43
	R.	1	2	1	6	2		1								5	8	22
Totals Qualit.	L.	49	20	8	40	20	12	11	62	32	3	1	6	3	1	123	144	
	R.	51	13	20	66	16	5	9	64	20	2	2	1			118	151	
Quant.	L.	69		48		32		73		35		7		4		267		
	R.	64		86		21		73		22		3				269		
Aver's.	L.	6.9		4.8		3.2		7.3		3.5		.7		.4		26.7		47.2
	R.	6.4		8.6		2.1		7.3		2.2		.3				26.8		29.1

TABLE I–B

70-Day Period. 3 Trials per Day

"Errors" At Turns

Last 35 Trials of Learning; Complete Redintegration

Turn		Start		1		2		3		4		5		6		Total		No. of Trials
		P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M	
Rat 1.	L.	9	3	4	5	1			1	2			1			16	10	150
	R.	5	1	5	5	3		4	12	1	3		1	1	1	19	23	45
2.	L.	11	4		2	4	3	1		1			2			17	11	138
	R.			2	3		1		6	3	3				1	5	14	22
3.	L.	7	2	3	6	1	1		2		1		1			11	13	153
	R.	3		3	4	1	1	2	15	1	1	1	1	2	6	13	28	29
4.	L.	5	3	1	6	1	1		3							7	13	101
	R.	4	2	5	3	1	2	1	2					1	3	12	12	33
5.	L.	3	3	6	8	4	1	1	3	1						15	15	107
	R.	3	2	6	8	3	3	4	14	4		2	2	6	3	28	32	28
6.	L.		7	10	6	2	1		4	2						14	18	93
	R.	4	4	2	7	4	2	1	3	1		1			1	13	17	42
*7.	L.	1		1	1		1		1							2	3	61
	R.	3		4	4	3	2		5	5	1	2	1	11	4	28	17	21
8.	L.	3			1											3	1	43
	R.	4	2	5	6	3	3	1	4	3	4	6	2	6	1	28	22	21
Totals Qualit.	L.	39	22	25	35	13	8	2	14	6	1		4			85	84	
	R.	26	11	32	40	18	14	13	61	18	12	12	7	27	20	146	165	
Quant.	L.	61		60		21		16		7		4				169		
	R.	37		72		32		74		30		19		47		311		
Aver's.	L.	7.62		7.5		2.62		2		.87		.5				21.1		105.7
	R.	5.25		9		4		9.25		3.74		2.37		5.87		38.8		30.1

* 7 and 8 omitted in Table I–A due to incomplete records of "errors" in learning.

Table III–A presents the total "errors" in both learning and redintegration for the 3 trials per day rats of the 45-day group. Rats 1, 2, 3, and 4 are from a litter of seven, the remaining three of the litter being in the 70-day group. In Table III–B rats 5, 6, and 7 are from a litter of six; of the remaining three in the litter one failed to complete the experiment and the other two are recorded in the 70-day group as 7 and 8. The dominance in "errors" of both learning and redintegration in these tables confirms the findings of the former tables. Table III–B is the comparison of "error" totals of redintegration and the last 30 trials of learning, which number was thought sufficient for the 45-day retention period. These totals confirm those of Tables I–B and II–B.

TABLE III–A
45-Day Period. 3 Trials per Day
"Errors" At Turns

Turn		Start		1		2		3		4		5		6		Total		No. of Trials
		P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M	
Rat 1.	L.	86	43	49	113	93	49	11	70	32	6	9	11	18	19	298	311	146
	R.	4	1	6	10	5	3	2	9	3		1	3	2	3	23	29	34
2.	L.	88	26	18	73	86	39	8	65	32	3	1	8	7	8	240	222	170
	R.	3	4	2	5	3		1	3							9	12	46
3.	L.	63	33	25	60	58	15	9	37	26	4	1	8	9	9	191	166	143
	R.	11	10	16	21	12	5	3	7	4	1		4	2	5	48	53	61
4.	*L.	123	47	61	162	127	51	18	128	81	7	7	14	7	7	424	416	252
	R.	5	2	2	4		1		4							7	11	27
Totals Qualit.	L.	360	149	153	408	364	154	46	300	171	20	18	41	41	43	1153	1115	
	R.	23	17	26	40	20	9	6	23	7	1	1	7	4	8	87	105	
Quant.	L.	509		661		518		346		191		59		84		2268		
	R.	40		66		29		29		8		6		12		192		
Aver's.	L.	127.25		140.25		129.5		86.5		47.75		14.75		21		567		177.7
	R.	10		16.5		7.25		7.25		2		2		3		48		42.

* Did not complete learning; completed redintegration.

TABLE III–B
45-Day Period. 3 Trials per Day
"Errors" At Turns
Last 30 Trials of Learning; Complete Redintegration

Turn		Start		1		2		3		4		5		6		Total		No. of Trials
		P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M	
Rat 1.	L.	2	4	1	3	1										4	7	146
	R.	4	1	6	10	5	3	2	9	3		1	3	2	3	23	29	34
2.	L.	3	2	3	4				1							6	7	170
	R.	3	4	2	5	3		1	3							9	12	46
3.	L.	6	2	7	8	5		1	2	1						20	12	143
	R.	11	10	16	21	12	5	3	7	4	1		4	2	5	48	53	61
4.	L.	9	7	10	19	7	2	3	6	1			1			30	35	252
	R.	5	2	2	4		1		4							7	11	27
*5.	L.	4	1	1	3											5	4	56
	R.	2			2	1										3	2	27
6.	L.	1			2	1										2	2	63
	R.	2	1		5	3			2					1		6	8	21
7.	L.	3			3				1							3	4	60
	R.	8			4	1	1		4					1	1	10	10	26
Totals Qualit.	L.	28	16	22	42	14	2	4	10	2			1			70	71	
	R.	35	18	26	51	25	10	6	29	7	1	1	7	6	9	106	125	
Quant.	L.	44		64		16		14		2		1				141		
	R.	53		77		35		35		8		8		15		231		
Aver's.	L.	6.28		9.14		2.28		2.		.28		.14				20.14		
	R.	7.57		11.		5.		5.		1.14		1.14		2.14		33.		

* 5, 6, and 7 omitted in Table III–A due to incomplete records of "errors" in learning.

TABLE IV–A

45-Day Period. 1 Trial per Day

" Errors " At Turns

Turn		Start		1		2		3		4		5		6		Total		No. of Trials
		P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M	
Rat 1.	L.	27	16	16	30	14	3	2	35	14	1	1				74	85	118
	R.	1			3	2	3	2	2							5	8	20
2.	L.	40	19	19	23	32	10	20	10	33	3	1	3	2	2	147	70	105
	R.	4		1	5	1			2	1			1			7	8	32
3.	L.	40	23	14	36	19	4	2	40	4		1	2		1	80	105	84
	R.	10	1	1	3			1	4	1	2		2			13	12	34
*5.	L.	30	19	17	33	27	13	6	26	10	7	3	9	11	11	104	118	59
	R.		1	4	2	1	1		1	1					1	6	6	27
6.	L.	21	9	11	24	24	7	7	14	15	1			3	1	81	56	45
	R.	5	5	2	2	2	1	1	4							10	7	25
7.	L.	12	24	5	22	15	5	3	14	13	2				3	48	70	57
	R.	1	5	6	3	2	1									9	9	29
8.	L.	21	15	8	19	11	3	3	16	5		1	1	1	1	50	55	62
	R.	5	5		2				3							5	10	17
Totals Qualit.	L.	191	125	90	187	142	45	43	155	94	14	7	15	17	19	582	562	
	R.	26	12	14	20	8	6	4	16	3	2		3		1	55	60	
Quant.	L.	316		277		187		198		108		22		36		1144		
	R.	38		34		14		20		5		3		1		115		
Aver's..	L.	45.14		39.65		26.7		28.28		15.4		3.1		5.1		163.4		75.71
	R	5.4		4.85		2.		2.8		.71		.43		.14		16.33		26.21

* –4 did not complete redintegration.

Table IV–A presents the total " errors " in both learning and redintegration for the 1 trial per day rats of the 45-day group. Rats 1 and 2 are from a litter of 5, and rat 3 is from a litter of 7, the remaining rats of both litters being in the 70-day group. Rats 5 and 6 are from a litter of 3, the remaining rats of which did not complete the experiment. Rats 7 and 8 comprise a complete litter. This table adds nothing further to the previous tables other than a confirmation of their general result—of dominance. Table IV–B is modeled after Table III–B. The results are not as definite as in the former tables but general results are confirmed.

TABLE IV–B

45-Day Period. 1 Trial per Day

"Errors" At Turns

Last 30 Trials of Learning; Complete Redintegration

Turn		Start		1		2		3		4		5		6		Total		No. of Trials
		P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M	
Rat 1.	L.	4	1	2	3		1	1								7	5	118
	R.	1			3	2	3	2	2							5	8	20
2.	L.	2		2	1	1	1				1	1	1			6	4	105
	R.	4		1	5	1			2	1			1			7	8	32
3.	L.	2	4		5				7							2	16	84
	R.	10	1	1	3			1	4	1	2		2			13	12	34
5.	L.	5	8	4	2	3	3	1						2	3	15	16	59
	R.		1	4	2	1	1		1	1					1	6	6	27
6.	L.	12	2			3			2	3	1					18	5	45
	R.	5		2	2	2	1	1	4							10	7	25
7.	L.		13	3			2		2							3	17	57
	R.	1	5	6	3	2	1									9	9	29
8.	L.	3	11				1		4	1			1			4	17	62
	R.	5	5		2				3							5	10	17
Totals Qualit.	L.	28	39	11	11	7	8	2	15	4	2	1	2	2	3	55	80	
	R.	26	12	14	20	8	6	4	16	3	2		3		1	55	60	
Quant.	L.	67		22		15		17		6		3		5		135		
	R.	38		34		14		20		5		3		1		115		
Aver's.	L.	9.57		3.14		2.14		2.42		.85		.42		.71		19.28		75.7
	R.	5.42		4.85		2.		2.85		.71		.42		.14		16.42		26.2

TABLE IV–D

45-Day Period. 1 Trial per Day

Distance in Centimeters

Alleys		1	2	3	4	5	6	Total
Rat 1.	L.	30341	18729	13497	17206	7898	8792	96463
	R.	3445	2622	2634	1978	1120	1500	13299
2.	L.	27935	20169	15562	16285	10562	8360	98873
	R.	5338	3961	3564	2548	2057	2400	19868
3.	L.	30382	14291	12392	11206	5298	6270	79839
	R.	5427	4211	3332	3408	2032	2475	20885
5.	L.	27681	14355	12513	7790	6098	7785	76222
	R.	4560	3704	2646	2145	1514	2271	16840
6.	L.	17545	13739	9117	7132	4658	3675	55866
	R.	4510	3766	2673	2428	1400	1875	16652
7.	L.	21074	16093	10303	8383	5278	4814	65945
	R.	5819	5150	2842	2262	1624	2175	19872
8.	L.	22681	13249	8878	6918	4121	4976	60823
	R.	4977	2579	1764	1475	1008	1350	13153

Table IV–D presents the distance totals of the 45-day group at 1 trial per day. The respective distances of each day's trial were computed by ration from the measurements of tracings obtained through the camera lucida, and the totals as here presented were summed on the adding machine. The object of computing the totals which this table presents was to ascertain whether distance in learning had influence in redintegration, either in particular alleys or in total result. No positive result was obtained on this point, as the table clearly shows. However, a subsidiary fact is evident, namely, that the distances generally diminishes toward the center of the maze with the exception of the last alley, where " fear " or timidity may intervene; but at the same time there are striking instances in which the rule does not hold, e. g., in the first record of the present table. The reduction of distance toward the center may have been expected, inasmuch as the construction of the maze is such that this result would be almost inevitable. But that distance in learning seems to bear no specific influence on distance in redintegration is an important fact and the necessary finding to eliminate distance as a prime factor in the consideration of final conclusions. The distance traversed in successive alleys, therefore, is not of such importance as the establishing of integration of turning where the dominant " error " is produced. There would not be excessive distance if no " error " was produced.

As has already been observed in previous pages, the maze is a compound of lesser problems which are located specifically at the successive turns. Turning to Figure 1, it may be seen that the serial order of integrations in the treading of the maze proceeds, first, with the acquiring of perfect integration of movement away from the entrance, or start, to the right; second, the solution of turn 1, which consists in the acquiring of perfect integration of movement in making the 180-degree turn to the left in passing from alley 1 to alley 2; third, the acquirement of similar integration, as in turn 1 at turn 2, except that here the turn is to the right and so on through the series of successive turns to the center.

It is quite true that to turn either way from the start would be equally easy. But when the rat has finally begun to run the correct pathway from the start the more easily integrated movement by which to enter alley 2, through turn 1, is in the direction which leads to a minus " error," i.e., straight away into the cul-de-sac. It is easier for the rat to continue straight ahead, past any turn, in the direction in which it is running, or straight ahead through the turn into the cul-de-sac. These " errors " are indicated by a minus sign in the turns 1, 3, and 5; and plus at the other turns. All figures show that many more " errors " are made here, both in learning and redintegration, than in making the more acute turns, which require established integration to be made continuously in a perfect manner. Thus it is clearly seen that the integrated movement at the respective turns must be learned before the habit can be established.

Some authors have attempted to show by logic rather than by research in the laboratory that this question is a mere matter of chance—which way a rat will go through a turn. But experimental observation clearly proves that it is a hard and fast question in experiment on the establishment of perfect integration of movement. It is not a matter of chance but of difficult integration versus easy integration. The minus " error " at turn 1 is thus dominant over the plus " error "; at turn 2, the plus over the minus, etc., as far as already limited. In other words, as already stated, the weak link in the chain of the habit—the dominant error or the integration difficult to acquire—appears in the process of *learning* and *reappears* after *retention* in *redintegration.*

(2) Effect of Distribution of Trials on Redintegration

It has been shown quite conclusively in animal experimentation that the wider the distribution of effort, within certain limits as yet undefined, the greater will be the economy [Yerkes (3), Hunter (12), Ulrich (18)]. Any attempt to ascertain the effect upon retention of different distributions of effort in learning should be begun with full cognizance of these conclusions.

As has been shown in the foregoing pages, in the process of learning, in the acquirement of a habit, the establishment of complex integrations of movement has a very marked effect on the retention of the habit. All methods of learning produce finally the same result, viz, the establishment of the perfectly integrated habit. Yet since each method of learning, according to the distribution of effort, has such a marked effect on the characteristics and general progress of the learning process, a legitimate working hypothesis may be laid down to the effect that retention and subsequent redintegration may be affected in a somewhat similar manner by the method of distribution of trials previously employed in learning. Within a definite limit it is the object of the present chapter to show some effects of the distribution of effort in learning on the retention and redintegration.

It was with the twofold object of attempting to throw some light on retention that the different groups of rats considered in the foregoing pages were divided into three trials per day groups and one trial per day groups. The " error " Tables I–A, II–A, III–A, and IV–A have already been explained in reference to the dominant " error." The economy of these same tables is summed in the " error " totals. It may be noted in these totals that the number of " errors " in learning were far more numerous for the three trials per day group than for the one trial per day group. This fact is significant in the explanation of the economical superiority of the one trial per day method over the three trials per day method. The group following the three trials per day method display a more pronounced difficulty in establishing the perfect integrations of movement in the solution of the successive turns and the consequent acquirement of the habit, if one is to judge from the " errors." The three trials per day method is productive of the greater number of " errors," and evidently a greater expense of energy. Therefore, the one trial per day method is the method of wider distribution of trials and is more economical.

Turning to the influence of retention, in redintegration, it may be seen that a somewhat similar situation exists.

But the fact is most evident that although the one trial per day method evokes a more rapid reestablishment of perfect integration and hence a lesser number of " errors," yet the three trials per day method has relatively gained in economy. This fact is illustrated in Plates I and II, where it may be observed that the average " error " curves tend toward a mean in redintegration.

It has been noted that every method of learning, in regard to the problem under consideration, arrives approximately at the same end, namely, the establishment of the perfectly integrated habit. That is, at the beginning of the retention period—and with the exception of the process or history of the establishment of integrations—the three trials per day group may be considered equal to the one trial per day group as far as habit integrations are concerned. In integration as is here considered this seems to be the fact. Otherwise there would be no tendency of the " errors " of the three trials per day group and the " errors " of the one trial per day group to tend to a mean, as the curves in Plates I and II show graphically; and likewise with the trials. In redintegration the absolute number of " errors " of the one trial per day method is less than the number in the three trials per day method; but the relative decrease of " errors " in the three trials per day redintegration is greater than in the one trial per day redintegration. And thus in economy the one trial per day method after retention is absolutely superior to the three trials per day method, but relatively inferior.

Tables I–C, II–C, III–C, and IV–C contain total trials in learning and redintegration; and also time and perfect trials in the last 15 trials of learning and the first 15 trials of redintegration of those groups in the " error " tables already considered. Curves (b), (c), and (d) in Plates I and II are constructed from the averages in the above tables. Curve (b) in both plates, showing average trials, displays the tendency to a mean which appears in redintegration totals, and further, also the superiority of the one trial per day method. Curve (c) in both plates of average perfect trials in the last 15 trials of learning and the first 15 trials of redintegration shows no marked

TABLE I–C

70-Day Period. 3 Trials per Day

Time in Seconds

No. of Trials			First 15 Trials of R.; Last 15 Trials of L.															Av.
Rat 1.	L.	150	*6	*7	*6	*7	*6	*7	*6	*6	*6	12	*7	*6	8	*6	*6	6.8
	R.	45	241	55	75	35	154	28	*12	*14	27	16	20	*12	*10	*12	8	47.9
2.	L.	138	*6	*6	*6	*6	*6	*6	*6	*6	*7	7	*6	*8	8	*6	*6	6.4
	R.	22	105	15	15	13	*10	*9	9	*8	*9	*8	*8	*9	*7	*6	*7	15.5
3.	L.	153	*6	*6	*6	*6	*6	*6	*6	*6	12	8	*7	20	*6	7	*7	7.5
	R.	29	87	145	127	27	170	68	35	*13	14	12	*8	8	12	17	*9	50.1
4.	L.	101	*6	*6	*7	*7	*6	*6	*7	*7	*6	*7	*6	13	12	7	13	9.9
	R.	33	100	23	13	15	10	17	17	*7	*7	*9	24	27	15	*8	*10	20.1
5.	L.	107	*6	*6	*6	*6	*6	*6	11	8	47	61	14	20	*7	*7	17	15.2
	R.	28	197	255	356	15	217	73	19	125	35	13	51	20	16	*8	*7	93.8
6.	L.	93	*6	*6	*6	*6	*6	*6	8	*6	*7	*6	*6	72	*8	15	8	11.4
	R.	42	59	12	10	*9	*7	*7	*7	15	*8	*7	14	*8	*7	29	11	14
7.	L.	61	*6	*6	*7	*6	*6	*6	*6	*6	*7	*6	*6	*6	25	*7	*6	7.4
	R.	21	581	147	55	85	187	23	*7	*7	*6	*9	*7	*6	*8	*7	*6	76
8.	L.	43	*6	*7	*6	*7	*6	*6	*6	8	*10	*7	*6	*8	*7	*7	*8	7
	R.	21	297	587	432	1330	27	8	*7	*6	*7	*6	*6	*6	*7	*6	*6	182.5

Averages—
Trials..L. 105.7 * (Perfect) Trials..L. 11.8 Time..L. 8.9
R. 30.1 R. 6.2 R. 62.4

* Starred trials were perfectly integrated.

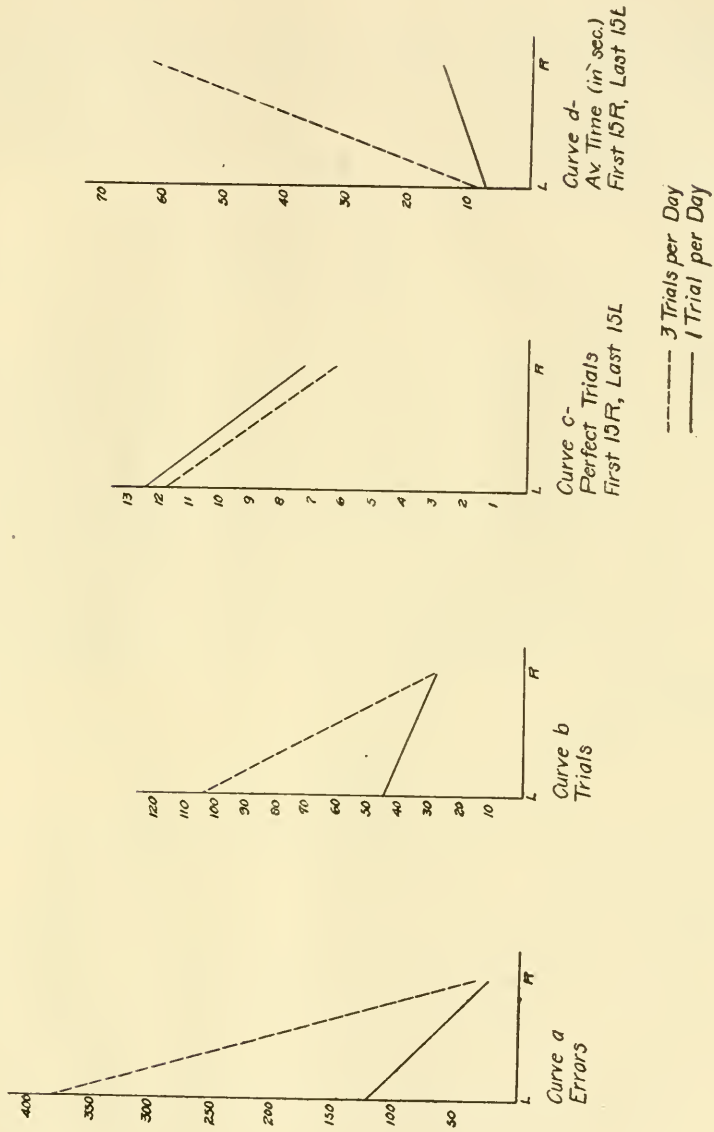
TABLE II–C

70-Day Period. 1 Trial per Day

Time in Seconds

No. of Trials			First 15 Trials of R.; Last 15 Trials of L.															Av.
Rat 1.	L.	52	*6	*6	*6	*6	*7	*6	*6	*7	*6	*6	7	*6	*6	20	*6	7.1
	R.	24	16	*6	*6	*6	27	10	*6	*6	25	*7	*7	*6	*6	*6	*7	9.8
2.	L.	48	*6	*6	*6	*6	*6	*6	20	*6	*7	*6	20	11	*6	*6	*6	8.9
	R.	17	53	11	*7	*6	*6	*6	*7	*6	30	*6	*6	*6	59	*6	*7	14.8
3.	L.	43	*7	*6	*6	*6	*6	*6	*6	*6	15	*6	8	*7	22	*6	*6	7.9
	R.	17	20	13	*7	*6	*6	*6	*7	*6	9	*6	9	153	*6	43	10	20.4
4.	L.	51	*6	*6	*6	*6	*6	*6	*8	25	10	*7	8	11	*6	7	30	9.8
	R.	65	36	14	*6	13	9	44	10	*7	*7	21	10	27	17	8	*7	15.7
5.	L.	48	*6	*6	*6	*7	*6	*6	*6	*6	*6	12	11	*6	*6	30	20	9.3
	R.	43	72	*12	10	9	8	*7	14	*7	26	*7	34	15	63	*7	9	20.
6.	L.	61	*6	*6	*6	*6	*6	*6	*6	16	*6	*6	*6	*7	*7	10	*6	7.
	R.	17	24	13	*9	*7	*7	*7	*7	*9	*7	*7	*7	*7	*7	15	*8	9.4
7.	L.	43	*6	*6	*6	*6	*6	*6	*7	*6	*6	*6	*7	*6	*7	*6	*6	6.2
	R.	29	135	16	29	12	19	15	9	15	*7	13	11	10	*7	20	*7	21.6
8.	L.	54	*7	*7	*6	*6	*7	*7	*6	*6	12	8	*7	*6	*6	*6	*6	6.8
	R.	28	31	15	16	9	9	11	*6	*6	30	9	10	*7	12	*7	*7	12.3
9.	L.	29	*6	*6	*6	*6	*6	*6	*6	*6	*6	*9	*6	*6	*6	*6	*6	6.2
	R.	29	57	10	40	9	8	7	7	14	15	9	13	8	7	7	*6	14.4
10.	L.	43	*6	*6	*6	*6	*6	*6	*6	15	*6	*9	10	*8	*8	*7	*6	7.4
	R.	22	36	*7	8	*6	*6	*6	7	*6	*6	*6	*6	*6	*6	11	*6	8.6

Averages—
Trials L. 47.2 * (Perfect) Trials L. 12.6 Time L. 7.6
R. 29.1 R. 7.1 R. 14.7



superiority of the one trial per day method. Curve (d) in both plates, showing average time in the last 15 trials of learning and the first 15 trials of redintegration, points clearly to a superiority of the one trial per day method

over the three trials per day method. These curves confirm the results in the " error " curves in the fact that the one trial per day method is absolutely superior in both learning and redintegration; but, owing to the tendency to the mean in redintegration, the one trial per day method becomes inferior in a relative sense only.

TABLE III–C
45-Day Period. 3 Trials per Day
Time in Seconds

No. of Trials			First 15 Trials of R.; Last 15 Trials of L.															Av.
Rat 1.	L.	146	*6	*7	*7	*6	*7	*6	*6	*6	*6	*6	*8	*7	*7	10	*6	6.7
	R.	34	155	195	205	17	*10	*7	*10	13	12	*8	*8	*7	*9	*7	26	45.9
2.	L.	170	*6	*6	*7	*7	*7	*6	*7	*6	*6	*6	*6	*6	*6	*6	*6	6.2
	R.	46	46	9	*7	*8	*6	*6	*7	13	14	*8	*6	10	*10	11	10	11.4
3.	L.	143	*7	*6	*6	*6	*6	*7	20	*6	*7	*7	*6	9	*7	*6	*6	7.4
	R.	61	54	26	37	19	110	71	25	75	95	20	70	27	8	10	20	44.4
4.	L.	252	45	85	51	*10	35	17	45	20	17	16	12	10	9	10	8	26
	R.	27	21	21	*11	*11	14	13	*9	*8	14	*8	20	19	*8	*7	*8	12.8
5.	L.	56	*6	*6	*6	*6	*6	*6	8	*6	*6	*6	9	8	*7	*7	*6	6.6
	R.	27	41	*8	*7	*7	*6	14	*6	*6	*6	*6	*6	12	*6	*6	*7	9.6
6.	L.	63	*7	*6	*6	*7	*6	*7	*7	*15	*7	*8	7	*7	7	*6	*7	7.3
	R.	21	192	*8	*8	*9	*7	*7	*8	*7	*6	17	*7	16	*8	*8	8	21.2
7.	L.	60	*6	*6	*6	*7	*6	*6	*6	*6	*7	*6	*6	*6	*9	*6	*6	6.3
	R.	26	63	18	21	*6	*6	13	*6	32	*6	*6	10	*6	*7	*6	*10	14.4

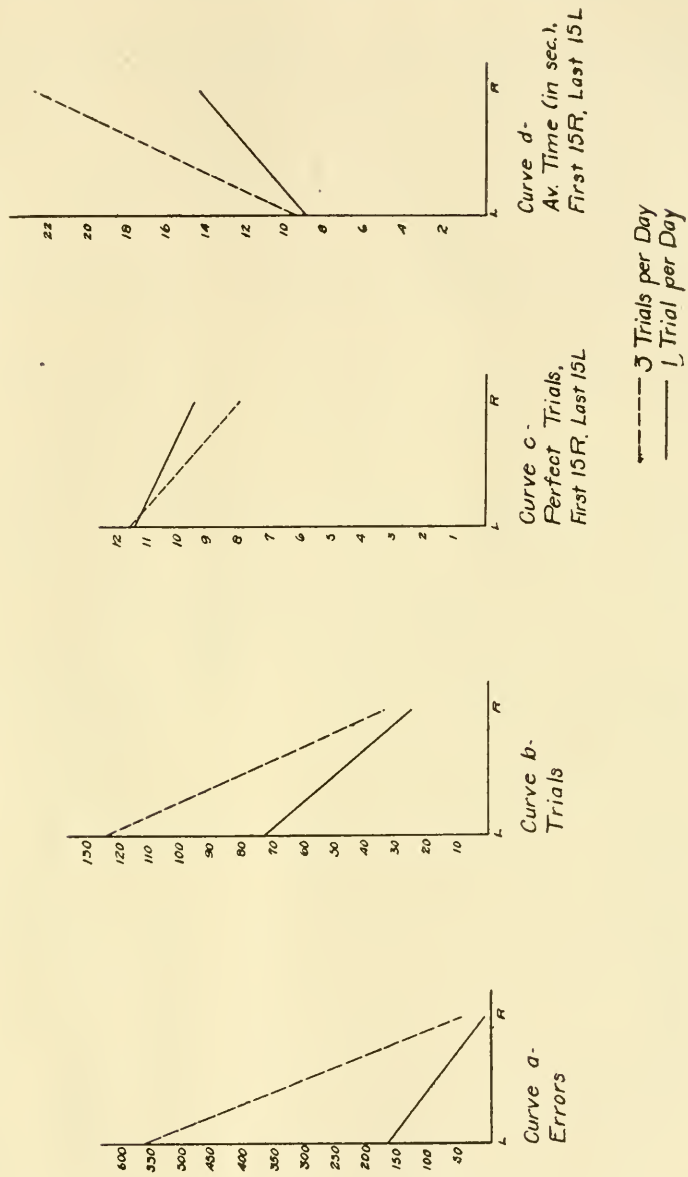
Averages—
Trials..L. 127.1 * (Perfect) Trials..L. 11.7 Time..L. 9.5
R. 34.5 R. 8 R. 22.8

TABLE IV–C
45-Day Period. 1 Trial per Day
Time in Seconds

No. of Trials			First 15 Trials of R.; Last 15 Trials of L.															Av.
Rat 1.	L.	118	*6	*6	*6	*7	*7	*7	*7	*6	7	*6	37	*6	*6	*6	8	8.5
	R.	20	115	*10	*8	7	10	*7	*7	10	*6	*7	*7	*9	51	*7	*6	17.8
2.	L.	105	*7	*6	*6	*7	*7	*6	*6	*6	*6	14	*7	9	*6	*6	*6	7
	R.	32	175	26	26	12	*9	*15	*14	25	*12	*8	*7	*7	25	*7	*7	25
3.	L.	84	*6	*7	*6	*7	*6	*7	*7	*6	*6	*6	*6	11	13	9	14	7.8
	R.	34	15	51	11	15	*6	*7	8	*7	*7	15	*8	*7	10	*8	*8	12.2
5.	L.	59	*7	*7	*7	*7	*8	*8	*7	10	13	*7	*8	*7	19	*7	*8	8.6
	R.	27	9	*7	*9	*6	*7	115	8	*8	*11	*9	27	11	*7	*7	*6	16.4
6.	L.	45	*7	*7	*6	*6	*7	*9	*6	*6	*7	125	10	*7	10	*9	*6	15.6
	R.	25	39	*9	8	*7	7	11	*7	*7	8	*6	*6	*7	*6	*7	*7	9.4
7.	L.	57	*7	*6	*6	*6	*6	*6	8	*7	*6	8	*6	14	*8	14	*9	7.8
	R.	29	73	14	11	*7	*6	13	*6	*6	12	8	*7	*6	*6	8	*6	12.6
8.	L.	62	*6	*6	*6	*6	*6	*6	*9	9	8	*8	*7	12	*6	13	9	7.8
	R.	17	17	8	*8	*6	*6	*6	*7	*6	*7	*6	*6	*7	10	*6	*6	7.4

Averages—
Trials..L. 75.7 * (Perfect) Trials..L. 11.5 Time..L. 9.
R. 26.2 R. 9.5 R. 14.4

PLATE II
ECONOMY AT 45 DAYS



These results do not present an exhaustive study of economy in retention. In learning, the question of economy has not yet been carried to its limits; and until that time

comes the question of economy in retention must remain more or less suspended. The results of the present experiment show conclusively that of the two distributions here considered, namely, three trials per day and one trial per day, the greater distribution in trials produces the greater economy both in learning and after retention. The totals given in the tables and the curves in the plates only indicate that economy is present; but, as may be expected from any statistical method, they do not give any physiological explanation for the economy itself.

(3) Redintegration After a 30-Day Retention Period

(*a*) *Retention Period for the Maze*

The effects of the respective retention periods of 45 and 70 days, which have been considered in the preceding pages, aid only negatively in the determination of the approximate period during which the maze habit may be retained with a precision approaching that of the norm in learning. No rat, after either of the two retention periods already considered, completed redintegration tests in the learning norm of 15 trials. This would have required a practically perfect retention of the habit and also its perfect exercise in the first six trials of redintegration.

In order to ascertain the approximate period after which integration appears perfect in the redintegration tests, it was determined to experiment with a group of rats by the one trial per day method and try redintegration after a 30-day retention period. With this immediate end in view, two litters, the first of three rats, namely, 1, 2, and 3 in Tables V–A and V–B, and the second of four rats, namely, 4, 5, 6, and 7 in the same tables, were set to learn the maze. All the rats of both litters completed learning and redintegration. The same norm and method was used with this litter as with the groups already considered.

The " error " results of these seven rats are presented in Table V–A, and the trial and time records in Table V–B. In two rats of the seven, redintegration was as good or even better than the learning; while a third rat required but one more trial, or 16. This may be understood more

clearly by reference to Table V–B, records 1 and 6 being perfect in redintegration, while in record 5 the first trial of redintegration was was imperfect, and thus 16 trials were required to complete the series. As individual differences show, it seems quite probable that there are some rats which would never exhibit perfect integration from the very first of the redintegration series of trials even if the learning period were excessively prolonged or the retention period shortened. And, therefore, although redintegration in the other rats of the group did not evidence such perfect retention, the fact that two retained the maze perfectly for 30 days seemed to indicate that this period may be laid down as the approximate maximal period of perfect retention for the maze. This was confirmed by a later experiment.

The records of this group of rats in Tables V–A and V–B will not be considered separately to confirm what

TABLE V–A
30-Day Period. 1 Trial per Day
"Errors" At Turns
Last 25 Trials of Learning; Complete Redintegration

Turn		Start		1		2		3		4		5		6		Total		No. of Trials
		P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M	
Rat 1.	L.		2	2	3		1	6	2	1	4	3	4	1	4	13	20	74
	R.																	15
2.	L.	5	1				1		1							5	3	39
	R.	4			3				5	2						6	8	28
3.	L.	1			1				2			1	1			2	4	47
	R.	4	1		6			1	7	1	1	1	1			7	16	30
4.	L.	4	1	5	4		1	1								10	6	74
	R.		1	5	5	4	1	1	2	4						14	9	29
5.	L.			5	4											5	4	130
	R.	1		2	3				1	1						4	4	16
6.	L.			5	2	1			2							6	4	100
	R.		1		1												2	15
7.	L.	1	3	2	2	2	1	1		2	1					8	7	72
	R.			6	5	2	3	4	2		2	1	2	2	5	15	19	22
Totals Qualit.	L.	11	7	19	16	3	4	8	7	3	5	4	5	1	4	49	48	
	R.	9	3	13	23	6	4	6	17	8	3	2	3	2	5	46	58	
Quant.	L.	18		35		7		15		8		9		5		97		
	R.	12		36		10		23		11		5		7		104		
Aver's.	L.	2.57		5		1		2.14		1.14		1.28		.71		13.84		76.5
	R.	1.71		5.14		1.42		3.45		1.57		0.71		1.		14.85		22.1

TABLE V–B

30-Day Period. 1 Trial per Day

Time in Seconds

		No. of Trials	First 15 Trials of R.; Last 15 Trials of L.															Av.
Rat 1.	L.	74	*15	*13	*11	*11	*10	*14	*16	*19	*15	*10	*13	*16	*13	*16	42	15.6
	R.	15	*13	*11	*11	*9	*11	*13	*14	*22	*8	*8	*8	*11	*9	*7	*8	10.8
2.	L.	39	*6	*6	*8	*7	*6	*7	*6	*6	7	*7	*6	18	*6	31	*7	9.3
	R.	28	35	*7	*7	8	*8	*7	33	21	*7	12	*8	*6	12	12	*7	12.6
3.	L.	47	*7	*6	*7	*9	*6	*7	*7	31	*7	*7	*6	*6	*7	*7	*7	8.4
	R.	30	76	28	11	11	*7	8	*7	*6	*7	16	13	*7	*6	*7	7	14.4
4.	L.	74	*6	*6	*6	*6	*7	*8	*8	190	*7	*13	*8	*9	*13	*12	*16	21
	R.	29	28	16	*20	*19	*14	38	23	*15	27	38	23	*16	*11	30	*11	21.9
5.	L.	130	*11	*19	*9	*12	*11	*13	*10	*12	*10	*11	*8	*9	*8	*9	*10	10.8
	R.	16	12	*7	*11	*8	*7	*6	*7	53	26	*9	24	*11	*8	*6	*6	13.4
6.	L.	100	*9	*11	*8	*8	*8	*9	*8	*8	*9	*10	* 7	17	98	46	17	18.2
	R.	15	*9	*8	*10	*7	*7	*7	*7	*7	*6	*6	*7	66	*7	*15	*17	12.4
7.	L.	72	*7	*7	*7	*6	*6	*7	14	*7	*8	66	255	36	57	35	*14	35.4
	R.	22	197	27	63	*13	255	*15	49	*23	*16	*8	*10	*12	*12	*10	*10	48

Averages—
Trials...L 76.5 * (Perfect) Trials..L. 12.7 Time..L. 16.9
R. 22.1 R. 10.2 R. 19.

has already been proven concerning dominant "error," but will be used as a norm for comparison with a second group, at 30-day retention, which will be taken up now.

(*b*) *Influence of Learning a New Problem during the Retention Period*

This group was undertaken with the view of obtaining some light in regard to the effect of the acquirement of a new habit on the retention and redintegration of a habit already acquired. The group comprised two litters, the first of three rats, 1, 2, and 3, respectively, and the second of seven rats, 4, 5, 6, 7, 8, 9, and 10, respectively, in Tables VI–A and VI–B. Rat 3 of litter 1 failed to complete redintegration, while rat 10 of litter 2 died before completing retention. Each litter was set to learn the maze by the one trial per day method. The object of the present problem required that at the beginning of the retention period, instead of following the method of exercise in the runway during retention, each rat was to begin the learning of a new problem. This new problem was the "rope-ladder" problem. As the name suggests, it was constructed of first, a rope about 1 cm. in thickness and 93 cm. in

length, fixed at one end to a broad topped upright, 46 cm. in height, from which the rat started; and at the other end to a second upright of the same height as the first. From the second upright, a ladder, 87 cm. in length and 8 cm. in width, with rope sides and wooden crosspieces, extended upwards at an angle of approximately 45 degrees to third upright 100 cm. in height, where food was placed as the incentive. The pathway was approximately 190 cm. in entire length. The learning of the rope ladder is of little concern to us here. Suffice it to say that the integration of movements required in running the rope and ladder in succession and maintaining equilibrium on them was difficult to acquire. No single rat of the group under consideration learned this problem perfectly in the 30-day retention period allowed.

At the end of the retention period the rats were not given preliminary feeding in the center of the maze but were put directly into the starting box of the maze and the first trial of redintegration was made. Thus it is to be noted that with this group the former norm and method was followed with the single exception that the learning of a new problem during the retention period took the place of daily exercise.

Tables VI–A and VI–B contain the complete records of this group. In Table VI–A, the last 25 trials of learning are compared with redintegration totals as is the case in Table V–A. The compilation of Tables VI–B and V–B was made in the same manner as the earlier tables of this nature. Coming to a consideration of the results of the present group, Table VI–A, compared with the records of the norm group at 30 days' retention, contained in Table V–A, it is evident that there is no increase in number of " errors " in redintegration with the group learning a new problem during retention, over that of the norm. In fact the number of " errors " in redintegration in Table VI–A is the lesser, relative to the learning total, while the number of " errors " in redintegration in Table V–A is the greater, relative to the learning total. In Tables V–B and VI–B, it may be seen that the learning of the new problem in the retention period has not interfered in point

TABLE VI-A

1 Trial per Day

30-Day Period, During Which A New Problem Was Learned

"Errors" At Turns

Last 25 Trials of Learning; Complete Redintegration

Turn		Start		1		2		3		4		5		6		Total		No. of Trials
		P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M	
Rat 1.	L.				4	1			1							1	5	114
	R.			1	1	1			2							2	3	21
2.	L.	1			4		1			1						2	6	106
	R.		1		2	2			3	5				1	1	8	7	15
*4.	L.	3		1	2								1			4	3	74
	R.																	.15
5.	L.	1		2	3		1									3	4	65
	R.								1								1	10
6.	L.	1		1	1	2										4	1	61
	R.	1		2	4											3	4	16
7.	L.		1	4	6	1	1	1	5						1	6	13	69
	R.	1			1			1	1							2	2	16
8.	L.	1	2		4			1	1	3				2	1	7	8	68
	R.		1	1												1	1	16
9.	L.	2			1				1							2	2	56
	R.	3		3	3			1	5	4	4	3	2	5	3	19	17	29
Totals Qualit.	L.	9	3	8	25	4	3	2	8	4			1	2	2	29	42	
	R.	5	2	7	11	3		2	12	9	4	3	2	6	4	35	35	
Quant.	L.	12		33		7		10		4		1		4		71		
	R.	7		18		3		14		13		5		10		70		
Aver's.	L.	1.5		4.12		0.67		1.25		0.50		0.12		0.50		8.87		
	R.	.87		2.25		.37		1.75		1.62		.62		1.25		8.75		

*3 Omitted, due to incomplete records of "errors" in learning.

of trials, nor in average number of perfect trials, nor in speed of movement. On the contrary, it seems from the results that the rats have been benefited in retention by the learning of the new problem during the retention period. A summary of these conclusions is presented in Plate III, the curves of which are constructed from the data in the four tables of the two groups under consideration. The norm group, according to these curves, is inferior to the group which learned a new problem during the retention period.

In considering the results of the present experiment where a new problem was learned during the retention period, there is on the one hand the fact that at the be-

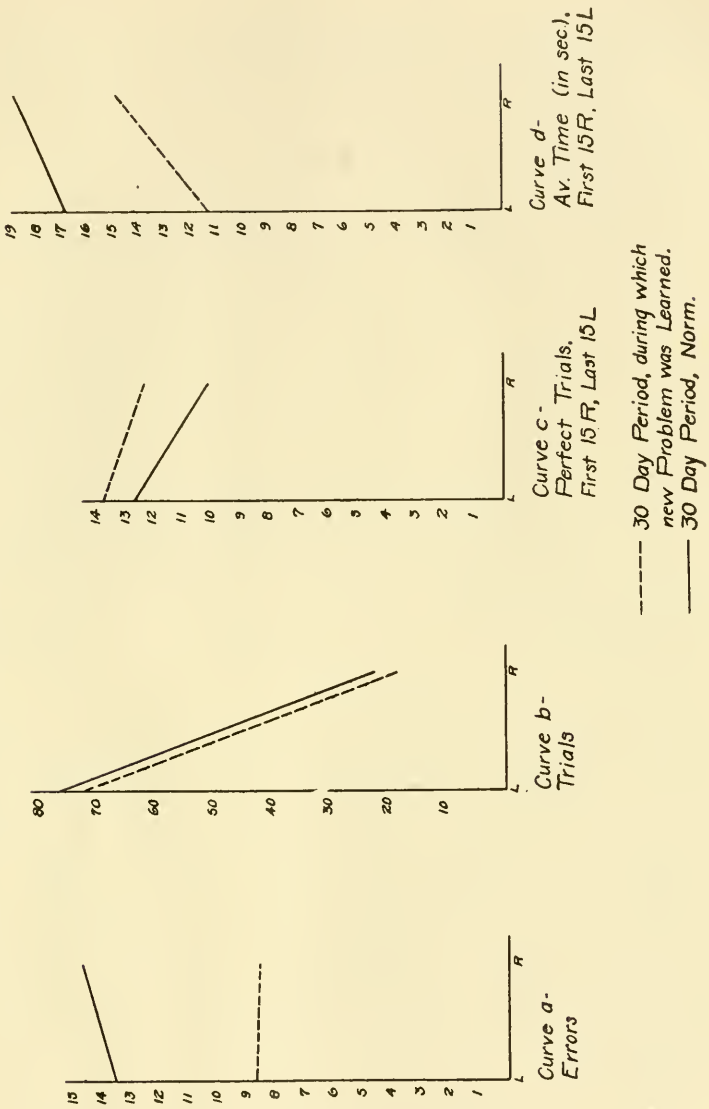


PLATE III
INFLUENCE OF LEARNING A NEW PROBLEM
DURING RETENTION PERIOD

ginning of such an experiment the ordinary working hypothesis would tend to anticipate the appearance of an adverse effect in redintegration. While on the other hand the fact is presented by the results, as stated above, that a greater number of the individuals of the group which

TABLE VI-B

1 Trial per Day

30-Day Period, During Which A New Problem Was Learned

Time in Seconds

No. of Trials			First 15 Trials of R.; Last 15 Trials of L.															Av.
Rat 1.	L.	114	*9	*15	*11	*14	*9	*9	*12	*11	*11	*12	*10	*12	54	*10	*21	14.6
	R.	21	35	*9	*8	*8	35	17	*12	*11	*9	*12	*11	*14	14	*7	*8	14.
2.	L.	106	*7	*7	*7	*7	*7	*8	8	*7	36	*9	*7	*9	*7	*7	16	9.9
	R.	15	*20	*8	*8	*8	*8	*12	53	21	*10	16	36	15	17	*9	*10	16.6
3.	L.	48	*6	*6	*7	*6	*6	*6	*6	*6	*6	13	*7	*7	*6	*6	*6	6.6
	R.	16	14	*6	*7	*7	*9	*6	*6	*6	*7	*7	*6	*6	*6	*6	*6	7.
4.	L.	74	*7	*7	*8	*6	*7	*7	17	*7	*6	*6	*6	*7	*6	24	*16	8.4
	R.	15	*10	*7	*6	*7	*10	*8	*6	*7	*8	*8	*7	*9	*7	*7	*9	7.7
5.	L.	65	*8	*7	*8	*8	*11	*7	*8	*6	*12	*11	*10	13	*7	*10	*7	8.8
	R.	19	*9	*9	*8	20	*8	*7	*7	*6	*8	*8	*7	*6	*8	*7	*7	8.3
6.	L.	61	*11	*7	*7	*8	*8	*7	*8	*7	*7	*7	*7	*7	*6	*7	*9	7.5
	R.	16	27	*7	*7	*7	*8	*7	*7	*7	*7	*6	*7	*8	*6	*6	*7	8.2
7.	L.	62	*11	*8	*12	*13	*15	*9	*10	*20	*18	*9	*8	*11	*9	*9	*20	12.3
	R.	16	46	*11	*7	*9	*8	*10	*7	*7	*7	*7	*9	*6	14	*6	*7	10.7
8.	L.	68	*47	*22	*22	*11	*21	*14	*10	*39	*14	*38	*19	*15	61	*29	*17	25.6
	R.	16	44	*10	*13	*11	*11	*9	*19	*9	*12	*11	*13	*14	*10	*10	*8	13.6
9.	L.	56	*8	*8	*8	*7	*7	*8	*7	*7	*8	*8	*8	*8	*9	13	*14	8.6
	R.	29	*13	12	11	15	*7	*9	*14	347	249	*19	*18	*9	*10	11	*8	50.1

Averages—
Trials..L. 72.6 * Trials..L. 13.8 Time..L. 11.3
R. 18.1 R. 12.4 R. 15.1

learned a new problem during retention were more nearly perfect in redintegration than of the group which represented the norm. The learning of the rope-ladder problem, in this instance, has not interfered with the retention of the acquired habit, and it would seem that no interference would result from the learning of any similar problem during the retention period. There is a possibility, however, that some problem different in nature from that of the rope ladder, and more difficult in point of the establishment of integrations may be detrimental to the retention of the maze habit. But this can be proven only by further experiment.

(c) *Influence of Incomplete Learning*

The individuals of every group already considered have completed learning and redintegration according to the standard norm of fifteen trials, as already explained. Although, according to this norm, any of the last nine trials

may or may not have exhibited perfect integration, yet it was necessary for each individual to have exhibited perfect integration of movement in at least the first six trials of the norm. From these facts it is evident that although at the end of the fifteen trials of the norm it is possible that no two individuals began retention with the necessary integrations established in the same degree of precision, yet all acquired the habit, as was shown in the first six perfect trials of the norm, and all underwent experiment according to the same standard.

Experiments with the present group of rats were undertaken in the attempt to ascertain some influence of incomplete learning on redintegration after retention. Two litters composed of five rats each were chosen for the present work and set to learn the maze by the one trial per day method. The standard norm and methods were applied to both litters, except that when the norm of fifteen trials had been completed by the first rat of each litter the whole litter was put on retention regardless of how far the learning had progressed with the remaining four rats. The same method was employed in redintegration.

Tables VII–A and VII–B contain the records of these two litters in "errors," trials, and time. In Table VII–B it may be seen that, in litter 1, rat 5 was the first to complete learning, in 33 trials; but in redintegration, rat 2 was the first to finish, in 15 trials. In litter 2, rat 9 was the first to finish learning, in 25 trials; but in redintegration, rat 10 was the first to finish, in 15 trials. At first sight it may appear somewhat questionable that in both cases cited the individual which finished first in learning according to the norm did not finish first in redintegration. But this fact simply points out that the rat which learned the problem first according to the norm seems not to have been the one which had most firmly established integration during learning, and hence was not the best in redintegration. The apparent discrepancy in the redintegration records must be solved, at least in part, from the records of the learning.

Considering first the learning of litter 1, in Table VII–B (supplement), it may be seen, first, that three rats of the

TABLE VII–A

30-Day Period. 1 Trial per Day

Norm: When The First Rat Finished

"Errors" At Turns

Last 15 Trials of Learning; Complete Redintegration

	Start		1		2		3		4		5		6		Total	
Litter 1. .	P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M
Rat 1. L.	2			3		1		4	1						3	8
R.						1	1	1	1						2	2
2. L.	1			1											1	1
*R.					1	1									1	1
3. L.		2		2												4
R.	1			1				1	1						2	2
4. L.		8	2	2	1										3	10
R.		1		2	1	1		2	1						2	6
5. *L.		1					1	1							1	2
R.		2	1					1							1	3
Litter 2.																
6. L.		7	1	3			1								2	10
R.		7														7
7. L.	1	1		2	3			2	4	3	2				10	8
R.				2	1										1	2
8. L.		6	4	1	1	1									5	8
R.																
9. *L.												1				1
R.			1												1	
10. L.		7		3				4								14
*R.																
Totals																
Quant. L.	4	32	7	17	5	2	2	11	6	3	2	1			26	66
R.	1	10	2	5	3	3	1	5	2						9	23
Quant. L.	36		24		7		13		9		3				92	
R.	11		7		6		6		2						32	
Aver's. L.	3.6		2.4		.7		1.3		.9		.3				9.2	
R.	1.1		.7		.6		.6		.2						2.3	

* First to complete norm.

five had 13 perfect trials in the last 15 trials of learning; second, that rat 2 is the best in redintegration in point of perfect trials; and finally that rat 5 is the only rat which did not make as many or more perfect trials in redintegration as in learning. It may be inferred from these facts that, first, either rat 5 did not retain as well as the other rats due to innate constitution, to some metabolic distrubance during retention, or to some extraneous disturbance; or second, at that particular time, when rat 5 completed the norm of learning, perfect integration was

TABLE VII-B
30-Day Period. 1 Trial per Day
Norm: When the First Rat Finished
Time in Seconds

No. of Trials		First 15 Trials of R; Last 15 Trials of L.															Av.
Litter																	
Rat 1. L.		10	*8	*7	*7	12	10	*7	7	12	13	*7	*9	8	*7	*7	8.73
R.		*11	*12	*7	*7	*8	9	*8	*7	*6	*6	9	*6	10	*8	*8	8.13
2. L.		*6	*6	*6	*6	10	*7	*7	*6	6	*6	*6	*6	*6	*6	*6	6.4
**R.	15	*20	*7	*7	*10	*9	*9	15	*7	*6	*7	*6	*6	*6	*7	*6	8.53
3. L.		15	*6	*6	*6	*6	*6	*6	*6	*6	*6	*6	*6	*6	*6	*6	6.66
R.		20	*40	*11	*13	*7	*7	18	*7	*6	*7	*7	*6	*6	*6	*6	9.8
4. L.		*6	9	10	*8	*6	10	15	25	15	*9	*7	*7	15	92	*10	16.26
R.		51	11	*8	*11	*8	*7	27	*8	*7	*7	*7	*6	8	13	*7	12.4
**5. L.	33	*7	*7	*7	*7	*6	*8	*7	*6	*7	12	*7	*7	8	*7	*6	7.93
R.		17	*7	9	*10	*8	10	*8	*8	*7	*7	*6	*6	*6	*6	*7	8.13
Litter 2.																	
6. L.		17	26	*6	*6	9	8	*7	8	*6	*7	10	*6	*6	9	9	9.33
R.		18	*9	*8	*7	*7	*9	*7	8	16	10	9	*7	11	9	*7	9.46
7. L.		15	*6	*8	46	*24	14	*12	36	55	47	74	*27	72	65	29	35.33
R.		16	*11	14	*10	*10	*9	*8	14	*9	*9	*7	*7	*6	*6	*7	9.53
8. L.		13	9	9	11	9	8	13	21	17	*8	*7	*7	*6	10	*9	10.46
R.		8	*7	*7	*6	*6	*7	*6	*7	*6	*6	*6	*6	*6	*6	*6	6.4
**9. L.	25	*11	*10	*6	*8	*7	*6	*9	9	*12	*8	*11	*7	*12	*12	*20	9.83
R.		*9	*7	15	*6	*7	*6	*6	*11	*6	*6	*7	*6	*6	*8	*7	7.53
10. L.		27	15	*7	*10	29	21	42	47	*4	17	22	*9	*9	*17	*14	20
**R.	15	*14	*7	*12	*9	*11	*9	*9	*10	*6	*7	*7	*6	*6	*8	*7	8.53

**First to complete norm. Av. * Trials..L. 9.3 Av. Time per Trial..L. 13.09
R. 12.4 R. 8.84

Supplement.—No. of * Trials

Litter 1. Rat—	1.	2.	3.	4.	5.	Litter 2. Rat—	6.	7.	8.	9.	10.
L.	8	13	13	7	13	L.	7	5	5	14	7
R.	12	14	13	10	12	R.	8	12	14	14	15

not as firmly established in this rat as it may have been in rat 2 and, as a consequence, rat 2 would be more likely to exhibit perfect integration than rat 5. Although it is possible that the first inference may be a fact, there is no data at hand to prove it, while there is some proof in Table VII-B in favor of the second view. Thus it may be noted that the last trials of learning in the records of rat 2 show perfect integration and maximum speed. There is no other record at this particular time in the learning which shows so much evidence in favor of the inference that at the end of the norm perfect integration at the locus of dominant " error " was more firmly established in any other rat than in rat 2. Metabolism, extraneous

disturbances, and innate constitution may have had some influence in the retention, but as already stated there are no means at hand to prove their influence in the present case.

The redintegration records of rats 1 and 4 could almost be taken as a direct continuation of the learning, were it not known that retention had intervened; redintegration was practically perfect for both these rats but the norm in both cases had not been reached. The redintegration of rat 3 is rather difficult to explain when compared with the learning. It appears that the habit had been fairly well established, excepting the "error" in the next to the last trial; and thus it seems that the evidence in this case, more so than in any other yet treated, points to poor retention on the part of the organism.

In litter 2 (Table VII–B), the final records of learning in rats 9 and 10 show that the integrations had been more or less firmly established by both rats at the completion of the norm. In the first two trials of redintegration the records of both rats, in integration of movement as well as speed, are equal if not superior to their records in the last few trials of learning. Rat 10 continued the perfect exercise of the habit throughout redintegration, but rat 9 in trial three of redintegration exhibited in alley 2 imperfect integration, due to an extraneous disturbance. Had it not been for this disturbance, it seems most likely that rat 9 would have had a perfect redintegration, as is credited to rat 10. Rats 9 and 10 both had the habit firmly established at the beginning of retention. Rats 6, 7, and 8, as those of a similar status in litter 1, had not firmly established integration, but retained the habit so that it was exercised as well after 30 days' retention as when learning ceased. This was likewise found true of rats 1 and 4 in litter 1, and to a somewhat less degree in rat 3.

It may be concluded from this experiment that in most cases, and under ordinary circumstances, the better established is integration in the organism when the learning ceases and the retention period begins the better will be the redintegration.

(4) *Influence of Previous Training at* 45-*Day Retention Period*

As a final experiment in retention on the maze, it was decided to give a group of rats some definite preliminary training before setting them to learn the maze. Following this plan two litters of six and four rats, respectively, were set first to learn the inclined-plane problem. (This problem is treated more fully on page 48, and for this reason it will not be considered here in detail. Only the important points of all preliminary training will be mentioned.) Rats 1, 2, 3, 5, 7, and 9 comprise the litter of six; 4, 6, 8, and 10 the litter of four. Rats 5 and 7 of the litter of six and rat 10 of the litter of four failed to complete the whole experiment. Concerning the remaining rats, 1, 2, 3, 4, 6, 8, and 9, it is a fact of importance here to note that three—rats 2, 3, and 4—failed to solve the inclined plane once after fifteen successive days. This point of information is mentioned here specifically to show that the rats used in this experiment were far from being above the average; in fact, if we may judge from the above fact, they were below the average, because the percentage of failures on the inclined plane is usually low.

At the completion of the inclined-plane problem, a definite period of 70 days was allowed to elapse in the case of each rat before the maze was begun. The last 3 days of the 70-day period was used to test the redintegration of each rat on the inclined plane. During the 70-day period each rat was required to continue the learning of one or more problems, the rope-ladder problem being first, and the sawdust box second. The sawdust box was a problem which necessitated the digging of a tunnel through the sawdust before the rat could reach its food.

Following the usual method, at the completion of a problem each rat was fed in the next problem for four days to accustom it to the environment. Rats 1 and 4 failed to establish perfect integration on the rope ladder, but rats 2, 3, 4, 8, and 9 had learned the rope ladder and had begun the learning of the sawdust box when the respective dates for their preliminary training had ended. Rats 1, 6, 8, and 9 which had learned the inclined plane were then tested in redintegration on the plane, while

the other rats continued the learning of their respective problem until the end of the 70-day period. At the completion of all this preliminary training, each rat was fed for four days in the center of the maze, and the methods of learning, retention, and redintegration, as originally described in the chapter on methods, were carried out. The same norm was also applied in learning and redintegration.

Tables VIII–A and VIII–B contain the records for this group of rats. For the sake of comparison a summary of the records of the rats in Tables IV–A and IV–C are given, and also a summary of the records of Table V–C, but not of Table V–A, owing to the fact that the records of "errors" in this table are not sufficiently complete to allow comparison with the present group. These tables

TABLE VIII–A

45-Day Period. 1 Trial per Day

"Errors" At Turns

With Previous Problems.*

From 15th Trial of Learning; Complete Redintegration.

Turn		Start		1		2		3		4		5		6		Total		No. of Trials
		P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M	
Rat 1.	L.	2							2							2	2	38
	R.			1					3								4	17
2.	L.									5						5		29
	R.					1		1		4						6		15
3.	L.	2		1												2	3	34
	R.	11					1		2							1	1	15
4.	L.	7		3		4	1		9	1						12	13	64
	R.			1					1	3						3	2	20
6.	L.		1						2								3	40
	R.	1		2												1	2	16
8.	L.	1		5					3	5			2	3	3	9	13	58
	R.								1		1						2	18
9.	L.	1		1		1			5	3						5	6	39
	R.								3	1						1	3	24
Totals Qualit.	L.	13	1	10		5	1		23	14			2	3	3	35	40	
	R.	2		4		1	1	1	8	8	1					12	14	
Quant.	L.	14		10		6		23		14		2		6		75		
	R.	2		4		2		9		9						26		
Aver's.	L.	2		1.4		.85		3.28		2.		.28		.85		10.7		43.1
	R.		.28		.55		.28		1.28		1.28					3.7		17.8

(IV–A, IV–C, and V–C) contain the records of rats at the 45-day retention period, and also at the 30-day retention period, hence afford a norm both of learning and

"ERROR" TOTALS FROM TABLE IV–A
45-DAY PERIOD. 1 TRIAL PER DAY
From 15th Trial of Learning; Complete Redintegration

Totals		P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M	
Qualit.	L.	114	92	32	50	16	13	7	53	26	3		2	5	4	200	217	
	R.	20	6	8	15	6	6	4	13	3	2		3		1	41	46	
Quant.	L.	206		82		29		60		29		2		9		417		
	R.	26		23		12		17		5		3		1		87		
Aver's.	L.	29.4		11.7		4.1		8.5		4.1		.28		1.2		59.5		75.7
	R.	3.7		3.2		1.7		2.4		.7		.42		.14		12.4		26.2

*All individuals of this group learned the inclined plane first. After this problem a 70-day period was allowed to elapse, when the maze was begun. During the 70-day period each rat was required to learn one or more new problems, the rope ladder being first, the sawdust box second. During the 45-day period after the learning of the maze, the rats were exercised in the runway, as outlined in the chapter on methods.

TABLE VIII–B

45-DAY PERIOD. 1 TRIAL PER DAY
WITH PREVIOUS PROBLEMS
TIME IN SECONDS

		No. of Trials	First 15 Trials of R.; Last 15 Trials of L.															Av.
Rat 1.	L.	38	*10	*8	*7	*8	*7	*7	*8	9	*7	*7	*9	*8	*8	*7	*8	7.86
	R.	17	11	*9	*7	*6	*7	*7	*7	*7	*8	*8	*8	*7	*8	*10	*7	8.
2.	L.	29	*10	*10	*10	*11	*9	*17	*8	*10	*9	*8	*9	*16	10	*8	*9	10.27
	R.	15	*20	*10	*8	*8	*9	*9	*8	*7	*9	*8	*8	8	12	*8	*8	9.33
3.	L.	34	*7	*6	*7	*7	*7	*7	*8	*7	*7	*7	9	7	*8	*7	*7	7.2
	R.	15	*8	*7	*7	*6	*9	*7	8	*6	*7	*7	*7	*7	*7	*7	*7	7.13
4.	L.	64	*9	*9	*9	*9	*9	*8	*9	*8	*8	*9	*7	*7	10	*8	*9	8.53
	R.	20	46	*8	*8	*8	14	*9	*8	*8	*8	*8	*8	*9	*8	*8	*8	11.06
6.	L.	40	*7	*7	*7	*7	*7	*7	*7	*6	*7	*8	*7	*7	*7	*7	*7	7.
	R.	16	15	*7	*6	*6	*7	*7	*6	*7	*8	*6	*7	13	*7	*7	*8	7.8
8.	L.	58	*9	*9	*8	*9	*8	*7	*9	*9	*9	*9	*10	*8	*8	*8	*9	8.6
	R.	18	*9	*8	25	*9	*8	*12	*10	*15	*8	*8	*7	*8	*7	*6	*7	9.7
9.	L.	39	*8	*7	*9	*8	*8	*6	*7	*7	*7	*7	*7	*8	*8	*8	*8	7.53
	R.	24	*11	14	*8	*7	9	*8	*7	*7	10	*7	*12	*8	*7	*7	*8	8.66

Averages—
Trials..L...43.1 Av. * Trials..L. 14.2 Av. Time per Trial..L. 8.14
R. 17.8 R. 13.4 R. 8.81

FROM TABLE IV–C
45-DAY PERIOD. 1 TRIAL PER DAY

Averages—
Trials..L. 75.7 Av. * Trials..L. 10.5 Av. Time per Trial..L. 9.02
R. 26.2 R. 9.55 R. 14.42

FROM TABLE V–C

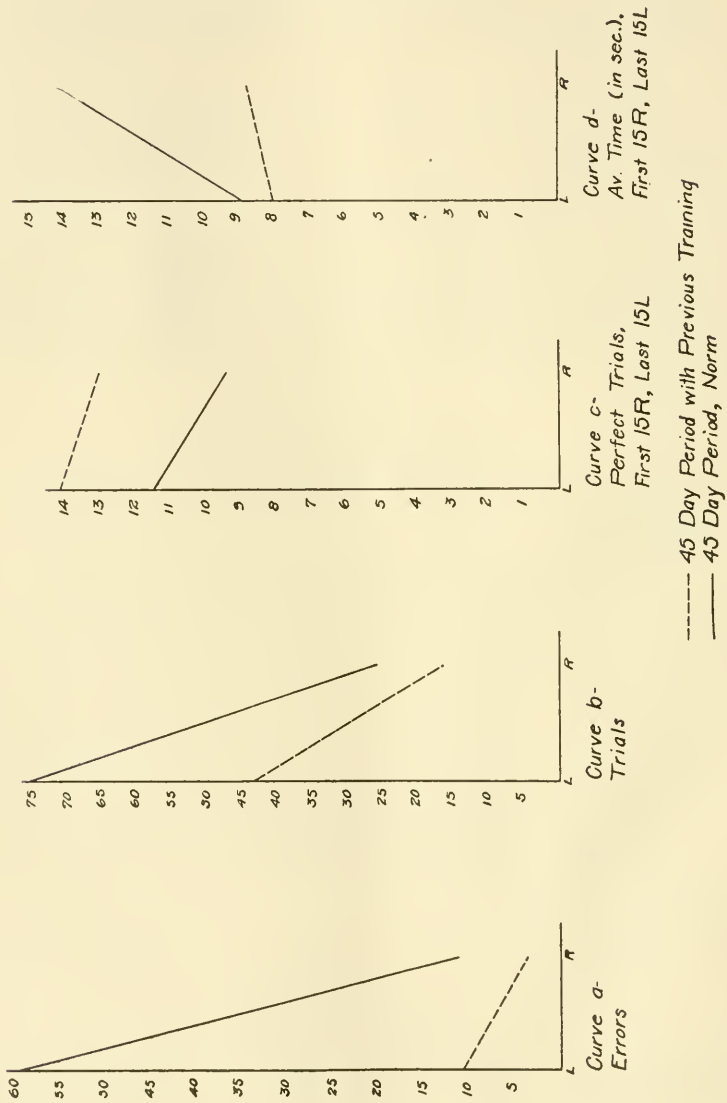
30-DAY PERIOD. 1 TRIAL PER DAY

Averages—

Trials..L. 76.5	Av. * Trials..L. 12.7	Av. Time per Trial..L. 16
R. 22.1	R. 10.2	R. 19.

PLATE IV

INFLUENCE OF PREVIOUS TRAINING



redintegration by which results of the group under consideration may be judged. A summary of the results of the present group and the 45-day norm group is contained in Plate IV.

In considering results, it may be noted particularly that in the learning records of the rats of the present group which had previous training, the average " errors " show that this group had far fewer " errors " than the 45-day norm group; and this fact follows with consistency in redintegration. It is evident in the comparison of Tables VIII–B with Tables IV–C and V–C that the learning of the rats with previous problems was complete in far fewer trials than the norm, one trial per day group. And in redintegration the average number of trials of the group under consideration is not only less than the 45-day norm group but less than that of the group with 30-day retention. In average perfect trials and in average time per trial the superiority of the group with previous training is shown not only in learning but also in redintegration; and further, what is most significant, the superiority holds in this in-instance, not only in comparison with the 45-day norm but also with the group at 30 days.

In considering the individual records the fact is brought out that the approximate retention period for the maze is increased in the group with previous training. This may be seen when one notes that of the group with previous training there were two perfect records in redintegration, as recorded in Table VIII–B, while not one is recorded perfect in Table IV–C of the group without previous training. A further fact is evident, namely, that after the retention period of the individuals with previous training, the best individual record is far superior to any record of the norm group and equal to the best of the group with 30-day retention period, while the poorest record of the group with previous training is superior to the majority of the records of the 45-day norm group and some of the records of the 30-day group.

From the results of these tables the facts are thus established: First, for learning, that previous training so affects the rat that the subsequent acquirement of a new

habit is less difficult; second, there are fewer "errors" in the learning, and integrations are more readily established. As a consequence, redintegration must necessarily be improved. In other words, when a rat has passed through a relatively long period, acquiring integrations, and then is set to learn a standard problem, the process of learnng the integrations necessary for this problem will proceed with much more rapidity than with the rat that has had no previous training, and the redintegration as a consequence will be better than with the untrained rat, not because of better retention—for retention is probably, not bettered by learning—but because of the fact that the learning is better than ordinary.

(5) *Inclined Plane*

The standard norm and methods which were described in the foregoing experiments on the maze were adopted for the present experiment. These comprise the feeding of the respective groups in the problem for a half hour on each of four days preceding the first day of learning, the exercise in the runway each day during the retention period, and the requirement of the fifteen-trial norm, the first six trials of which must be perfect. Three seconds is the usual time set for the exercise of the habit in the present problem, but this time norm was not rigidly adhered to, the same flexibility being allowed as in the maze, providing that perfect integration of movement was exhibited.

The inclined plane (Fig. III) was a problem made up essentially of a box to which access was gained through a small door that opened on the pressing down of an inclined plane located at the rear of the box. The inclined-plane box was 25 cm. square. In the lower center of one side of the box was a door, 11.2 cm. square. The box and also the door was covered with wire netting of 1 cm. mesh. A solenoid coil was so placed above the door that its armature projected approximately 0.3 cm. over the edge of the door, holding the door shut against the force of a small spiral spring. The plane itself was 7.5 cm. long, 4.5 cm. wide, and was hinged to the plate beneath, which was in

turn imbedded in the base of the problem. The plane was raised at an angle 15 degrees, approximately, and was held in this position by means of a spring beneath. The weight of a rat stepping on the plane was sufficient to force the plane down far enough that a contact would be made under the plane, thereby raising the armature in the solenoid coil and the door would open inward. The plane and plate were constructed of aluminum but were

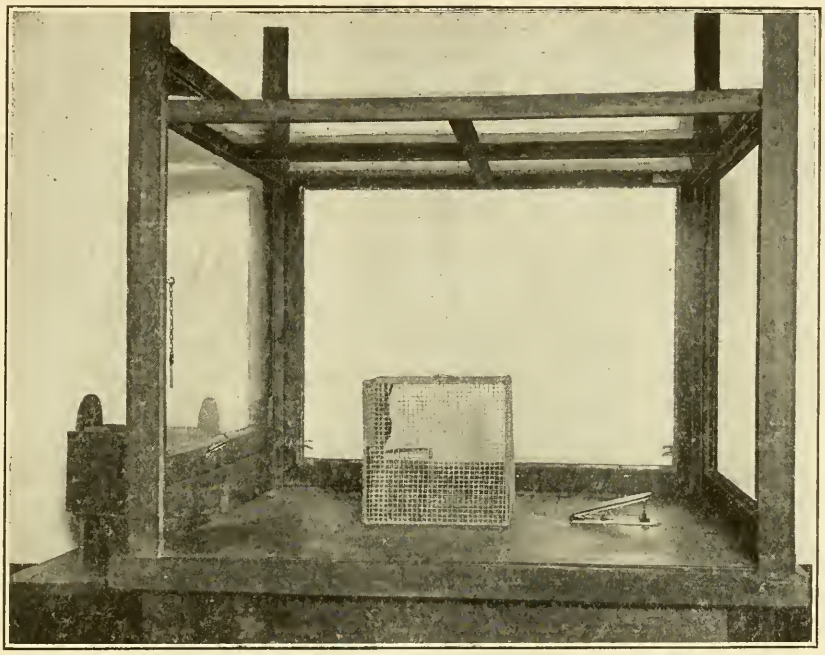


FIGURE III

insulated by wood fiber. The plane was located 12 cm. behind the problem box.

The plane and box were placed on a base 92 cm. square, inside measurement, and were covered by a glass top, 68 cm. from the base, and glass sides in a wooden framework. The object of the glass sides was to prevent excess waste of movement and effort which always occurs in problem boxes with a mesh covering. Because the glass sides limited the rat's activities to the floor of the problem box, there resulted a greater conservation of movement

and effort, and concentration of these on the problem itself. The glass sides were firmly fixed in grooved wooden uprights located at each of the four corners of the base of the problem box. They could easily be slid upward, and access readily gained to the problem box within. The entrance to the problem box was located at a distance of 28 cm. directly in front of the door of the inclined-plane box. This entrance box was constructed of wood with a wire-mesh top.

In the learning of the inclined plane-problem the behavior of the rat appeared more complex than in the learning of the maze. This point is well worthy of notice. The present problem is one requiring a habit of manipulation to solve it, while the maze evokes a general motor habit. Motor habits are in general the simplest habits in the entire repertoire of the rat's movements, while habits of manipulation require more complex integrations of movement in their process of establishment. The maze evokes a habit requiring the integrating of movements of running in a certain direction and turning the whole body at certain intervals in response to the environment. The inclined plane likewise calls forth the motor movements of running and turning the body at certain stages; but it calls forth the additional integration of certain definitely adjusted movements of the body and particularly the forelimbs in the pressing down of the inclined plane. Simpler methods of pressing down the plane may be used, such as stepping on the plane in running over it; but the method of pressing down the plane with the forelimbs is the most satisfactory. Although these movements may be included under motor movements in the widest sense, yet they are movements of manipulation in the strict sense and are much more complex and difficult of adjustment than the movements of running, etc. Thus the establishment of integration in the learning of the inclined plane is much more difficult than the establishment of integrations in the learning of the maze.

As in the first trial on most new problems, the rat usually entered slowly and investigated every accessible place in the problem. If it so occurred that in the first trial the rat

stepped on the plane and thus opened the door to the food, this action may be said to have been a response to the stimuli which the plane presented to the rat and no more a matter of chance than the walking of the rat in any other part of the inclosed area. Similarly in the first few trials the solution of the problem can neither be attributed to chance on the one hand nor to any established integration on the other. Gradually, at approximately the 8th or 9th trial, response to the plane became established as the stimulus to the successive integration of going direct to the food box. Whether the establishment of the integration—going to the plane preceded the establishment of the integration—coming from the plane to the door of the food box can not be definitely stated. But the fact is certain that these integrations as a whole comprised the first part of the learning, while the linking of the two by the establishment of the integration of pushing

The most difficult integration to acquire in the learning, and likewise the redintegration of the inclined plane, is that of pushing down the plane. Invariably this movement appears to be what has been already designated as the "weak link" in the chain which constitutes the successive integrations of the habit. When the integrations of this movement are beginning to be established, and when precision of movement first appears in the pushing down of the plane, it may then be observed that the learning of the problem has been delayed by this difficulty of pushing down the plane. The mass of qualitative data on the learning of the plane problem confirm these facts. In redintegration a similar situation presents itself. All responses which the problem calls forth may be exhibited on the first trial of redintegration, but frequently the stepping on the plane is imperfectly integrated and the habit can not be perfectly exercised. And, therefore, a confirmation is here found for the results which were noted in the study of the maze, namely, dominant "error" appears in the process of learning and also in redintegration.

Dominant "error" and imperfect integration can not be shown in tabulated form for the inclined plane as they were shown for the maze. But Table IX, of the three

trials per day group, and Table X, of the one trial per day group, presenting records of time, will serve to indicate to some extent the effect which was produced by the difficulty of establishing integration at the locus of dominant "error." Each table presents the complete time records of three rats, the first three columns (a, b, and c) containing records of the poorest individual of the group, the second three columns containing records of the best, and the last three columns containing records of the second best. In the respective columns, records 2, 4, and 8 in Table IX correspond to records 2, 4, and 8 in Table XI; records 5, 9, and 8 in Table X correspond to records 5, 9, and 8 in Table XII. Column "a" presents time in seconds from the moment the rat entered the problem until it stepped on the plane; column " b " presents time in seconds from the moment the rat stepped on the plane until it entered the food box; and column "c" is the total time. The effect of the dominant " error " may be seen in column "a" where the time is considerably greater than in column " b." The distance from the entrance of the problem to the plane is approximately equal to the distance from the plane to the entrance of the food box; or, in other words, the distance the rat must cover to produce the time of column "a" is approximately equal to the distance the rat must cover to produce the time in column " b." But the rat must exercise the integration of stepping on the plane before the time of column "a" is recorded; and the difficulty of exercising this integration of stepping on the plane frequently called forth such responses as merely touching the plane, going round the plane, etc., which greatly increased the time of column " a." These records of time thus give some intimation that the locus of dominant " error " is at the plane.

Table XI contains perfect trials and time in the first fifteen trials of redintegration and the last fifteen trials of learning for the three trials per day group at the 70-day retention period. Table XII contains a like summary for the one trial per day group at the 70-day retention period. One rat of each group failed to complete learning; and three of each group failed to begin the norm in redintegration within 30 trials. According to these tables the averages

TABLE IX
70-Day Period. 3 Trials per Day
Time in Seconds.

Rat—	8			2				4			
Trial	a	b	c	Trial	a	b	c	Trial	a	b	c
1	632	40	672	1	380	38	418	1	364	108	472
2	1800			2	181	14	195	2	16	58	74
3				3	54	9	63	3	158	59	217
4	848	39	887	4	136	6	142	4	193	14	207
5	1800			5	149	6	155	5	150	25	175
6				6	30	3	33	6	309	36	345
7	1800			7	68	4	72	7	100	19	119
8				8	12	2	16	8	122	10	132
9				9	4	3	7	9	291	15	306
10	1098	86	1184	10	15	4	19	10	81	10	91
11	123	16	139	11	42	2	44	11	50	8	58
12	123	13	136	12	16	2	18	12	33	7	40
13	1546	25	1571	13	5	2	7	13	74	5	79
14	616	5	621	14	2	2	4	14	19	5	24
15	576	14	590	15	2	1	3	15	41	6	47
16	146	10	156	16	8	2	10	16	31	5	36
17	55	4	59	17	2	1	3	17	34	4	38
18	24	7	31	18	11	1	12	18	9	3	12
19	7	9	16	19	8	2	10	19	20	4	24
20	24	3	27	20	2	1	3	20	16	2	18
21	218	5	223	21	6	1	7	21	27	9	36
22	570	6	576	22	14	1	15	22	14	3	17
23	38	4	42	23	2	1	3	23	35	4	39
24	18	3	21	24	2	1	3	24	31	7	38
25	69	3	72	25	2	1	3	25	16	5	21
26	25	11	36	26	1	1	2	26	2	2	4
27	14	5	19	27	1	1	2	27	12	4	16
28	4	3	7	28	2	1	3	28	2	6	8
29	4	2	6	29	3	1	4	29	6	5	11
30	5	2	7	30	2	1	3	30	7	2	9
31	32	4	36	31	2	1	3	31	15	4	19
32	3	2	5	32	1	1	2	32	10	3	13
33	2	2	4	33	1	1	2	33	2	6	8
34	57	2	59	34	9	1	10	34	22	2	4
35	2	1	3	35	2	1	3	35	2	1	3
36	3	2	5	36	2	1	3	36	2	1	3
37	4	4	8	37	8	1	9	37	19	10	29
38	12	9	21	REDINTEGRATION				38	8	2	10
39	8	2	10					39	11	3	14
40	5	1	6					40	12	2	14
41				1	12	1	13	41	1	1	2
42	2	1	3	2	2	1	3	42	2	4	6
43	100	2	102	3	5	1	6	43	13	2	15
44	35	2	37	4	1	1	2	44	3	4	7
45	14	1	15	5	2	1	3	45	4	2	6
46	20	2	22	6	2	1	3	46	10	1	11
47	103	3	106	7	2	1	3	47	3	1	4
48	10	1	11	8	2	1	3	48	9	2	11
49	46	2	48	9	1	1	2	49	7	1	8
50	31	1	32	10	8	8	9	50	3	2	5
51	12	2	14	11	3	1	4	51	2	1	3
52	40	3	43	12	4	1	5	52	5	1	6
53	10	2	12	13	4	1	5	53	7	1	8

TABLE IX—(*Continued*).

TIME IN SECONDS

Rat—	8			2				4			
Trial	a	b	c	Trials	a	b	c	Trial	a	b	c
54	9	3	12	14	2	1	3	54	10	2	12
55	17	2	19	15	2	1	3	55	12	2	14
56	8	2	10	16	1	1	2	56	2	2	4
57	82	2	84	17	1	1	2	57	4	4	8
58	64	2	66	18	2	1	3	58	5	1	6
59	9	2	11					59	4	3	7
60	7	2	9	8. (concluded)				60	5	2	7
61	31	3	34					61	7	2	9
62	5	1	6	111	100	3	103	62	8	2	10
63	11	1	12	112	202	2	204	63	2	1	3
64	52	2	54	113	130	2	132	64	2	1	3
65	32	2	34	114	89	2	91	65	2	1	3
66	19	2	21	115	66	30	96	66	11	1	2
67	55	2	57	116	29	4	33	67	2	1	3
68	4	3	7	117	39	2	41	68	2	1	3
69	19	1	20	118	65	10	75	69	1	3	4
70	233	3	236	119	50	4	54	70	9	4	13
71	61	2	63	120	26	2	28	71	2	7	9
72	107	2	109	121	138	2	140	72	2	1	3
73	70	3	73	122	91	2	93	73	3	1	4
74	33	2	35	123	39	2	41	74	3	2	5
75	5	2	7	124	107	2	109	75	5	1	6
76	145	2	147	125	31	2	33	76	4	1	5
77	10	1	11	126	49	2	51	77	2	1	3
78	41	2	43								
79	48	5	53	REDINTEGRATION				REDINTEGRATION			
80	18	1	19								
81	15	2	17	1	23	2	25	1	6	3	9
82	16	2	18	2	4	3	7	2	15	2	17
83	9	2	11	3	2	1	3	3	2	1	3
84	35	4	39	4	5	1	6	4	2	1	3
85	21	4	25	5	2	1	3	5	2	1	3
86	40	2	42	6	1	1	2	6	3	1	4
87	10	2	12	7	2	2	4	7	2	1	3
88	10	2	12	8	2	1	3	8	2	2	4
89	3	1	4	9	2	1	3	9	15	3	18
90	6	1	7	10	2	1	3	10	2	1	3
91	55	2	57	11	2	1	3	11	2	1	3
92	10	3	13	12	2	1	3	12	12	2	14
93	25	1	26	13	3	1	4	13	1	1	2
94	59	3	62	14	3	1	4	14	2	1	3
95	55	2	57	15	4	1	5	15	7	1	8
96	51	1	52	16	6	4	10	16	8	2	10
97	81	2	83	17	27	2	29	17	2	2	4
98	5	2	7	18	10	3	12				
99	37	1	38	19	28	2	30				
100	12	1	13	20	15	2	17				
101	3	1	4	21	4	1	5				
102	45	2	47	22	7	2	9				
103	8	1	9	23	3	1	4				
104	17	1	18	24	4	1	5				
105	3	2	5	25	15	2	17				
106	4	2	6	26	12	2	14				
107	38	16	54	27	5	2	7				
108	35	2	37	28	6	1	7				
109	195	2	197	29	11	2	13				
110	62	3	65	30	5	1	6				

TABLE X

70-Day Period. 1 Trial per Day

Time in Seconds

Rat—	8			9				5			
Trial	a	b	c	Trial	a	b	c	Trial	a	b	c
1	28	4	32	1	395	8	403	1	145	53	198
2	58	3	61	2	155	8	163	2	28	9	37
3	118	3	121	3	1800			3	168	27	195
4	19	5	24	4	1800			4	30	7	37
5	66	25	91	5	582	22	604	5	491	32	523
6	50	5	55	6	145	8	153	6	68	17	85
7	35	2	37	7	94	8	102	7	55	3	58
8	58	3	61	8	82	5	87	8	13	2	15
9	346	4	350	9	51	30	81	9	48	2	50
10	19	2	21	10	699	11	710	10	17	2	16
11	10	3	13	11	70	3	73	11	25	2	27
12	5	2	7	12	70	3	73	12	745	10	755
13	16	4	20	13	32	2	34	13	320	3	323
14	8	4	12	14	22	2	24	14	166	3	169
15	50	3	53	15	6	2	8	15	13	2	15
16	24	1	25	16	5	2	7	16	4	2	6
17	6	2	8	17	6	2	8	17	12	2	14
18	5	2	7	18	3	2	5	18	6	2	8
19	10	2	12	19	3	1	4	19	9	2	11
20	8	2	10	20	2	2	4	20	3	1	4
21	22	1	23	21	6	1	7	21	5	2	8
22	14	1	15	22	6	1	7	22	8	1	9
23	7	2	9	23	7	5	12	23	2	1	3
24	7	1	8	24	2	1	3	24	6	1	7
25	5	2	7	25	2	1	3	25	7	2	9
26	25	3	28	26	1	1	2	26	14	2	16
27	3	1	4	27	5	6	11	27	6	1	7
28	6	1	7	28	6	2	8	28	2	1	3
29	7	1	8	29	2	1	3	29	2	1	3
30	6	1	7	30	2	1	3	30	5	2	7
31	6	1	7	31	1	1	2	31	1	1	2
32	3	1	4	32	1	1	2	32	1	1	2
33	7	1	8	33	1	1	2	33	5	1	6
34	4	2	6	34	1	1	2	34	1	1	2
35	5	1	6	35	1	1	2	35	14	2	16
36	4	1	5	36	6	2	8	36	1	1	2
37	10	1	11	37	4	2	6	37	8	1	9
38	7	1	8	38	7	1	8	38	7	1	8
39	4	1	5	39	6	1	7	39	14	1	15
40	2	1	3	40	5	1	6	40	1	1	2
41	5	1	6	41	1	1	2	41	10	2	12
42	5	1	6	42	1	1	2	42	1	1	2
43	5	1	6	43	2	1	3	43	8	1	9
44	3	2	5					44	11	1	12
45	6	1	7	REDINTEGRATION				45	9	1	10
46	9	1	10					46	6	1	7
47	4	2	6	1	10	1	11	47	1	1	2
48	4	1	5	2	2	3	5	48	1	1	2
49	5	1	6	3	4	1	5	49	9	1	10
50	5	1	6	4	5	2	7	50	8	1	9
51	2	1	3	5	1	1	2	51	5	2	7
52	3	2	5	6	2	1	3	52	2	1	3
53	5	1	6	7	2	1	3	53	6	1	7
54	5	2	7	8	2	1	3	54	2	1	3

TABLE X—(*Continued*)

Rat—	8			9				5			
Trial	a	b	c	Trial	a	b	c	Trial	a	b	c
55	2	1	3	9	2	1	3	55	2	1	3
56	3	1	4	10	2	1	3	56	2	1	3
57	8	1	9	11	1	1	2	57	2	1	3
58	4	1	5	12	2	1	3	58	1	1	2
59	5	1	6	13	1	1	2	59	1	1	2
60	4	1	5	14	2	1	3	60	3	1	4
61	8	1	9	15	3	1	4	61	5	1	6
62	4	1	5	16	2	1	3	62	1	1	2
63	4	1	5	17	2	1	3	63	2	1	3
64	7	1	8	18	2	1	3	64	1	1	2
65	7	1	8	19	2	1	3	65	2	1	3
66	4	1	5					66	1	1	2
67	3	2	4	8. (concluded)				67	1	1	2
68	7	1	8					68	1	1	2
69	5	1	6	112	2	1	3				
70	3	1	4	113	3	1	4	REDINTEGRATION			
71	4	1	5	114	3	1	4				
72	3	1	4	115	3	1	4	1	5	2	7
73	4	1	5	116	3	1	4	2	2	1	3
74	4	1	5	117	2	1	3	3	2	1	3
75	7	1	8	118	2	1	3	4	2	1	3
76	3	1	4	119	3	1	4	5	2	1	3
77	3	2	5	120	2	1	3	6	1	1	2
78	2	1	3	121	2	1	3	7	2	1	3
79	5	2	7	122	2	1	3	8	4	1	5
80	2	1	3	123	2	1	3	9	1	1	2
81	4	2	6	124	3	1	4	10	1	1	2
82	5	1	6	125	4	1	5	11	1	1	2
83	4	1	5					12	7	2	9
84	5	1	6	REDINTEGRATION				13	2	1	3
85	8	1	9					14	2	1	3
86	5	1	6	1	6	2	8	15	5	1	6
87	6	1	7	2	7	1	8	16	3	1	4
88	3	2	5	3	3	1	4				
89	2	1	3	4	5	1	6				
90	2	1	3	5	7	1	8				
91	3	1	4	6	8	2	10				
92	5	1	6	7	6	2	8				
93	2	1	3	8	4	1	5				
94	10	1	11	9	4	1	5				
95	2	1	3	10	3	1	4				
96	4	1	5	11	2	1	3				
97	2	1	3	12	6	2	8				
98	2	1	3	13	5	2	7				
99	3	1	4	14	2	1	3				
100	5	1	6	15	2	1	3				
101	4	1	5	16	2	1	3				
102	3	1	4	17	2	1	3				
103	2	1	3	18	3	1	4				
104	5	1	6	19	3	1	4				
105	3	1	4	20	4	2	6				
106	2	1	3	21	3	2	5				
107	3	1	4	22	3	1	4				
108	5	1	6	23	2	1	3				
109	2	1	3	24	2	1	3				
110	2	1	3	25	3	1	4				
111	4	1	5	26	2	1	3				
				27	2	1	3				
				28	3	1	4				
				29	3	1	4				
				30	2	1	3				

TABLE XI

70-Day Period. 3 Trials per Day
Time in Seconds

No. of Trials			First 15 Trials of R.; Last 15 Trials of L.															Av.
Rat 1.	L.	73	*3	*3	*3	*3	*3	*3	*4	*3	*4	6	*3	*3	*3	*2	*5	3.46
	R.	30	17	*5	*5	*4	7	9	21	18	6	6	*3	7	10	9	8	9
2.	L.	37	*3	*3	*3	*2	*2	*3	*4	*3	*3	*2	*2	10	*3	*3	9	3.66
	R.	18	13	*3	6	*2	*3	*3	*3	*3	*2	9	4	6	5	*3	*3	4.53
3.	L.	83	*3	*3	*2	*2	*3	*3	*2	*4	*3	*3	6	116	10	*3	*3	4.4
	**R.	30	45	10	8	10	16	*6	*2	*3	5	7	5	*3	11	7	*3	9.33
4.	L.	77	*3	*3	*3	*2	*3	*3	*4	13	9	*3	*3	*3	5	4	*3	4.26
	R.	17	9	17	*3	*3	*3	*2	*3	*3	8	*3	*3	14	*2	*3	8	5.6
5.	L.	70	*2	*2	*2	*2	*2	*3	*2	*5	6	*2	*3	6	*2	*2	*3	2.93
	R.	20	29	*3	*3	17	7	*3	*3	*2	*3	*2	*3	*3	7	*3	6	4.53
6.	L.	72	*3	*3	*3	*3	*3	*3	8	*3	*2	*3	*3	24	*3	*3	21	5.86
	R.	19	12	*4	*3	13	*3	*3	*3	*3	*3	*3	8	6	*3	*4	19	6
7.	L.	75	*3	*3	*3	*3	*3	*3	*3	*3	*4	*4	*3	*3	11	*3	*4	3.73
	**R.	30	8	7	10	11	7	7	*3	9	*5	9	*3	*5	*3	15	12	7.6
***8.	L.	126	204	132	91	96	33	41	85	54	28	140	93	41	109	33	51	82.66
	R.	23	25	7	*3	6	*3	4	4	4	*3	*3	*3	*3	*4	*4	*5	5.4

Averages—
Trials..L. 76.6 Av. * Trials..L. 11.1 Av. Time per Trial..L. 13.8
R. 23.3 R. 7.7 R. 6.4

** Had not begun norm of perfect trials at end of 30th trial.
*** Had not begun norm of perfect trials at end of 126th trial.

TABLE XII

70-Day Period. 1 Trial per Day
Time in Seconds

No. of Trials			First 15 Trials of R.; Last 15 Trials of L.															Av.
Rat 1.	L.	88	*3	*3	*3	*3	*3	*3	*2	11	12	*3	*3	*3	5	*3	*4	4.26
	R.	22	43	*5	*3	25	*3	11	11	*4	*3	*6	*3	*3	*3	*3	*4	7.93
2.	L.	91	*3	*3	*3	*3	*3	*2	*3	5	*3	*3	*3	*4	*3	*3	11	3.66
	**R.	30	136	23	*6	8	*3	5	*4	9	7	11	*3	*3	7	8	6	15.93
4.	L.	45	*2	*3	*2	*2	*2	*2	8	7	*3	*3	*2	*2	10	*3	*3	3.6
	R.	21	13	*3	*3	5	*3	6	*3	*3	*3	*3	*2	*3	8	7	6	4.73
5.	L.	68	*3	*3	*3	*3	*2	*2	*4	6	*2	*3	*2	*3	*2	*2	*2	2.8
	R.	16	7	*3	*3	*3	*3	*2	*3	5	*2	*2	*2	9	*3	*3	6	3.73
6.	L.	45	*3	*3	*3	*3	*3	*2	11	10	*4	*5	*3	9	*3	*3	*3	4.53
	R.	29	8	5	5	*4	5	7	6	*4	*3	20	*4	*3	*3	5	*4	5.73
7.	L.	83	*3	*3	*3	*3	*3	*2	*3	*3	*2	*3	9	6	*2	*3	*2	3.33
	R.	27	5	*3	6	*3	6	*3	6	5	*3	*4	*3	5	*3	*3	*3	4.66
***8.	L.	125	5	3	4	4	4	4	3	3	4	3	3	3	3	4	4	3.66
	**R.	30	8	8	4	6	8	10	8	5	5	4	*3	8	7	3	3	6
9.	L.	43	*3	*3	*2	*2	*2	*2	*2	8	6	8	*7	*6	*2	*2	*3	3.86
	R.	19	11	5	5	7	*2	*3	*3	*3	*3	*3	*2	*3	*2	*3	4	3.93
10.	L.	61	*2	*2	*2	*2	*3	*3	*4	*3	*2	*2	*2	*2	*2	4	*2	2.46
	**R.	30	8	22	*3	*3	*3	5	5	4	5	5	4	9	*3	4	10	6.33

Averages—
Trials..L. 72.1 Av. * Trials..L. 12.1 Av. Time per Trial..L. 3.5
R. 24.8 R. 7.5 R. 6.5

** Had not begun norm of perfect trials at the end of the 30th trial.
*** Had not begun norm of perfect trials at the end of the 125th trial.

of learning fall very close together, but it seems that the method of wider distribution is the most economical. A similar situation developed in redintegration but the averages, if any conclusion may be drawn from them, show that the three trials per day group is superior. From these tables it must be admitted that the results of these two groups are inconclusive in regard to the question of economy. Because the averages of time and trials are so nearly equal it may be said that on the whole neither the three trials per day method nor the one trial per day method has any decided advantage in point of time and trials.

The data from observation indicate a greater number of movements, such as in the attempt to push down the plane, due to the three trials per day methods, and this fact may be interpreted to indicate a greater economy of the wider distribution of trials. Because of the persistance of the dominant "error," the inclined plane presents one of the most difficult problems with which to carry on any satisfactory and consistent experiments. In any case, a larger group of rats should be experimented with before one can be certain of anything definite; and, certainly, as far as economy is concerned in redintegration, the problem must be approached on a broader scale than the one here presented before there may be any hope of a conclusive result.

In order to ascertain the effect of retention on incomplete learning, two litters of rats were set to learn the inclined plane by the one trial per day method. The results of this experiment are presented in Table XIII. In this experiment the usual norm was adhered to, except that each litter was taken from the problem when the first rat of the respective litter finished both in learning and redintegration. Under similar conditions on the maze it was seen that the rat which completed learning first did not complete redintegration first. The present table shows that the result on the inclined plane follows that on the maze in this respect.

Probable explanations of this fact, as already stated in the consideration of incomplete learning on the maze, are as follows: That the rat which finished first in learning

TABLE XIII

70-Day Period. 1 Trial per Day

Time in Seconds

No. of Trials		First 15 Trials of R.; Last 15 Trials of L.															Av.
Litter 1.																	
Rat 1. L.	**34	*3	*3	*3	*3	*3	*2	6	*3	*3	*3	*3	5	8	*3	*2	3.53
R.		77	9	*4	*3	*3	4	*3	5	5	5	*3	6	5	17	17	11.66
4. L.		*5	16	24	46	8	*4	*5	*3	*3	*3	*2	*3	*3	4	16	9.66
R.		11	*5	*4	*3	*3	30	*4	*3	*3	35	*5	*4	*4	*3	6	8.2
5. L.		86	82	59	52	51	23	74	46	39	25	33	87	89	45	48	55.93
R.		30	15	*5	9	7	6	*5	5	10	38	9	25	112	69	149	33.6
6. L.		29	*7	*6	18	10	14	12	39	17	22	9	30	26	30	*5	18.26
***R.	17	27	10	*3	*3	*3	*3	*3	*3	7	11	6	6	*5	*7	*8	5.86
Litter 2.																	
7. L.		19	130	79	21	42	146	*3	*3	*3	*3	*3	*3	*3	*4	*3	31
R.		*3	*2	5	6	*3	5	5	7	5	8	7	*3	*3	5	*3	4.66
8. L.		*7	15	4	10	*3	*3	7	8	*4	*4	*3	7	8	*3	8	6.26
R.		10	14	6	*3	6	10	*4	*4	*5	4	9	22	*3	9	*4	7.53
9. L.	**57	*3	*3	*3	*3	*3	*3	*4	*4	7	15	67	25	*7	*3	*3	10 2
R.		*2	13	*4	7	*3	*3	*3	7	*4	8	*3	*3	8	6	*3	5 13
10. L.		78	34	*4	*5	7	7	7	*3	6	6	*4	*3	*3	*5	*3	11.6
R.		*4	14	6	10	6	6	*3	12	5	7	*3	*3	3	4	*3	5.93
12. L.		252	93	30	28	22	*6	11	14	10	*4	10	*7	*6	6	*5	33.6
R.		24	18	24	19	*4	6	12	7	15	10	123	15	*6	13	6	20.13
13. L.		*—	*—	*—	*—	*—	138	*6	*5	*5	*4	10	*3	*3	*5	*3	18.2
R.		*6	7	22	9	4	6	*3	11	*4	*3	7	*3	7	*3	8	7.26
14. L.		*5	5	*5	6	*6	6	*5	*4	*5	6	*5	*5	*4	*4	*4	5
***R.	29	26	*5	10	*4	*3	*3	*4	6	*3	*3	9	5	4	6	*3	6.26

** L.—First in Learning.
*** R.—First in Redintegration.
* — Sick.

Supplement—No. of * Trials.

Litter 1.	Rat—	1.	4.	5.	6.			
	L.	12	9	0	3			
	R.	5	11	2	9			
Litter 2.	Rat—	7.	8.	9.	10.	12.	13.	14.
	L.	9	7	11	8	5	8	11
	R.	6	6	9	6	2	5	8

and did not complete redintegration first may be due to (a) poor retention owing to innate constitution, some metabolic disturbance during the retention period, or some extraneous disturbance; (b) at that particular stage when this first individual completed learning, perfect integration was not as firmly established in it as in the rat which completed redintegration first; and, as a consequence, in

the redintegration of the rat which had the more poorly established integrations the dominant "error" would be likely to occur first, and persist the longest. As with the results on the maze it would be well to repeat that, although innate constitution may bear some influence, yet the data at hand on the inclined plane point to the second explanation as more satisfactory, and more open to proof than the intangible hypothesis of the first.

In experiment on the inclined plane there are numerous cases, not found frequently on the maze, where the first trial or trials of redintegration were perfect and a number of subsequent trials were imperfect; e.g., in the records of rats 7, 9, 10, and 13. Had the present experiment been conducted according to the norm which holds that the first trial is "pure" retention and evidently adequate to ascertain how well a habit is retained, the individuals mentioned would certainly have been credited with perfect retention. And further, according to this norm, if the first trial after the retention period was perfect, it would logically and theoretically follow that, with everything else equal, the subsequent trials would also be perfect, in accordance with the theories of recency, frequency, and repetition or intensity. The subsequent trials in the cases cited were not perfect; and thus it may be inferred that the capacity of the individual organism to retain integrations may not be completely known in the first trial after retention, but only when a number of successive perfect trials show conclusively that the habit has been acquired. It is thus important to remember that all "errors" and imperfect integrations of the redintegration series of trials throw light on how well the habit has been learned in the *first place* and how well it was retained in *the second.* Or it may be said further that the problem is so difficult that it is impossible to get six consecutive trials in redintegration since it is so difficult to get these in learning; but all these rats made six consecutive trials perfect in order to attain the norm.

From the data of both litters the dominant "error" was found, as stated in the previous records on the plane, at the point in the problem where the rat must establish

the integration of stepping on the plane, and the same "error" followed in redintegration. It seems possible then that a dominant "error" is to be found in every problem, and that the recurrence of this "error" is to be expected in trials after retention. In regard to the effect of incomplete learning on retention and redintegration, therefore, the conclusion from the maze has been confirmed by these results on the plane. That is, in general, the better established is integration in the whole process of the learning, the fewer will be the imperfect integrations during redintegration, allowing always that the capacity of the organism to retain the integrations may tend to affect the exercise of the habit after the retention period. Evidently, then, the dominant "error" that appeared in learning reappeared in redintegration—a recapitulation being probable; that is, in the inclined plan problem "errors" in learning and redintegration are chiefly those pertaining to the plunging of the plane. The maze and the inclined plane present similar difficulties in establishing integrations, which with some individuals are more difficult than with others. These integrations are recorded in the imperfect integrations usually called "errors."

III. Individual Differences

Before proceeding to the general discussion of results, the subject of individual differences, appearing in learning and redintegration, seems worthy of consideration. The point has been observed in preceding pages that the learning and redintegration of all individuals have many characteristics in common, such as the reappearance in redintegration of "errors" which appeared in learning. The object of this chapter is to show some differences which characterize individuals in learning and redintegration. It is not necessary for the present *purpose* to reconsider the records of every individual. However, in order to explicitly point out concrete examples of differences, some certain group should be considered. Tables V–A and V–B will be most advantageous for the present, owing to the fact that some individuals in this group were perfect in redintegration.

The individual " error " totals of Table V–A of the maze show the relative extremes in redintegration, namely, where redintegration was completed (a) with numerous " errors " and (b) without " error." These extremes may be seen (a) in records of 3, 4, and 7 and (b) in record 1. In considering the " errors " in records 3, 4, and 7, the fact significant of individual differences, is that the number and kind or, in other words, the quantity and quality of " errors " in each case are not the same. From this fact, it is clear that the process of the establishment of integrations in each case proceeded with more difficulty with some than with others. The integrations difficult for one individual to establish—as in record 4, turn 2, are readily established by another—as in record 3, turn 2; while on the contrary the source of " error " for the second individual—records 3, turn 5—is not the source of " error " for the first—record 4, turn 5. There are individual differences also in the number of trials necessary to complete learning and redintegration. In Table V–B it may be noted in record 5 that 130 trials were required to complete learning and 16 for redintegration; while in record 2, 39 trials were required for learning and 29 for redintegration.

It is true that the differences which characterize the learning process, and that also of redintegration, are influenced to some extent by extraneous disturbances and stimuli. But the important basis of difference is to be found in the *individual*. Every *individual* possesses an heridetary neuromuscular endowment, or organization, capable of performing a limited repertoire of actions. The functioning required in the performance of certain actions is called forth by stimuli of environments; but beyond the limit of the repertoire of actions and their integration in the organism, stimuli are ineffective to produce action which may result in a habit. One *individual* may possess an endowment whose functions may be called forth by certain stimuli from environments and rapidly integrated in a learning process until the integrations are established in a habit. Another may be so endowed that the process of learning under the conditions of environment as above mentioned proceeds much more slowly. While a third

individual may be placed in the same environment, *but* repertoire of actions *is so* limited that the *individual* can not respond. Examples of each of these cases may be seen in records of the inclined plane already cited, where some learned rapidly, some more slowly, and some failed entirely.

In regard to responses of *individuals*, as above considered, it is an open question whether the muscular or the sensory aspect of the endowment is the most important. The object of the sensory experiments by Vincent (22) and others would indicate that the response of the *individual* in the acquirement of the maze habit, for example, is for the most part sensory. It is undeniable that the sensory endowment of the *individual conditions* reception of stimuli to a great extent; but the fact should not be overlooked that the muscular endowment of movement is of equal if not of greater importance, because upon this the habit depends first and always, while the sensory response is confined more particularly to the beginning of the learning. Individual differences in endowment would thus result in individual differences in behavior, in the establishment of integrations, as may be seen in the number of "errors," in rapidity of the process of establishing integrations, as may be seen in the number of trials and in speed of movement, and as may be seen in the time totals. This is true because of the persistence of the dominant "error," and the difficulty of the rat to establish the integrations of movement at the locus of dominant "error." For example, the rat has all the sensory cues of going to the plane and coming from the plane after it is plunged, and these are usually established at approximately the 9th trial, yet the integrated movement of plunging the plane is not yet established. Evidently the sensory cues are present, but integrated movement required in plunging the plane remains imperfect for many subsequent trials.

Numerous other cases could be cited to illustrate concretely the fact that scarcely, if ever, are two individuals found to exhibit the same behavior in any given environment. One individual may learn as rapidly as another,

but the responses of each differ, and the methods of learning are never the same, *in toto*. The redintegration of two individuals may likewise seem identical by comparison, but there are degrees of difference which characterize each and differentiate one from the other. Individual differences are thus to be considered as facts which can not be called into question.

Conclusion

1. The foregoing experiments were undertaken with a view to attempting to discover some characteristic in learning which likewise appeared as a characteristic in redintegration after a period of retention.

2. In the learning of the maze and the inclined-plane problems, there is a process through which the integrations of the habit are established. In the chain of integrations which constitute a habit, the learning process discloses certain definite integrations which are more difficult to establish than others. These may be said to be " weak links " in the chain of the habit integrations. Because of the fact that the " errors," due to these weak links, are the more numerous, these " errors " are called dominant.

3. The locus of dominant " error " in the maze specifically indicates those movements which are difficult to integrate. They are movements which are nearer the higher functional limits of the rat's organization than are other integrations required in the habit.

4. Though at the end of the learning period the dominant " error " may appear to have disappeared, it is the first one to reappear in the redintegration series. This discloses the fact that the integration or integrations which are most difficult to establish are the first to be lost, whereas the integrations which are most readily established persist the longest.

6. In order that the problem of establishment of integrations be approached from as many points of view as laboratory conditions will allow, additional experiments were conducted.

7. The method of wider distribution of trials is a better method of learning; and second, that although both methods

establishment of a habit, yet by the three trials per day method perfect integration is more difficult at the locus of dominant " error." Such a method is absolutely more economical in learning, retention, and redintegration, but is relatively less economical during retention and integration than it is in the process of learning.

8. The learning of another problem during the period of retention, before giving redintegration series, does not result in a loss of redintegration; that is, the acquisition of a second habit does not produce distrubances in the organism which might interfere with redintegration tests for the first habit established.

9. Previous training improves subsequent learning and redintegration. The condition of the organism is in many ways superior after a period of training.

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Journal of Educational Psychology—Baltimore: Warwick & York.
Subscription $3. 600 pages annually. Founded 1910.
Monthly (10 numbers). Managing Editor, J. Carleton Bell.
(Educational Psychology Monographs. Edited by Guy M. Whipple.
Published separately at varying prices. Same publishers.)

Journal of Animal Behavior—Cambridge, Mass.: Emerson Hall.
Subscription $5. 450 pages annually. Founded 1911.
Bi-monthly. Robert M. Yerkes, Managing Editor.

The Behavior Monographs—Cambridge, Mass.: Emerson Hall.
Subscription $5. 450 pages per volume. Edited by John B. Watson.
Published without fixed dates, each number a single research.

Psychoanalytic Review—Washington, D. C.: 3617 Tenth St., N. W.
Subscription $5. 500 pages annually. Psychoanalysis.
Quarterly. Founded 1913. Ed. by W. A. White and S. E. Jelliffe.

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Company. 480 pages annually. Experimental. Founded 1916.
Subscription $3.25 Bi-monthly. Edited by John B. Watson.

Journal of Applied Psychology—Worcester, Mass.: Florence Chandler.
Subscription $4. 400 pages annually. Quarterly. Founded 1917.
Edited by G. Stanley Hall and L. R. Geissler.

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Edited by JOHN B. WATSON
The Johns Hopkins University

Discrimination of Light of Different Wave-Lengths by Fish

BY

CORA D. REEVES

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CONTENTS

DISCRIMINATION OF LIGHT BY FISH[1]

I. STATEMENT OF THE PROBLEM

In the early part of the second half of the nineteenth century many comparative studies of the anatomy of the eye were made. Studies of the physiology of the human eye followed, but experimental work upon animal vision was delayed. Not until 1885 were Graber's results published. He was among the first to test experimentally the effects of light of different wave-lengths upon fish, and found that they showed a preference for the shorter wave-lengths. Then a number of other experimenters decided that fish discriminate color. But in 1909 and 1910 Hess published an account of experiments from which he concluded that fish do not show the responses to wave-length apparently established by his predecessors in this field. He attributed the responses obtained by him as well as those already obtained by others to differences in the brightness rather than to differences in the quality of the light used and held that fish are color-blind. His evidence has been given favorable consideration by a number of investigators of color vision in higher vertebrates (Watson 1914, Parsons 1915). From this discussion arose the definite problem,—to determine whether fish can respond to differences in wave-length of light or can respond only to differences in intensity[2] of light.

II. EXPERIMENTAL WORK

A. *Introduction.*—The first requirement for the solution of the question was to determine whether our native fish show responses[3] available for experimentation. For some

[1] Contribution from the Zoological Laboratory, University of Michigan

[2] In this paper intensity is used as a physical term, and brightness as a sensation term; quality is used to describe that phase of sensation dependent upon wave-lengths.

[3] The study of first responses will be referred to as the Method of Response. Section *H* of this paper is devoted to the presentation of data gained by this method.

months three small fish, of undetermined species, had been living in a crystallizing dish on my desk. One morning the dish was placed so that one-half of it was in the direct sunlight and one-half in the shade. The fish came to rest most frequently in the shade. Then a prismatic solar spectrum was thrown on the bottom of the shaded half of the dish and the fish were observed to start or leap as they entered the red-orange area. They often swam around this area, to rest with the head in the blue or green, facing in the direction of the incident rays. Some shiners (*Notropis cornutus*) were then tested by throwing the intense light from a projection lantern, one meter distant into the glass-walled aquarium in which they were kept. At first some of the fish gave a start as they entered the lighted area, while others swam along the side of the lighted space but did not enter it.

It was evident in both of these experiments that light called out differential responses, presumably unlearned or instinctive; but whether intensity or wave-length differences induced the response in the test with the spectral band was in no way indicated.

These reactions to the intensity of white light, as well as to different parts of the spectral band, were evanescent. They were obtained in the first trials, but were not evident in later trials, when the fish, having become used to the stimulus, no longer responded to it. These first responses showed the behavior of an untrained animal when stimulated but cannot be assumed to have shown the animal's inherent power of discrimination. To secure sustained responses and to show by them the full capacity of the animal it seemed essential to resort to habit-forming experiments. For these experiments two large intense patches of light of restricted and definitely known wave-length were used as stimuli and were presented simultaneously. In order to form a food association and thereby to secure continued response the fish were always fed before the same patch and the position of this positive stimulus was, of course, irregularly shifted, while it was kept at constant intensity. When an association had been formed with the positive patch of light it became necessary to

determine to which of the two variables involved, intensity or wave-length, the response was to be attributed. In order so to control the experiment that response could be made to but one of these variables the brightness of the negative plate was varied until it was equal to that of the positive for the human eye. Continued response to the positive plate might then be due to the quality of the stimulus light. But since it could not be assumed, without proof, that the relative brightness values of the spectrum were similar for fish and man the response might be due to a brightness difference between the two plates. To follow the usual practice of equating the brightness of the plates by the human eye only could not lead to dependable results, and so a means was sought by which it might be possible to determine by the behavior of the fish when the two plates were of equal brightness for them. It is believed that such means has been found.

As an aid in interpreting the responses obtained when two stimuli of different wave-lengths were used, an effort was made to determine the minimum intensity differences between two white light stimuli capable of producing differential response. For this purpose an attempt was made to form a food association with the duller one of two white plates, which was kept at constant intensity while its companion plate was varied in intensity. If there should occur any difference in the relative ease of discrimination of the stimulus plates when the quality difference was absent then the value of difference in wave-lengths for discrimination would be shown. The minimum intensity difference necessary for the discrimination of two lights should be the same for white and for colored lights if wave-length differences are not able to differentially stimulate fish.

For normal activity it is essential that the fish be kept in a normal environment; otherwise response is often inhibited by unnatural conditions or by manipulations that induce fright. The water should be of constant temperature from one container to another, shifting of containers from place to place, variations in intensity of the general illumination, and manipulations likely to frighten the

fish should be avoided. In the experiments to be described the fish have been kept under normal conditions and have remained in the same containers during the tests and in the intervals between them, often for months together. The experiments have been so conducted as to reduce fright behavior to a minimum. During three years the fish have taken food regularly, have remained healthy, have grown and have been at all times very tame.

The apparatus described in the following section was devised to meet the experimental conditions already outlined. These call for:

(1) An experiment aquarium in which the fish could live continuously without being taken from the water.

(2) An experiment procedure which would not arouse fear behavior.

(3) Two large stimulus patches of either mixed light or light of restricted and known wave-length, interchangeable in position, one of which could be varied through a wide range of measurable intensities.

(4) Provision for offering food before one of the patches of light, which thus becomes the positive stimulus in the formation of an association.

(5) Constant conditions in the general luminous and in the aqueous environment of the fish.

(6) The experimental procedure involves further a method of equating the brightness of the patches of light of different wave-length by means of the behavior of the fish.

B. *Apparatus and Methods.*

1. General Description of the Apparatus

For the experiments a black-lined, galvanized-iron aquarium was used. Its ground plan is shown in figure 1. Movable partitions separate it into three parts, referred to as the stimulus, the discrimination, and the retention-compartments, respectively (1, 2, and 3, in fig. 1).

The removable partitions *A* and *B* separate these compartments as indicated by their positions in figure 1. In partition *A* is a vertically sliding door, *D*, shown partly

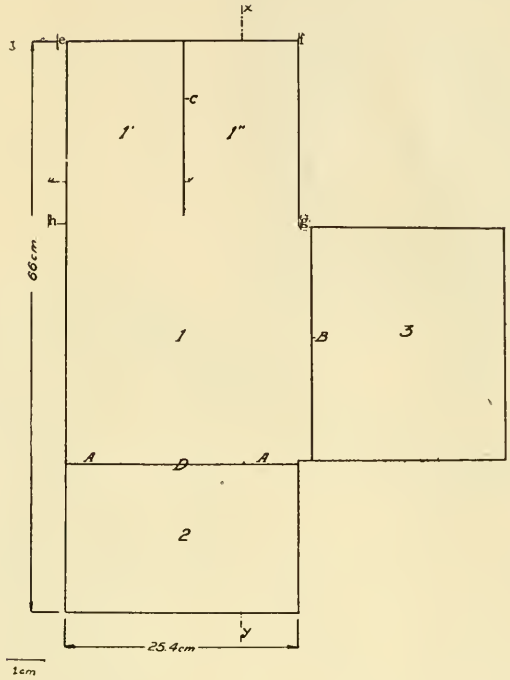

FIG. 1

Ground plan of the Experiment Aquarium.
1. Stimulus compartment. *1'* and *1"* recess for stimulus plate.
2. Discrimination Compartment.
3. Retention Compartment.

A and *B* movable partitions; *C* fixed partition; *D* sliding door in partition *A*; *efgh* indicate the positions of the corners of a frame above this end of the aquarium; *xy* plane of section shown in figure 4; *uv* plane of section shown in figure 5.

lifted in figure 2. A vertical fixed partition, *C*, divides one end of the stimulus compartment, *1*, into two sub-compartments, *1'* and *1"*. Lengthwise of each of the sub-compartments, *1'* and *1"*, extends a plate of opal ground glass set across it so as to form an angle of 45° with the floor and with the end wall. These plates are illuminated from above by patches of white or colored light, and from them this light is diffused into compartment *1*. When the sliding door (*D* in fig. 2) is lifted, a fish in the discrimination compartment, *2*, has before it a patch of light upon each of the white stimulus plates (*S* in fig. 2). If the patches, are unlike in either intensity or wave-length, its instinctive behavior toward them may for a time be differential.

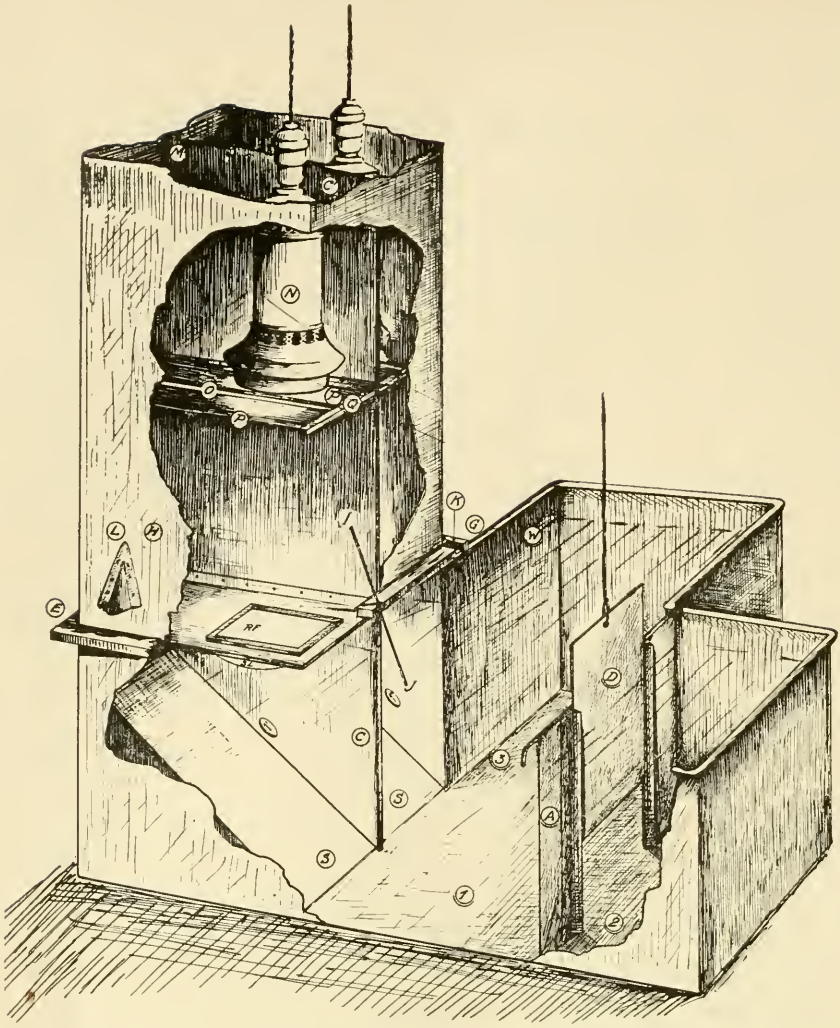

FIG. 2

Perspective View of Aquarium and lamphouse with part of each cut away, to show interior.

Aquarium and food release.

1. Stimulus compartment: 1′ 1″ recess for stimulus plate.
2. Discrimination Compartment.
3. Retention Compartment.

A, movable partition between 1 and 2 (the partition between 1 and 3 not in place).
C, fixed partition.
D, sliding door in *A*.
EG, parts of the frame which surround the base of the lamphouse.
IJ, slender food-bar in position for feeding the fish.
K, position of electro magnet by which the food-bar may be held in horizontal position.

Light Apparatus.

L, *H*, lamphouse. Below L, H, hooded air-inlet.
M′, *C′*, partition through lamphouse, an upward extension of *C*.
N, Nernst lamp in one half of lamphouse, one in the other half partially shown. The glowers of these lamps are across the compartments and thus parallel with the long axes of the cylindrical lenses shown at *SL*. They are at the principal foci of these lenses:
O, slit opening of variable width.
P, sliding metal plates which form the slit.
Q, frame which supports metal plates *PP* and in which they slide.
RF, ray filter in its kit.
SL, cylindrical lens.
S, *S*, stimulus plates.
W, indicates water level.

(See section H.) Such differential instinctive responses may show the ability of the fish to discriminate, but they persist only a short time. To secure responses persisting for a longer period the fish were fed before one of the stimulus patches, and thus a food association with the one patch of light was built up in order to test the ability of fish to discriminate between the two lighted areas.

To secure patches of light of definite form on the stimulus plates two cylindrical lenses (*SL* in fig. 2) are mounted in a frame (indicated by *EG* in fig. 2) which rests above the sub-compartments *1′* and *1″*. The major axis of each lens is across its sub-compartment. These lenses parallelize the rays in one plane and give two stimulus patches of equal size, having sharp parallel upper and lower edges across the opal glass plates. The lower margin of each patch is always adjusted so as to coincide with the lower margin of its plate. Control of wave-length of light is obtained by colored filters (*RF* in fig. 2) laid above the cylindrical lenses. A blue filter of gelatine and a red one of ruby glass are provided and may be shifted from side to side, so that patches of light of either color may be used on either plate. The light for the illumination of the stimulus plates comes from two single-glower Nernst lamps (*N* in fig. 2) contained in a lamphouse. The house rests upon the aquarium, above compartments *1′* and *1″*, and its cross section is nearly that of these sub-compartments taken together. It is divided by a vertical partition (*M′C′* in fig. 2), which is an upward extension of partition *C* of the aquarium. Access to its interior is through a door above the end of the aquarium, which is not visible in figure 2. The long lamphouse extends nearly to the ceiling, from which it is so suspended that it may be swung out free from the aquarium. The lamps remain always at the same height in the lamphouse, and the intensity of the light reaching the plates is controlled by a slit (*O* in fig. 2) of variable width placed beneath each lamp at right angles to its glower. Thus by varying the width of the slits and by shifting the filters a patch of either white or colored light of any desired intensity may be secured on either plate.

Food may be supplied to the fish from the food-bar (*IJ* in fig. 2) weighted at one end and pivoted at its center. After food has been placed at both ends, the bar is brought into a horizontal position and held there by an electromagnet (*K* in fig. 2). When a fish approaches the patch of light before which he is to be fed, the bar is released by opening a switch. The bar is then free and turns on its pivot until its weighted end is beneath the water in front of the stimulus plate where the fish can secure the food.

The aquarium is supported on a low table and supplied with running, filtered water. To exclude extraneous light and secure uniform illumination of the apparatus during experimentation the space about the table is enclosed by black building-paper to form a room 6 ft. by 10 ft. This light-tight room includes a west window with light-tight shades. Suspended from the ceiling directly above the aquarium is a 40 watt tungsten lamp at a distance of 157 cm. from the water. This lamp is enclosed in a cylindrical metal shade 145 cm. high. As the diameter of the shade is 14 cm. the light is reduced, being only that passing out from its open lower end. To give the fish an environment of more nearly normal color and to keep them from seeing the experimenter, the aquarium table is surrounded by a curtain of yellow cheese-cloth hung from the ceiling within the light-tight room. A cord attached to the sliding door (*D* fig. 2), in partition *A*, runs straight up to an eye in the ceiling and ends outside the curtain. A counter weight on this door-cord enables the operator to leave the door open at any height. The switch for control of the food-bar magnets is also located outside the curtain.

2. General Method of Procedure

Before an experiment is begun, the window shades are lowered and the ceiling light is turned on, so that the fish may become accustomed to the light and their eyes adapted to the conditions of illumination maintained during the experiment. After half an hour or more all of the fish in the aquarium are shut into the retention compartment (3 in figs. 1, 2) by means of the movable partition *B*. The experimenter then adjusts the illuminating apparatus and

the food-bar with its food. Next, by manipulation of the movable partitions, the individual fish needed for an experiment is allowed to swim from compartment *3* into compartment *2*. The further operations of lifting the sliding door and releasing the food-bar when the fish has reacted suitably are carried on from without the curtain, while observations are made through a peek hole.

When experiments are not in progress, the ceiling light is turned off, the yellow curtain drawn aside, the shades at the west window raised, and the movable partitions taken from the aquarium. The fish then live in a black pool into which the sunlight penetrates for a short time each day. On the sides of the pool the fish may see the yellow curtain and above it the gray of the ceiling. At one end of the pool towers the black lamphouse. The visual surroundings are then somewhat like the black pool and the sky of the natural fish habitat.

The tap water supplied to the aquarium is passed through a Berkefeld filter. All fecal material and excess food are daily removed from the aquarium. Frequently the aquarium is almost emptied through a drain at the bottom; then it is refilled. By these means the water is kept uniformly clear and its light transmission constant.

That the fish may have all necessary food substances, pieces of angle worm, fish, chicken, or bits of boiled egg or fish food are occasionally substituted for the usual scraped beef. The fish are healthy and active, and are growing rapidly after over two years of experimentation.

3. Detailed Description of the Apparatus[4]

a. *The Experiment Aquarium.*

The aquarium is 22 cm. deep, 66 cm. long, and 25.4 cm. wide, inside measurements. Each of the three movable partitions (*A*, *B*, *T* in figs. 1, 2, 6) measures 23 cm. high by 25 cm. wide, and has attached to its upper edge a small rod of metal extending 3 cm. beyond the ends. By hanging the projecting ends of this rod over the edges of the aquarium, a partition can be set at different places across the aquarium. One of these partitions (*A*) has an opening 10 cm. wide, extending 13 cm. from the bottom. This is provided with a sliding door (*D* in fig. 2) 13 by 23 cm. Opposite to the door when it is in place are the stimulus plates (*S*, *S* in fig. 2). Each plate extends entirely across its sub-compartment and reaches from the floor at the projecting end of the partition *C* to the surface of the water at the back of the sub-compartment. The tap water, after passing through a Berkefeld filter, flows over

[4] The further descriptions in this section and in section 4 are included especially for those who may wish to duplicate the apparatus and methods.

a glass plate 20 cm. long, not shown in the figures, and enters at the top of the closed end of compartment 2. The water flows in a thin sheet over the glass plate and drops from it into the aquarium. This permits the escape of excess gases from the water. When the plate is not used the fish develop symptoms of gas-bubble disease. From the plate the water drips into the aquarium at a rate somewhat above one drop per second. Outflows are provided in the center of the ends of sub-compartments *1'* and *1"* at 17 cm. from the bottom.

b. *The Lamphouse.*

The lamphouse is a black rectangular wooden box 172 cm. long, with an internal cross-section 22 cm. by 23 cm. A partition of thin tin divides it lengthwise into two equal compartments. The inside of the lamphouse is blackened with several coats of lamp black and shellac. The single glower Nernst lamp inside each half of the house (*N* in fig. 2) is of the 0.6 ampere, 220 volt D.C. type. Openings, shown opposite arrow-heads in fig. 4, at the bottom and at the top of the lamphouse, and below L. H. in fig. 2, afford ventilation and prevent excessive heating. They are hooded to prevent the escape of light. The lower end of the lamphouse rests on the experiment aquarium, which is so placed that the partition *C* (figs. 1 and 2) is beneath the partition *M'C'* (fig. 2) in the lamphouse. Thus two continuous, dark-lined tunnels are formed with a white diffusing surface set at an angle of 45° across the bottom of each. A wooden frame (*EG* in fig. 2) rests on the top of the sub-compartments *1'* and *1"* of the aquarium in the position of *efgh* of fig. 1, and surrounds the lower end of the lamphouse.

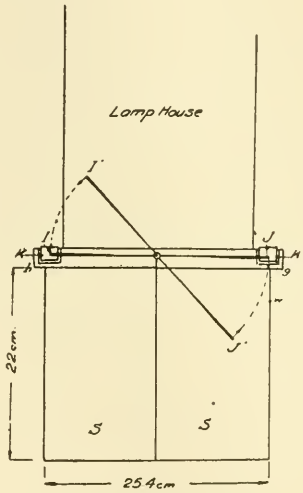

FIG. 3

Diagram of compartments *1'* and *1"* as seen from the center of the doorway of partition *A*, figure 2, showing the lower end of the lamphouse with food-bar attached to the frame upon which it rests.

IJ, *I'J'*, food-bar.
K, electro-magnet which holds *IJ* horizontal until released.
S, *S*, stimulus plate.
w, water level.

c. *Food-bar.*

At the center of the side *gh* of this frame is fastened a narrow metal strip or food-bar. It is 0.8 cm. wide and 24 cm. long after being looped at its center to surround

a pivot. This strip is folded to form a short trough at each end and has a drop of solder in one end to give weight enough to cause that end to fall when not held in place. At the corners *g* and *h* of the frame (figs. 1 and 3) are placed electro-magnets connected with a dry cell. When the switch outside the curtain is closed and the free end of the food-bar is placed against the magnet, the bar is held in position along the side of the frame, *gh*, above the aquarium. When the switch is opened, the weighted end of the food-bar falls so that it is beneath the water surface immediately above the front edge of the positive stimulus plate, at which point it is stopped by a peg in the frame *efgh*. Food placed in the shallow trough is thus allowed to fall immediately in front of the stimulus patch. When the stimulus patch is shifted from side to side, the food-bar is removed from the pivot and the ends reversed.

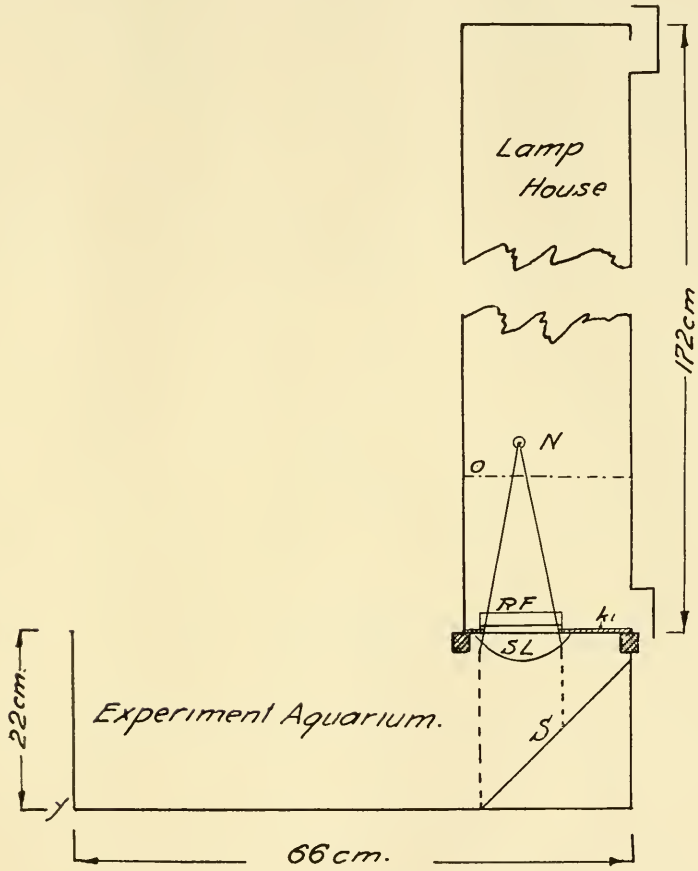

FIG. 4

Section of aquarium and lamphouse along line *xy* in figure 1.
N, Nernst glower in cross section.
O, level of slit.
RF, ray filter.
SL, cylindrical lens in kit *ki*.
S, stimulus plate of ground opal glass.

d. *Apparatus for Regulation of the Intensity and Distribution of Light.*

A plano-convex cylindrical lens (Yerkes 1903) 20 cm. long and 10 cm. wide, with a radius of curvature of 12.5 cm., was divided crosswise into halves. One of these was fitted into the frame at the bottom of the lamphouse in each side (*SL* in figs. 2, 4). The Nernst lamps are placed at the principal foci of the lenses with the glowers parallel to and above the long axis of the lenses. In this position the cylindrical lenses serve to parallelize the light rays in the direction indicated in figure 4. As the walls of the aquarium are black, the diverging rays which strike them at the sides of the stimulus plates (see fig. 5) are so little reflected as to be scarcely visible. But as the margins of these areas remain parallel they vary only in brightness not in shape. Their variation in brightness will be the same as the variation of the stimulus patches depending upon the slit-width. By this method no direct light from the glowers reaches the floor of the aquarium, and though the whole of each stimulus plate (S in fig. 2) is not illuminated, the patches of light on the two are exactly the same in shape and size. They are rectangular 12.3 cm. by 11.6 cm., and their edges are always sharp and straight across the plates.

To regulate the light intensity a slit is used (figs. 2, 4, 5). The slit consists of two steel plates and a narrow steel frame which is the size of the inside cross-sec-

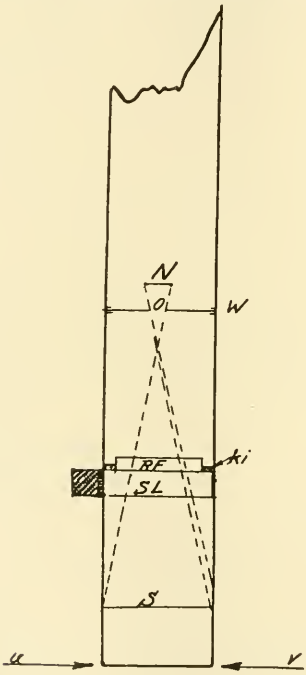

FIG. 5

Cross-section of one-half of lamphouse through Nernst glower along line *uv* in figure 1.

N, Nernst glower.
O, slit opening.
RF, ray filter in kit *ki*.
SL, cylindrical lens.
S, stimulus plate of opal ground glass.
W, groove in which the frame for the slit slides in and out

tion of one-half of the lamphouse and can be slid into a groove in either half of the house. Sliding in this frame is a pair of wide steel plates, each 48 mm. by 170 mm. with beveled knife-edges. The wide plates can be brought close together when a narrow slit is desired, or separated for slit apertures up to 4 mm. For greater slit widths two other pairs of plates 35 mm. and 25 mm. by 170 mm. are provided to replace the wider ones. The widths of the slit openings can be read on a millimeter scale on the frame. For regulating the slit width of 0.1 mm. intervals, a series of strips of accurately measured thickness are used. One of these strips is placed in the slit, the plates are brought against it, and the strip is then carefully withdrawn. The slit in position in the house is 3 cm. beneath the glower of either Nernst lamp. The direction of the slit is at right angles to the length of the glower and to the long axis of the lens.

To prevent any variation in the appearance of the lower surfaces of the lenses being seen by the fish, a curtain is hung across the top of the front of the sub-compartments *1'* and *1"*, reaching to the level of the upper edge of the stimulus patches. This is not shown in figure 2.

e. *Color-filters.*

The color filters, each 9 cm. square, are placed as shown in figures 2, 4, 5, in a photographic kit or frame 9 cm. by 9 cm., resting upon the lenses. The wave-lengths of light transmitted by the blue filter are λ4600 to λ5245 with the maximum in the blue; those transmitted by the red ruby glass are from λ5890 to the end of the visible spectrum. None of the yellow is let through by either filter, so that the light used is from two separated parts of the spectrum. The blue filter is a Wratten

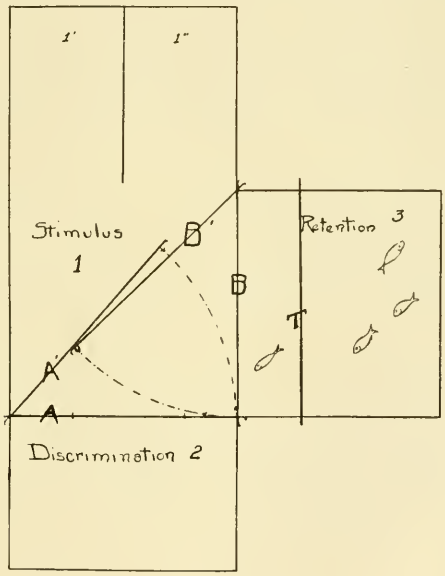

FIG. 6

Ground plan to show how the partitions are manipulated in testing the fish.
1'1", compartments for stimulus patches.
A, movable partition with sliding door.
B, *T*, movable partitions; *T* is used for cutting out single fish to be tested.
A'B', movable partitions swung out to allow fish separated from the others to swim from 3 to 2.

ray filter (Red 3.65 C 3-48 A) secured from the Eastman Kodak Company. The red is a piece of copper-flashed ruby glass.

4. Detailed Description of Methods

To make clearer some methods employed during experimentation the following details of procedure are included. That the fish might behave normally care was taken to avoid frightening them. They were allowed to live for months in the experiment aquarium without being lifted from the water or being moved in the aquarium. The partitions were moved very slowly. Often when they were shifted from one compartment to another, the fish showed absence of fear by swimming up to the partition as if to nibble its lower margin. It may be that the partition when thus moved resembles a clod which gradually settles to the bottom or slides along the stream margin and offers the fish a good place to feed, because worms previously covered are exposed. Because the fish exhibit little fear of these moving partitions, they were used exclusively when changing the fish about in the aquarium. A third partition, *T* in figure 6, was often put into the position shown, in order to separate from the other fish the one that it was desired to test.

Then after swinging the partitions *A* and *B*, figure 6, out to positions *A'* and *B'*, the fish to be tested would swim quickly into the discrimination compartment, and with *A* and *B* brought back into place, was ready for the raising of the sliding door, *D*, when a test was to be made. If when the door was raised, the fish swam toward the plate determined upon for the food association, that is, toward the positive stimulus plate, then the bar with the food was allowed to fall. After time had been allowed for feeding, the fish was brought back into the discrimination compartment by lifting the partition *A* with the door closed and slowly lowering it so that the fish was on the side away from the stimulus plates. The partition was then slowly returned to its former place. If the fish made a wrong choice it was not fed but brought back into the discrimination compartment without releasing the food-bar. The latter was not set free until the fish had come within 15 cm. of the positive stimulus plate. It was thus possible for the fish to change direction of response within the discrimination compartment or at any point between it and the distance of 15 cm. from the positive plate.

It was determined by the use of a mirror (see p. 46) that when the fish was swimming low in the aquarium, a reflection of the slit over the red plate on the surface of the cylindrical lens was sometimes visible to the fish when within 15 cm. of the stimulus patches and might guide it in its choice. Choice must therefore be made at a point farther from the plates. If the fish entered the negative half of compartment 2 but while still more than 15 cm. from the stimulus plates turned in a straight course toward the positive plate, then the food-bar was released and the choice recorded as correct.

It was found that caution was required, for when a fish swam up toward the positive plate, there was a tendency to drop the bar too quickly. The fish soon learned to go up to one side of the aquarium and wait, and if the bar was not dropped, to swim promptly to the opposite side. Only by very careful attention as to whether the fish was more than 15 cm. from the positive plate was this error avoided. If the fish was more than 15 cm. from either plate, the food-bar was not dropped and either side might be correct. Waiting for the food-bar could not indicate need for change of direction when the fish was at a greater distance from the plate.

That there might be no regular order for the side on which the positive stimulus was presented, six slips of paper were prepared, each with one of these inscriptions upon it:

1 *left*
1 *right*
1 *left*
1 *right*
2 *left*
2 *right*

Before the day's series was begun these slips were shaken together and drawn by chance, and the order in which they were drawn determined the positions of the positive plate. It will be noted that there is here possibility for only four consecutive tests to be made on one side. This procedure was followed to prevent the formation of "position habits." In order to prevent any possible "alternating swing," *i. e.* fish going first to one side and then the other, it appeared best occasionally to modify this possible order of choices by substituting for two of the single choice slips two with 3 *left* and 3 *right*. These gave the possibility of six consecutive choices to occur on one side.

When a fish had been given from five to twelve chances to discriminate between the stimulus patches, it was closed back into the retention compartment by means of partition *B* and was not used again until the following day's series. Care was not taken to keep the number of trials per day exact. The number of food masses seized and eaten was thought to be a better index of the physiological condition of the hunger of the fish than the number of tests given. Trials with an individual were, therefore, kept up until its behavior indicated that it was no longer hungry (until it had eaten about 6 to 8, or 8 to 10 food masses). This largely depended upon whether the fish were being tested every day or every second day. Care was taken to place the food-bar in exactly the same position with reference to the magnets. The two masses of food on the ends were made as nearly as possible of the same size and shape. Frequently, as the day's series progressed, new masses were placed on the lighter end of the bar. Both ends of the bar were kept wet. They were alike in appearance.

During the tests the operator observed the fish from behind the yellow curtain already mentioned. The stop watch and the string running to the sliding door were manipulated together in one hand while the other hand was placed on the switch so that no jar or body movement or motion of the curtain might indicate the correct side. The time was taken from the raising of the door until the food was snapped at or the fish was before the negative stimulus patch and less than 15 cm. from it. The path taken by the fish was then traced on a plan of the aquarium floor, the time recorded, and other notes made. The fish was then closed back for a second trial or closed out into the retention compartment while others were tested.

Matching Brightness.

Whenever it was necessary to match the brightness of two stimulus patches, either direct judgment of the appearance of the patches was used or the flicker photometer was employed. In the first case where the Equality of Brightness Method (Ives 1912) was employed one of the following graduate students in psychology,—Miss Marion Bills, or Miss Z. Pauline Buck,—directed the changes to be made in the variable plate until the two plates appeared to be equally bright. For assistance in this matching my gratitude is acknowledged.

The method for the use of the flicker photometer was as follows. The lamphouse with the frame and lenses was swung out past the end of the aquarium. The flicker photometer was placed immediately beneath the partition separating the halves of the lamphouse. Plates of ground opal glass, like the stimulus plates, were set beneath the lamphouse, each at an angle of 45° facing the flicker photometer. The light that fell upon these plates of ground glass was that which would give the stimulus patches when the lamphouse was in place, so that, as nearly as possible, the patches were matched against each other by this means.

5. Determinations of the Intensity and the Distribution of Light

In order to determine the relative brightness of the colored lights employed, so that the conditions may be duplicated in the future, the illumination used for the blue stimulus plate was measured. The method was to illuminate with a 110 volt tungsten lamp, at a suitable

distance and voltage, an area of the white stimulus plate equal to that illuminated by the Nernst lamp with the blue filter interposed and without a slit. These equal blue and white areas were then similarly placed with reference to the flicker photometer, and were equated by varying the distance of the lamp. The tungsten lamp, at its given voltage, was then calibrated by Dr. E. F. Barker of the Physics Department of the University of Michigan.

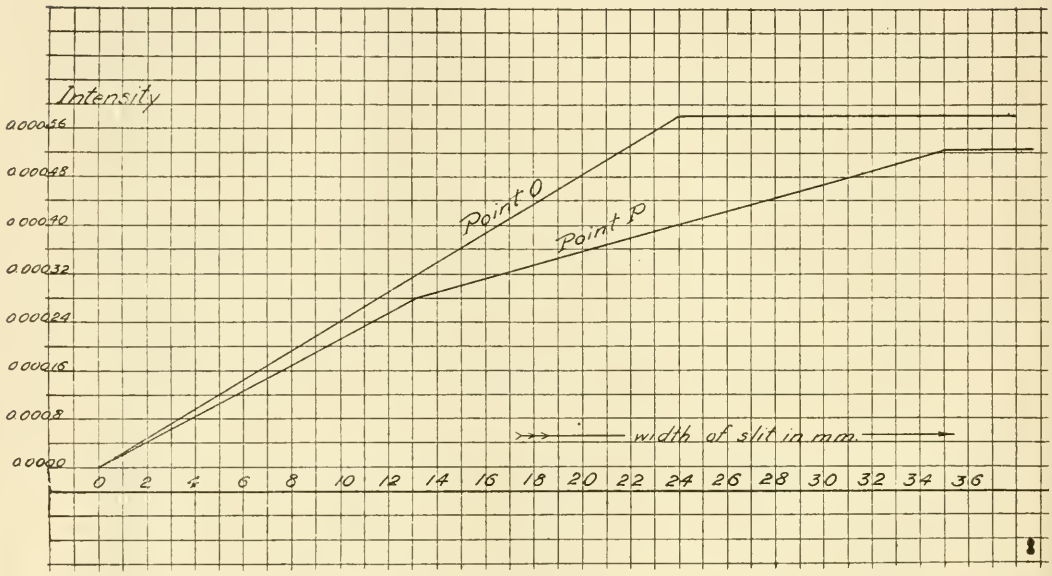

FIG 7

Graph of light energy in terms of width of slit. The relative intensities of light reaching the center *O* and the margin *P* of the lens aperture is represented. Abscissae give widths of slit, ordinates give relative light intensities.

Measurements against Bureau of Standards Lamp No. 2435 gave 2.35 candle power for the lamp. As it was 1 meter from the plate when equated, the blue stimulus patch had an intensity of 2.35 meter candles. It is to be understood that the blue plate was kept as nearly as possible at this intensity throughout the experiments.

In order to determine the relation between the light energy reaching the lens aperture and the width of the slit, and also to determine the relative light at the center

and at the margins of the lens aperture, the curves shown in figure 7 were prepared under the direction of Professor John F. Shepard. He also prepared the following description and determinations. The conditions of illumination

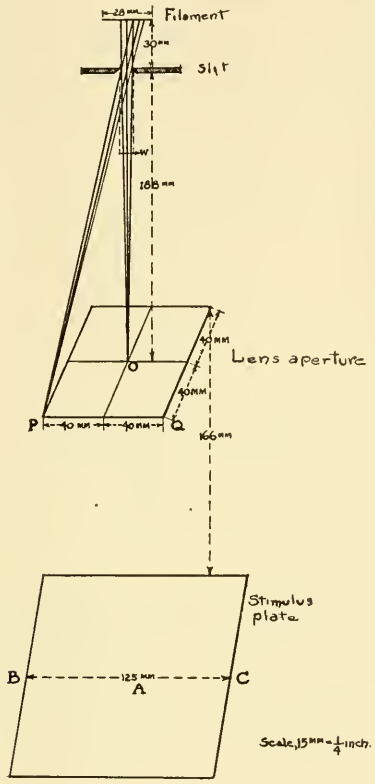

FIG. 8

Diagram to show the relations of light energy at the center and margin of the lens aperture.

were as shown in the diagram, figure 8. The effective portion of the Nernst filament used was 28 mm. long.

The slit was placed 30 mm. below the filament, and the lens was 188 mm. below the slit. The distance from the lens to the highest portion of the stimulus plate which received illumination was 166 mm. The aperture of the lens was 80 mm. square, and the stimulus plate was 125

mm. wide, measured on a line parallel to the Nernst filament and to the width of the slit.

Assume the conditions shown in figure 8 and let W equal the width of the slit. To find the intensity of illumination at O, let z be the range of points on the light-source from which light reaches O, and let d be the distance from such points to O. Also let Θ be the angle which d makes with the line perpendicular to the plane of the lens at O. Then the intensity of illumination received at O from each point on the source is:

$$\text{Intensity received at O from each point on the source} = \frac{K \cos^2\Theta}{d^2}$$

$$d^2 = 218^2 + z^2$$

$$\cos^2\Theta = \frac{218^2}{218^2 + z^2}$$

$$\text{*}_{*}\text{* the total intensity at O} = K \int_{-\frac{109w}{188}}^{\frac{109w}{188}} \frac{218^2 dz}{(218^2 + z^2)^2}$$

Similarly, let d' be the variable distance from points on the light source to P; let β be the angle which d' makes with the perpendicular from the light source to the line PQ; and let γ be the angle which d' makes with the line perpendicular to the plane of the lens at P; then the intensity at P from a point in filament equals:

$$K \times \frac{1}{(d^1)^2} \times \cos\beta \times \cos\gamma$$

Perpendicular from filament to PQ

$$= \sqrt{(218)^2 + 1600}$$

$$d^1 = \sqrt{(40 + z)^2 + (218)^2 + 1600}$$

$$\cos\beta = \frac{\sqrt{(218)^2 + 1600}}{\sqrt{(40 + z)^2 + (218)^2 + 1600}}$$

$$\cos\gamma = \frac{218}{\sqrt{(40 + z)^2 + (218)^2 + 1600}}$$

$$^{*}_{*}{}^{*}\ \text{Intensity at P} = K \int_{-\frac{109}{188}w + 6.38}^{\frac{109}{188}w + 6.38} \frac{[218\sqrt{(218)^2 + 1600}]dz}{[(40+z)^2 + (218)^2 + 1600]^2}$$

$$\text{Reducing-Intensity at } P = K \int_{-\frac{109}{188}w + 6.38}^{\frac{109}{188}w + 6.38} \frac{48374\ dz}{[z^2 + 80z + 50724]^2}$$

For the limiting case when the slit is removed,

$$\text{The intensity at O} = K \int_{-14}^{14} \frac{218^2 dz}{(218^2 + z^2)^2}$$

$$\text{The intensity at P} = K \int_{-14}^{14} \frac{[218\sqrt{218^2 + 1600}]dz}{[218^2 + 1600 + (40+z)^2]^2}$$

From these determinations the curves of figure 7 are plotted.

The curve " Point 0 " (fig. 7) shows the intensities of light at the center of the lens aperture for different widths of the slit, while the curve " Point P " shows the intensities of the light for point P, in figure 8, at the border of the lens aperture, for different slit-widths. The intensities are expressed on the ordinate by means of an arbitrary scale. It is to be noted that there is less difference in the light distribution between the center and the margin with a wider or with a narrower slit width than with a slit of 24 cm. Whenever a stimulus plate is illuminated without the use of the slit, or with any width in excess of 35 mm. the light passing through the lens aperture at its center will be as 100 per cent to 90 at the border. From the graph (fig. 7) it is plain that when the slit width is 24 mm. this difference in intensity will be maximum or the ratio will be as 100 to 71, and the difference between the center and the margin will be less with narrower slit widths. In

the blue-red series of experiments, pp. 25 and 48 the blue plate was illuminated through a 35mm. slit, the red through a slit constantly changed in width during the series. Relations were about as follows for the red:

Slit width	Ratio of illumination at centre and border	
35 mm.	100	90
24 mm.	100	71
14 m.	100	82
6 m.	100	89
3 m.	100	90
1 m.	100	95

For the blue as 100 at the center to 90 at the border.

C. *Experiments to Test Discrimination by the Formation of a Food Association.*—In this section are presented all experiments in which the attempt was made to establish a food association, together with a few experiments on innate response to white-light differences. In the case of each individual fish used the chronological order of the tests has been preserved, so that the past experience of each fish may be known in its relation to any particular series of tests.

1. Intensity Discrimination of Dace

To test the effectiveness of differences in intensity of white light in control of behavior, a horned dace or creek chub (*Semotilus atromaculatus* Mitchill) which had been in the laboratory for two years but which had not been worked with, was placed in the experiment aquarium. The ceiling lamp was lighted. After some hours the fish was closed into the retention compartment, the two Nernst lamps were lighted, and a slit with a 5.0 mm. aperture was placed in one side of the lamphouse, while the opposite side remained without a slit. The slit cut off about three-fourths of the total light reaching the stimulus plate upon that side. (See graph, fig. 7.) Both stimulus patches looked bright, but the one without the slit was of dazzling brightness.

By moving partitions *A* and *B* (fig. 6) this fish, called *Bu*, was brought into the discrimination compartment. On opening the slide door *Bu* swam up to the stimulus patches. Of the first seven responses, five were to the

duller plate, and each time the fish fed from the bar on that side. It seemed that, since the fish had fed from the bar at once and on the side of the duller plate, only a few trials would be required to fix the response. But more than 150 trials were not enough to show any increase in accuracy of response, and at no time was a more persistent " position habit " formed than developed here. The lack of learning is expressed in the curve, figure 9, which was made by plotting the average percentages of correct choice of each twenty consecutive trials.

Because there are individual differences and abnormalities among fish, *Bu* was taken from the experiment aquarium, and two other dace of the same reserve stock were placed in the aquarium and tested one at a time, under

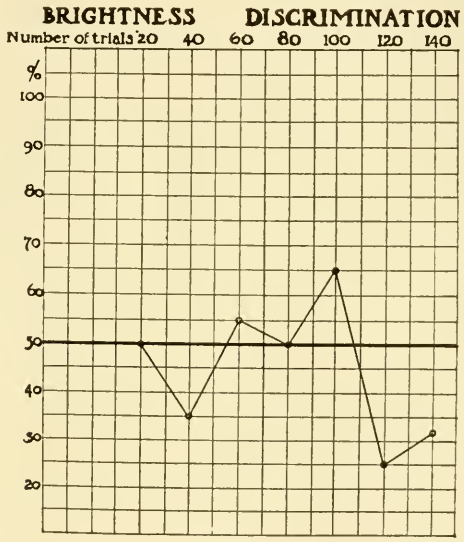

FIG. 9

Graph showing the percentage of correct choices in each 20 consecutive trials in a series of 140 trials of horned dace *Bu*. The choice was between two white plates of relative brightness 1:4. The fish was fed at the duller plate.

the same conditions as described for *Bu*. Of the first ten trials given, seven for each fish were to the duller, or positive plate. Again it seemed that it would be easy to train the fish to go to that plate for food, but sixty-five trials

for each fish showed no improvement. Fifty per cent of the choices were to each plate. The fish failed to learn to discriminate between white plates illuminated as 1 to 4 (see fig. 7). The early preference for the duller plate in these trials and the slow discrimination of the dace upon other problems (see fig. 13) made it seem probable that with a very long series of tests the fish might learn to discriminate. But neither the 150 tests of the fish *Bu*, nor the aimless behavior of the three fish in their swimming about before the stimulus patches, supports the opinion. Whatever the capacity of horned dace to discriminate intensity differences, they probably make little use of such

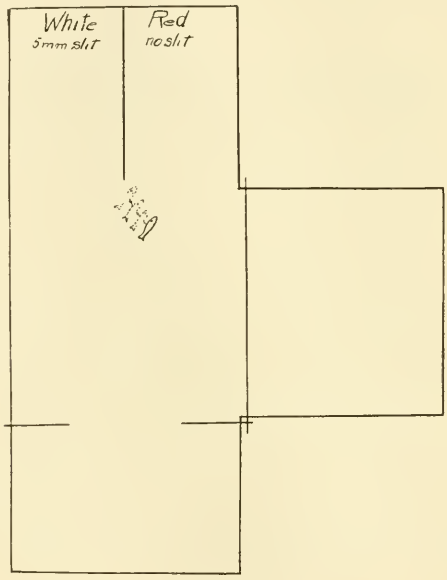

FIG. 10

Path of the dace along the limiting plane between the area illuminated by light from the red plate and from the white. (See p. 23.)

differences in discriminating familiar objects. By way of comparison it may be noted that under the same conditions of illumination these two large intense plates differed for the human eye when illuminated by slits of 8.0 and 8.5 mm., respectively.

2. Wave-Length Discrimination: White-Red by Dace

While the last two dace were failing to discriminate the two white plates, a red filter without the slit was placed on the side of the brighter plate. This cut off the rays shorter than λ 5890.[5] The illumination of the positive plate continued to be with white light through a 5 mm. slit. The results were most surprising. When the red was first introduced, each of the fish went to it for the first three responses. But the manner of approach was noticeably different from that to the white plates. The fish swam more swiftly toward the red plate, or after approaching darted away from it, or sidled along the edge of the red illuminated area, as shown in figure 10. This sort of behavior is described later in the case of "Large Sunfish," in which it was somewhat more striking. But it is to be noted that it took place here when the red filter had reduced the brightness of the total light to which the fish were accustomed, by cutting off a considerable part of its energy. It was not then a response to increased intensity. Each fish after from twenty to thirty trials, equally divided between white and red or showing a strong position habit, got the "cue," and for the following thirty trials gave 80 to 90 per cent white, or correct choices. When ten successive correct choices had been given, it seemed possible to conclude that discrimination was by means of brightness.

Hess (1909) has stated that the red rays have little effect on fish. If the introduction of the red plate had greatly reduced for the fish the brightness on that side, then the brightness differences between the red and white plates might now be greater for them than it had previously been between the two white plates; it might be greater for the fish than 1 to 4. This increased brightness difference might enable the fish to discriminate between the red and white, although they had previously failed to discriminate the two white plates illuminated as 1 to 4. It has been noted that the fish tended to swim along a plane separating two white illuminated spaces when there

[5] It is to be noted that the orange as well as the red wave-lengths, are included whenever the red stimulus is mentioned in this paper.

was a very considerable difference in their intensity. Their similar behavior toward the same spaces now illuminated with red and white might then be regarded as an intensity response. But the occasional peculiar method of approach to the red area was in no way like the behavior toward a dull white plate. It indicated that the fish were reacting to a difference between the quality of the dull white and that of the red. To learn whether the fish were reacting merely to a brightness difference between the white and red patches or, as indicated by their behavior, to a quality difference, a method was sought of equating the brightness of the red and white for the fish.

A tendency of the fish to rise to the surface of the water in pursuit of floating bubbles and dust had been noted when the red plate was first used in the red-white tests just described. This rising was like that often seen in natural waters on dull days or at sunrise or sunset when the sky is red. It was possible that under the conditions the rising was a response to light of any quality but of a definite brightness for the fish. In that case, if the rising response were shown toward two lights of different quality when presented separately, these might be regarded as of such brightness for the fish as to induce similar reaction. If the fish then showed differential behavior toward the two lights, the response must be based on wave-length, or quality differences. This supposition was tested by using a very dull white plate in place of the red.

The 5 mm. slit was left above the one plate, which thus remained illuminated with mixed light, while the red filter was removed from above the other plate and a second slit was introduced. This slit was gradually narrowed in successive tests until it was but little more than 0.1 mm. wide, but the rising response was not noted. When the slit reached 0.1 mm., the fish rose to the surface and snapped at small floating objects. Thus while the white light illumination of one of the plates remained constant, *i. e.*, that through a 5 mm. slit, that on the other plate was changed from red without a slit to white with a 0.1 mm. slit. The rising response took place with these two conditions of illumination. Apparently the light from the

red plate without the slit was for the fish in some way equal to white light through a 0.1 mm. slit, or the behavior was a chance response.

I decided to see whether the fish could discriminate between the two light patches that had apparently induced the rising action and were presumably equated in brightness, *i. e.*, the red without the slit and the white through the 0.1 mm. slit. I tested them with the red on one side and this very dull white on the other. The fish which had given the best response to the white continued to go to it and to feed before it as I shifted the plates from side to side, though the brightness of the white presented was now presumably reduced to that of the red. The other fish gave slight evidence of a "position habit," but on the second day responded accurately to the reduced white. The width of the slit used with the white was again changed to 5 mm., then to 2 mm,, then to 4 mm. Eighty per cent of the choices continued to the white. There seemed little possibility that brightness was controlling the behavior when a continually shifting brightness for positive stimulus was presented. The avoidance of a red plate at first and the ability to distinguish it from the white plate, even when the latter presumably matches it in brightness, is a more consistent explanation. The shifting brightness of the white plate did not prevent discrimination. That this red plate had a very definite value and a very different one from any dull white, was shown also by a tendency on the part of the dace to avoid the red illuminated area as compared to their indifferent approach toward the dimly illuminated white. But this initial tendency to avoid red was very brief on the part of the dace. It is doubtful whether such a tendency would be shown by all individuals.

3. Wave-Length Discrimination: Blue-Red by Dace

a. *Red chiefly at constant maximum intensity.*

To test the power of dace to discriminate longer and shorter wave-lengths, the apparatus already described was used with both the red and blue filters in place. By this means two patches of light were presented to the fish,

the one of wave-length λ 4600 to λ 5245, with maximum in the blue; the other of wave-length from λ 5890 to beyond the end of the visible spectrum. The two filters were quite different in the degree to which they interrupted the light. When the stimulus patches were observed with the filters in place but without the slit, the red was brilliant, while the blue was somewhat dull but a saturated color. In order to tell whether the illuminations used were effective, dace that were tame but without experience in the experiment aquarium were observed when put into compartment 2 and presented with the stimulus patches. They were not fed. At first one plate was illuminated with the light passed through the blue filter while the other was unilluminated. The straight approach to the blue as compared with the zigzag swimming on the non-illuminated side showed that the particular illumination was effective in modifying the behavior of the fish. Then with my eyes dark-adapted I matched this blue and a red in brightness by varying the width of a slit used with the red. The red thus reduced was presented to the fish in contrast with no-illumination. It was certain that the fish again responded to the lighted area by definite straight approach but moved in a zigzag course in the non-illuminated side. When the slit was removed and the brilliant red presented, while the other plate remained unilluminated, the approach to the red area was in a straight line; but the fish came only half the distance to the stimulus plate from the slide-door, then turned suddenly across the aquarium into the dark half, and retreated. Other tests showed that the brilliant red gave strong stimulation.

It was evident that both red and blue patches of light were effective as stimuli for the fish, and that without the slit the red stimulated more strongly than the blue. It now remained to discover whether the fish could learn to go to the blue for food, and whether at any intensity the red would give the same stimulation as the blue. If the fish could discriminate the red and blue patches at all intensities of red, it must be concluded that discrimination was on the basis of quality and not brightness. If, at any intensity of red, discrimination of the two patches became

impossible, it must be concluded that the patches were then of equal brightness for the fish and that they were unable to discriminate them by their quality difference.

The first tests were made without the slit, that is, with the red much more intense than the blue. They are presented in this section, while those with shifting values of red appear in the following section. The plate illuminated by the spectral band λ 4600 to λ 5245 (blue) was chosen for the positive plate, and the fish were fed before it and

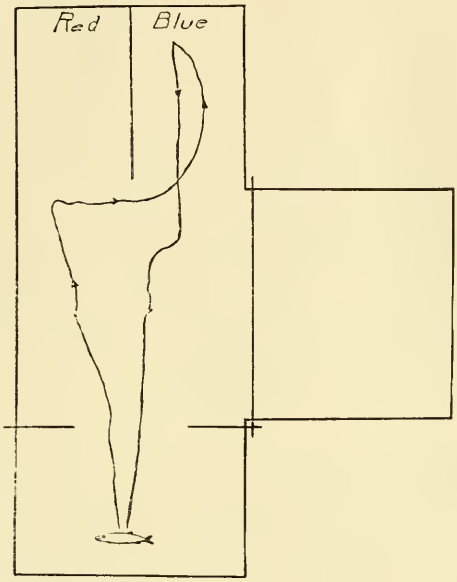

FIG. 11

The First Record of Fish *H* (see p. 28).

not before the red. The experiments were made with two horned dace, *Md* ♀ and *H* ♂. These fish had been in the laboratory a year, and the previous spring had been tested with red and blue in the experiment aquarium for some weeks. When they were again introduced into the experiment aquarium on the morning of October 13, 1914, they showed absence of fear by coming within two minutes to feed from my fingers. A detailed account of a single experiment will serve to illustrate their general character.

At 1:30 P. M. the curtains were drawn to exclude all extraneous light from the experiment aquarium, and the ceiling light was turned on. At 2 P. M. the Nernst glowers were lighted. By the method already described the fish were brought into the discrimination compartment. The slit was not used, so that the brilliant red patch and the saturated blue were presented. The slide door was raised a short distance. The two dace were swimming about the top of compartment 2, figure 2, and did not appear to note the opening. At 3:21 P. M. the slide door was again opened. *H* went into the blue lighted area, and although the food-bar was released and he remained near the end of the bar with its piece of worm, the food was not touched. His path is shown in figure 11. The approach to the red and then the straight path across in front of that plate appear to show an inhibition of further approach to the bright red area. At 4:20 P. M. the door was again raised and both dace swam out in the wavering paths characteristic of exploring fish. One went to the blue lighted area and fed. *H* was then closed into the retention compartment, while the fish *Md* was tested. A typical record (fig. 12) follows:

P. M.

4:53 Slide door opened.
4:54 Swimming back and forth in the discrimination compartment; pauses frequently with head in midline.
4:58 Pauses on either side of the midline.
5:00 Went out to blue area and up into the direct blue light; stayed there a time; fed.

In this preliminary work *H* was next tested. The first thirteen out of fifteen responses were to the blue. When *Md* was again tested thirty-eight out of forty responses were to the blue.

For the next ten trials of *H* the slit was used, so that the light intensity of the red was reduced to 66, 37, and 20 per cent of its maximum value. The fish went to the blue area nine out of ten times with this shifting intensity of red. It appeared that there was a decided tendency to approach the blue rather than the red. It was now evident that this was true even when the bright red was reduced in intensity.

During the following weeks a separate series of tests with the red at maximum value was made for each fish. The percentages of blue choices for each ten trials were:

For *H*: 80, 90, 80, 60, 40, 90, 70, 30, 60, 70 per cent.
For *Md*: 85, 50, 70, 70, 70, 80, 50, 80, 70, 90, 100 per cent.

The variations in the records from day to day, as shown in the above percentages and in the graphs, indicate that

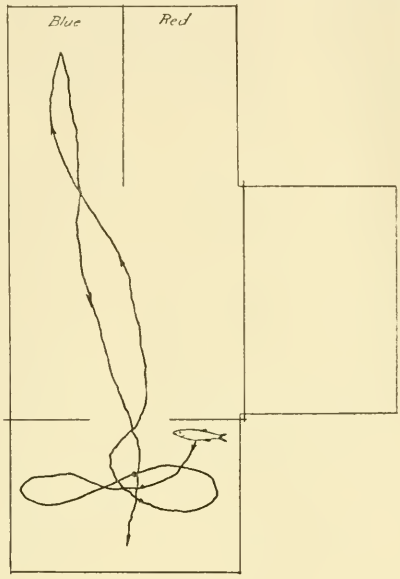

FIG. 12

Path of *Md* going from the discrimination tank to the blue illuminated area, p. 28

uncontrolled factors modified behavior. In figure 13, at. the left over the heading " Red Maximum " the records of these fish are shown in graphs plotted from the average percentages of correct choices in each twenty successive trials. In the graphs of *Md* and *H* the first 20 preliminary trials are also included. During the period covered by this series there were variations in the quality of the water supplied to the aquarium, due to changes in the filter cores, which become porous, and variations in the light due to changes in the electric current, which affected the intensity of the ceiling light. Besides these external variables some manifestations of breeding behavior indicated

an internal factor. A further indication of an internal factor was the behavior of fish *H*. He jumped from the aquarium once or twice and this jumping was on days when the fish had approached the bright light. In its native brook the male fish in the spawning season remains in the brightly lighted shallows rather than hiding in the dark pools (Reighard 1910). His jumping from the aquarium may have been a positive reaction toward stronger light. In spite of these modifications of behavior the record indicates that the fish discriminated between the red and blue when the red was very bright. This is especially true of the fish *Md*.

b. *Tests of dace Md. Blue with red decreasing in intensity.*

Since discrimination appeared to be possible with the red at the maximum intensity as well as at 2/3, 1/3, and 1/5 maximum, *Md* was again tested while the slit on the red side was gradually reduced in width so as to give a wide range of reduced intensities. The results are shown in figure 13, graph *Md*, at the right over the heading "Red decreasing." Her percentage of red choices remained between 85 and 95 as long as the slit opening was more than 1 mm. At a slit width of about 0.9 mm. the percentage of correct choices was only 60 for the first twenty trials (trials 201-220). But when the slit width was kept at about this value for twenty additional trials, the fish made 83 per cent of correct choices (trials 221-240). With greater reduction of the light intensity of the red area the fish continued to show a high percentage of positive or blue responses. This happened when the red was reduced in brightness so as to be duller than the blue for the human dark-adapted eye, and finally so dull that it had little color value to the human eye. The slit width was reduced successively to 0.9 mm., 0.6 mm., and 0.4 mm. Following this a photographic negative[6] was interposed to further reduce the light and was used with slit widths of 0.6 mm., 0.4 mm., and 0.2 mm., successively.

[6] A photographic negative was made by passing the light through the blue filter so that any local differences in the amount of light transmitted by the filter might be duplicated on the other side.

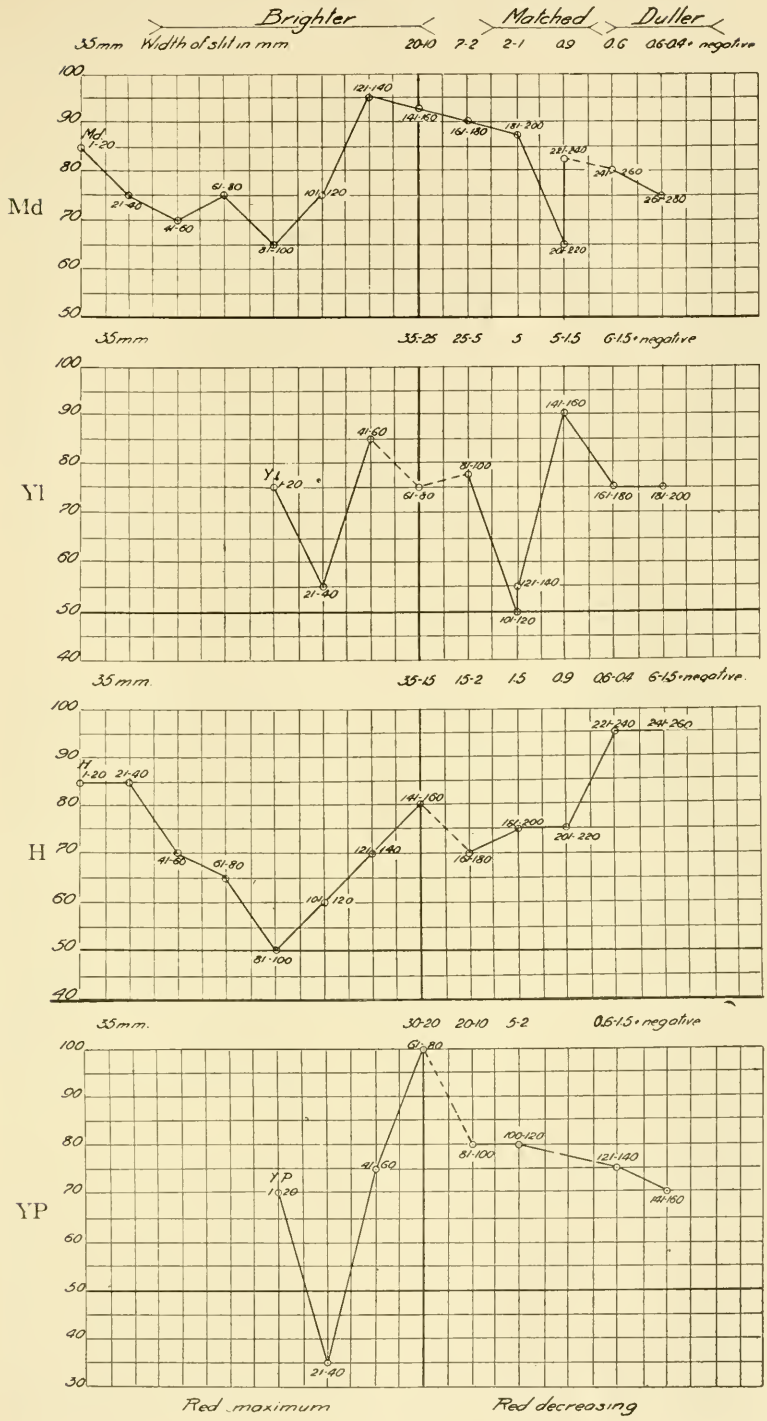

FIG. 13

Graphs made by plotting the percentages of correct or blue choices for each successive 20 trials of the four dace, *H, Md, YL, YP*.

Abscissae indicate successive slit widths in millimeters.

Ordinates percentage of correct choices

Short Dash lines show rapid changes in slit widths.

Long Dash lines indicate that no tests were made at intermediate widths.

Numbers on the graphs indicate successive groups of 20 trials from which percentages were calculated.

c. *Tests for the dace H. Blue with red decreasing in intensity.*

The fish *H* was tested day after day in the same manner as *Md* (fig. 13, graph *H* at right), except that the reductions in the width of the slit, and therefore in the intensity of the red plate, were more rapid. Changes in slit width, cutting off 15 per cent and 50 per cent of the light, did not cause failure to discriminate. When the intensity of the red plate approached the point where it matched the blue in brightness for the human dark-adapted eye (slit width 1.5 mm. to 0.9 mm.), the changes in slit were made more slowly. No failure to discriminate resulted, as the plotting of correct choices shows (fig. 13, graph *H*, red decreasing).

d. *Tests of dace Yl and YP. Blue with red decreasing in intensity.*

Other dace, *Yl* and *YP*, were introduced into the aquarium two months later than *H* and *Md*. Their records, also shown in figure 13, are less regular, but they show some points where the discrimination was very accurate at slit widths at which the records for *Md* and *H* were not taken for as long a series.

e. *Discussion of blue-red graphs of the dace H, Md, Yl, YP, and conclusions.*

The graphs of these fish, made by plotting the percentage of correct choices for each successive twenty trials, and distributing these according to the width of slit used with the red variable, are shown in figure 13. The slit widths appear at the top of the graphs, and the corresponding relative intensity of illumination of the red filter may be read from the curve, figure 7.

Each graph falls into two parts, as indicated at the bottom of figure 13. During the first part the red remains at maximum intensity. During the second part the red is slowly decreased in intensity by means of the slit. Each graph (except YP) may also be divided into three parts, determined by the human dark-adapted eye as indicated at the top of the figure. In the first of these the red is brighter than the blue; in the second the region of matched brightness for the human dark-adapted eye is reached;

while in the third the red is duller than the blue. The introduction of a negative to further reduce the intensity of the red is also indicated at the top of the graphs.

The general features of the entire graphs may first be noted. At first there was avoidance of the bright red plate. This shows in all the graphs in the high percentage of blue choices at the beginning. After the initial avoidance, there follows in the record of each fish a time when the bright red and the blue were approached with nearly equal frequency, as shown by the fall in the curves toward 50 per cent. This drop in the curves probably indicates that the fish were becoming accustomed to the bright red so that they no longer avoided it, while the association blue-food had not yet been formed. After the curves have descended they again rise while the red is still at maximum value. The curves thus reach a maximum indicating 80-100 per cent of correct or blue choices. Their rise is evidence of the formation of the association blue-food. With reduction of intensity of red the curves again descend to a level indicating but 50 to 70 per cent of correct choices. Thus as the brightness of the red patch is reduced to that of the blue for the human dark-adapted eye (slit width about 1.0 m), the ability of the fish to discriminate the two diminishes, but in differing degrees in different individuals. Failure to discriminate is evident in *Md* at a slit width of about 1 mm. (trials 201-220). In *Yl* the failure comes at slit width 5 mm. (trials 101-140). If no other trials than these had been made at these slit widths the curves would show for these two fish failure to discriminate at a certain value of the red variable. It would be fair to conclude that at this red value the red and blue were matched in brightness for the fish and were indistinguishable by means of any quality difference. The entire curves might then be interpreted in terms of brightness differences in the two stimulus patches. But when the fish failed to discriminate at a brightness of the red corresponding to slit width 1.0 mm. to 0.9 mm., in the case of *Md* and width 5 mm. in the case of *Yl*, the trials were continued at these widths (trials 221-240 for *Md*. 121-160 for *Yl*). The curves of *Md* and *Yl* then rise, and a return

of discrimination is thus shown. This return of discrimination is probably due to the failure to secure food, which has made the fish hungry and alert. With further reduction in the intensity of the red, discrimination is maintained in varying degree by all the fish. Discrimination continues when slit widths of red are reduced to 0.6 mm., 0.4 mm., and 0.2 mm., and finally when the interposition of the photographic negative has made the red so dull that it has scarcely any color value for the human eye. That the difference in distribution of light over the plates does not control the behavior of the fish appears from the results. For it is at slit width of 35 mm. for both plates that discrimination is easiest and at that width the light distribution is identical for the two plates. On the other hand discrimination is more difficult at slit width 5. to 0.9 mm. for the red plate and in this region there is a difference varying from 0.1 per cent to 10 per cent in the relative intensities of center and border in the variable plate. The ease or difficulty of discrimination does not vary with variation in illumination of the variable plate (Note the graph of fish *H*.) It is shown elsewhere that the dace did not learn in my own experiments to discriminate intensity differences less than 1:4. The most accurate brightness discrimination found by any worker is that reported by Hess (1909) in which differential response was obtained to two white plates illuminated as 1.0 to 1.23.

When the graphs of the four dace are compared, it is at once evident that they are not alike. Identity is not to be expected since fish differ in the degree to which they are influenced by external stimuli, in readiness of response, and perhaps in ability to discriminate wave-lengths. If we compare first the ' red maximum ' part of the curves, it is seen that the initial fall is more gradual in *Md* and *H* than in the other two fish. In both of them it involves 100 trials as compared with 20 in *YP* and *Yl*, and in the case of *H* there is no descent of the curve for the first 40 trials. Both *H* and *Md* had to be taken from the aquarium during the first part of this series of trials in order to perfect the adjustment of the apparatus. This probably accounts for the greater number of trials required

for them to "get used" to the red. *H* was of distinctly different temperament from *Md;* he gave more evidence of fright reactions and was more "cautious." Doubtless his failure to approach the red until after 40 trials was due to these peculiarities. The curves of *Yl* and *YP* are then more typical than those of *H* and *Md* in so far as they show a rapid adaptation to the red stimulus patch. During the 'red decreasing' part of the curves, temporary failure to discriminate is shown for *Md* at slit width 0.9 mm. In *Yl* it occurs at width 5.0 mm. In the case of *YP*, as the graph shows, no trials were made between slit widths 2.0 mm. and 0.6 mm. Had trials been made at this width, *i. e.*, between trials 120 and 121 of this fish, a drop in the curve would probably have taken place. Although trials were made with *H* at slit width 1.0 mm. and 0.9 mm., no considerable drop occurs at this point or elsewhere in his curve. The curve shows merely a lower region between slit widths 2.0 mm. and 0.9 mm. Somewhere in this region the stimulus patches probably matched in brightness for this fish. The fact that this fish discriminated more accurately than any of the others when the red was greatly reduced in intensity (trials 221-260) is consistent with his better discrimination at matched brightness. The greater caution of this fish has been referred to.

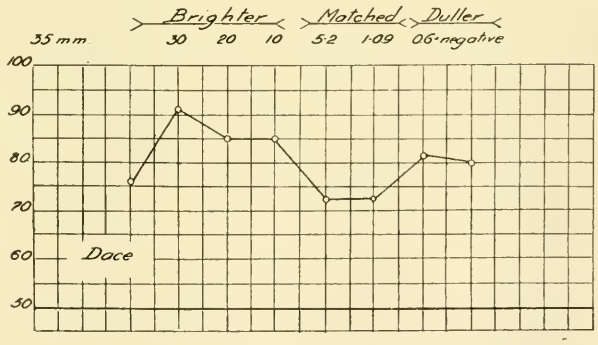

FIG. 14

Graph made by plotting the percentage of correct choices found by averaging all the records from the four dace for each successive width of slit. The individual graphs of these dace are shown in figure 13. Abscissae indicate successive slit widths in millimeters, ordinates percentage of correct choices at the given widths.

When we compare the curves of the fish *Md* and *Yl*, in which a distinct drop marks failure to discriminate, we find that this failure does not occur at identical slit widths in the two. It occurs about 5.0 mm. for *Yl* and at 0.9 mm. for *Md*. It is probable that in this region of decreasing red-brightness the exact point at which discrimination is lost and recovered depends on the chance rushing of the fish toward a red plate similar to the blue in brightness. When this occurred, it was shown by a fall in the percentage of correct choices—a fall in the curve. The slit-width was then held constant. As hunger increased through failure to get food, it may be that the fish became more alert and looked at the plates before it swam toward them. The percentage of correct choices then increased. Ability to discriminate between the plates was present at all these slit widths, but became manifest only when hunger helped the association blue-food to function in behavior.

If we take the records of these four fish, more than eight hundred in number, and plot the averages of correct choices at the successive widths of the slit, the curve (fig. 14) shows a region from 5.0 mm. to 0.9 mm. in which discrimination is less accurate. This region includes the point where the blue and red are matched in brightness for the human dark-adapted eye. But even here there is over 70% of correct choice; while the average percentage of correct choices for the whole series is a little above eighty. The individual curves show that at every intensity of the decreasing red the fish sooner or later discriminated. The composite curve shows no region of very low discrimination. It appears to follow from these experiments that:

(1) Dace do not easily learn to differentiate white stimulus patches of considerable difference in intensity (1 to 4).

(2) They discriminate promptly between red and white with variation in the intensity of the white, which includes a white intensity inducing a similar response to that of the red used.

(3) They discriminate between blue and red at all intensities of red. While there is at first lack of accuracy in response when these two colors were similar in brightness

for the fish, response becomes more accurate as trials with similar brightness are continued.

4. Intensity Discrimination by Sunfish as Indicated by Response

To study the relative sensitivity of sunfish to white light of different intensities, tests were made with some small (4 cm.) untrained sunfish. These fish had shown themselves sensitive to lower intensities of light, than the dace, for they stayed motionless in the farthest corner of the aquarium if brilliantly lighted patches were presented. The stimulus patches were therefore reduced in intensity by the use of slits on both sides. The fish were not fed, but their reactions were observed when the stimulus patches were exposed by lifting the slide door. When one plate was illuminated through a slit of 0.4 mm. and the other through one of 0.6 mm. there were slight differences in behavior toward the two. One record shows a straight return along the midline; another shows that in approaching the patches the fish swung back and forth to the mid-line. These turns, doubtless, were responses to a change of stimulus intensity at the mid-line. When one stimulus plate was illuminated through a 0.2 mm. slit and the other plate through slits successively 0.2 mm., 0.25 mm., and 0.3 mm., I could determine no difference in the behavior of the fish toward the two plates. The approach to either plate was in a smooth, straight line at these narrow widths of the slit. But when the two slit-widths were 0.2 mm. and 0.4 mm., then the approach to the brighter side was no longer straight but slow and wavering. When in this series the slit-width for the brighter plate was increased to 0.6 mm., while the other remained at 0.2 mm., the fish, instead of approaching the plates, lurked in the corner farthest from them. Reference to the graph (fig. 7), which indicates the light intensities reaching the aperture of the lens as varied by slit-widths, shows that with slit-widths 0.2 and 0.4 mm. the intensities were about 1 to 2 (as they would be for 2 mm. and 4 mm.). Hence a capacity to respond to intensity differences of white light somewhat greater than a 1 to 2 ratio is present in sunfish. This result was obtained by the method of response.

Two years after the tests just mentioned, one of the sunfish[7] which had meantime been trained in the discrimination of the colored plates, was tested by training methods for brightness discrimination of white light. A 1 to 2 intensity difference was not found effective even after long training. At first, slits of 4 mm. and 0.6 mm. were used, and food was given in front of the duller plate. The first fourteen responses were positive, *i. e.*, to the duller side. The width of the wider slit was then reduced. When the slits were 1.8 mm. and 0.6 mm. the fish showed 70 per cent of correct choice. When the slit-widths were 1.2 mm. and 0.6 mm., a long training failed to secure more than 50 or 60 per cent of responses to the duller plate. It is therefore certain that under training methods this sunfish was able to make use of a difference of intensity of 1 to 3 corresponding to slit-widths 0.6-1.8 (see fig. 7, graph for Point *O*) but not of a smaller difference under the conditions of illumination already described. It is possible, as indicated in the preceding experiment, that its unlearned response is the more accurate.

5. Wave-Length Discrimination. Blue-Red by Sunfish, with Red Decreasing in Intensity

a. *General Account.*—Three sunfish were used for this test, and each was separately tested.

A 10 cm. female sunfish (*Eupomotis gibbosus*) named Large Sunfish was put into the experiment aquarium at the same time and subjected to the same training test under the same conditions as the dace *Md* and *H* (p. 25). The red and blue stimulus patches were presented, but for a time the fish lurked in the dark corners at the farther end of the discrimination compartment. Then the fish when tested approached to the blue illuminated area in a series of rapid mouse-like movements, but it refused to eat before the lighted plates. It required *more than a month* to so build up the food association with the blue area that shifts could be made in the intensity of the red plate without inhibiting the response; and even then sev-

[7] This sunfish was " Small Sunfish " and was about 8 cm. long when used for these tests.

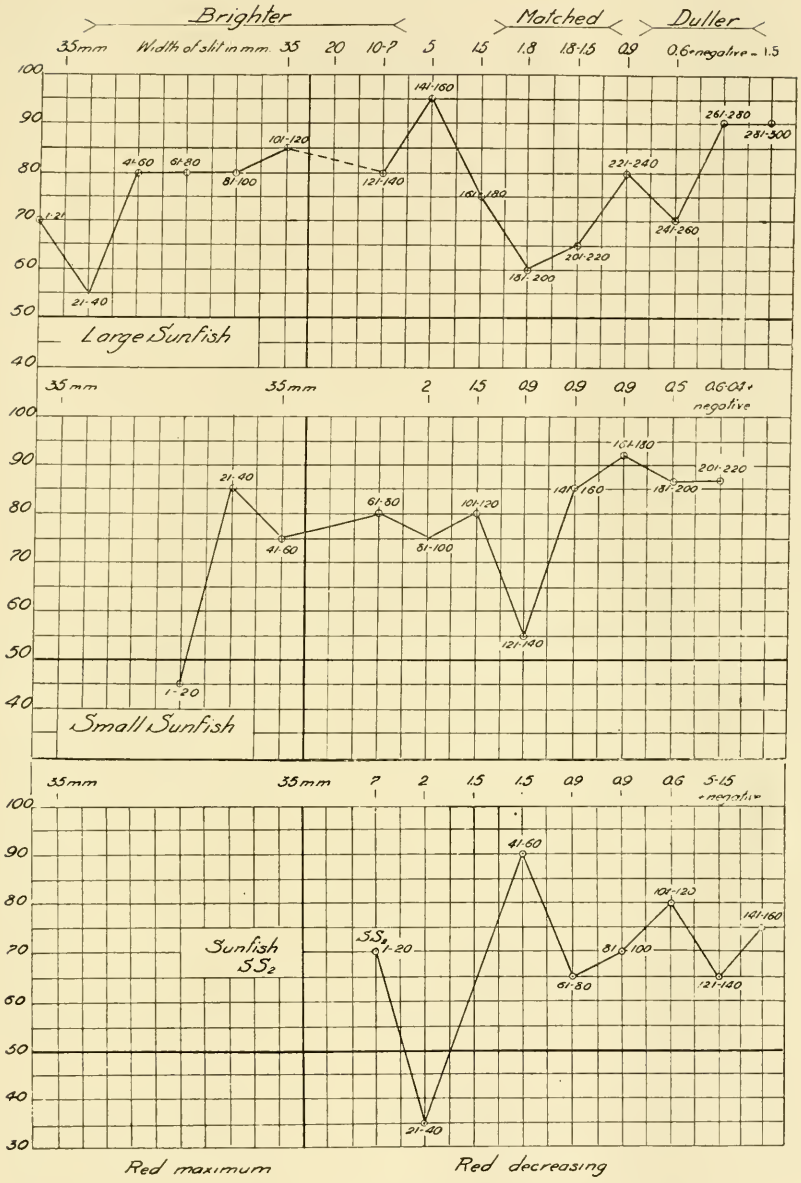

FIG. 15

The per-cent of correct choices of 20 successive trials for each of three sunfish. Dotted lines indicate rapid changes in width of slit.
Abscissae indicate successive slit widths in millimeters.
Ordinates percentages of correct choices at the given widths.
The numbers on the graphs indicate the successive groups of 20 trials from which the percentages were calculated.

eral minutes might elapse after the sliding door had been opened before the fish would leave the discrimination compartment. The inconvenience of this slow approach was in part compensated for by the rapid rush back to the discrimination compartment when the test was over. A series of tests was finally made with this fish, with gradual reductions of the width of slit.

Two small sunfish, which had had the same treatment as Large Sunfish, were brought into the experiment aquarium about the time that dace *YP* and *Yl* were introduced. Records were made of their first approach and behavior toward the red and blue stimulus patches in contrast with no-illumination. The eye movements of the fish, their orientation, and the straighter paths followed in approaching the illuminated plates, showed that both colored patches were effective in modifying behavior. Tests for the two small fish, Small Sunfish, of undetermined sex, and SS_2, a male, began in November, 1914.

The graphs of these three fish, made by plotting the percentage of correct choices for each twenty successive trials and distributing these according to the width of slit used with the red variable, are shown in figure 15. The slit widths appear at the top of the graphs and the corresponding intensity of illumination of the red filter may be read from the curve, figure 7. Like the graphs of the dace these may be divided into two parts, one in which the red was held at maximum intensity (35 mm. slit) and one in which the red was of decreasing intensity. They are also divisible into the three parts shown at the top of the figure, in the first of which the red is brighter than the blue for the human dark-adapted eye, while in the second the colors are matched in brightness, and in the third the red is the duller.

In the 'red maximum' part of the graphs it is to be noted that that of Large Sunfish is essentially like the graphs for dace (fig. 13). It shows (1) an initial avoidance of red, indicated by a high per-cent of blue choices (trials 1-20), (2) a subsequent getting used to the red (adaptation) (trials 21-40), shown by a drop in the curve to the 55 per cent level, and (3) a final establishment of

the blue-food association, *i. e.* the learning to discriminate, indicated by the rise in the curve to the 85 per cent level. The curve of SS_2 shows the same divisions (trials 1-60), but since this fish was given no trials with the red at maximum value the whole of its curve falls within the red decreasing part of its series of trials. In the case of Small Sunfish there is no initial avoidance of red. Its curve rises immediately from the 45 per cent (trials 1-20) level and ascends to 85 per cent (trials 21-40) as the food association is established.

In the red decreasing part of the series of trials the graphs again show a general likeness to those of the dace. In each of these curves there is a drop, shown most typically in the curve of Small Sunfish. Here it corresponds to slit width 0.9 mm., at which point the curve falls to the 55 per cent level (trials 121-140). This is in the region of matched brightness for the human dark-adapted eye and shows an initial failure to discriminate at this value of the red. As the slit-width is held at this value, discrimination is re-established in Small Sunfish (trials 140-180), and its curve rises above the 90 per cent level. A similar but less pronounced drop in the curve occurs in SS_2 (trials 61-80) and is followed by recovery. In Large Sunfish the drop occurs at 1.80 mm. slit (trials 181-200) and is followed by recovery. In general the sunfish graphs show the same characteristics as those of dace. In the composite sunfish graph (fig. 16) there is, however, a shorter region of inaccurate response with decreasing red brightness than in that of the dace. This might be expected from the greater ability of the sunfish to discriminate intensities of white lights. Their brightness discrimination has been shown to be more accurate. The peculiarities of the individual sunfish graphs may now be considered.

b. *Large Sunfish.*—The long graph of this fish differs from those of the other sunfish in showing a lack of discrimination at slit-widths 1.8-1.5 mm. rather than at 0.9 mm. None of the other experiments with red and blue indicates that in this region the brightness of the red matches the blue for sunfish. Small Sunfish and SS_2 gave from the first high percentages of blue choice at these

widths, as did three untrained sunfish which were tested. Two years after the experiments represented by the graph of this fish, Large Sunfish was again tested with blue against red with a 1.8 mm. slit. The first responses, made after 16 months absence from the experiment aquarium, showed great differences in behavior when compared with the earlier tests of this fish. It at once went toward the stimulus patches and either waited at a little distance or jumped toward the end of the food-bar. There was apparently retention and recall of kinesthetic behavior. I could discover no memory of the blue-food association. The avoidance of red was less marked than in the first responses of two years previous. A " position habit " soon developed. More than ten days passed before I discovered any differential response toward either plate but then noted that there was a difference in the length of time for the response to blue as compared with that to red. Then some days later the discrimination between the blue and red with 1.8 mm. slit became definite and exact. The ability of this fish to discriminate at slit widths 1.8-1.5 mm. does not then differ from that of the other sunfish. Its earlier failure at these widths may have been due to some internal factor or some undiscovered effect of manipulation. No further trials were made with it at slit width 0.9 mm. The curve of this fish indicates that it formed the blue-food association more slowly than the smaller sunfish. Eighty trials are required to bring the curve to the 85 per cent line (trials 40-120), while in the other fish this level is reached in twenty trials. This slowness is perhaps due to the greater age of Large Sunfish and the fear behavior at first so dominant.

c. *Small Sunfish.*—Small Sunfish learned the food association very quickly and gave high percentages of correct choice with the red at maximum intensity, but did not show the initial avoidance of the bright red plate shown by all the other fish. For this exceptional behavior I have no explanation other than that the fish lacked fear of the bright red plate as shown by the fact that it fed immediately from the bar. As the red light was reduced in intensity, there was no lack of discrimination. The percentage of correct choice remained about 80 per cent until a 0.9 mm.

slit was reached (tests 121-140). There was then, at first, a very great drop in correct discrimination, but with the slit held at this width the fish learned to go regularly to the blue for food, and when tested further with the intensity of the red lessened, showed no confusion.

d. *Sunfish* SS_2.—The small male fish, SS_2, was first tested with the slit at 7 mm. (graph SS_2 in fig. 15). For a time there was avoidance of this relatively weak red as shown by the 70 per cent average of correct choices for the first twenty trials. As the red was weakened, the tendency to approach it is shown by a marked fall in the percentage of correct choices at 2 mm. slit (trials 21-40), but the learning of the food association followed (trials 41-60). The record then gives a curve of learning more typical than that of the other fish (fig. 15, trials 21-160),

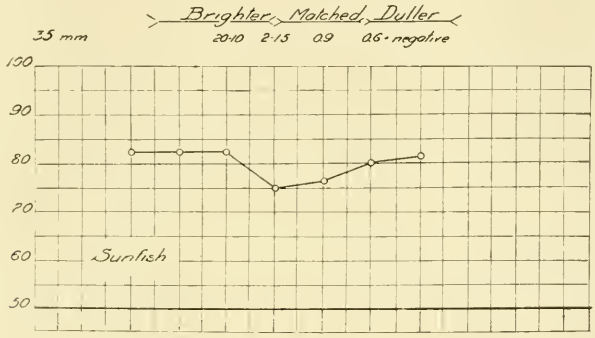

FIG. 16

Graph made by averaging all the percentages of correct choice of the three sunfish at the successive widths of slits indicated.

with fluctuations as the red became duller, but no lack of discrimination after the food association had been established. When the negative already described was used to further reduce the light, there was at first a few red choices (trials 121-140); but, as with the other fish, there was recovery, and discrimination became more accurate. The percentage of correct choices was then 75 or over.

When the graphs (fig. 15), made by plotting the percentage of correct choices for each twenty tests for each

of the three sunfish, are compared, it appears that with all three fish discrimination was easier and more exact when great brightness differences were present; but there was no intensity of red light tested where some fish did not show ten consecutive tests, with 90 to 100 per cent of correct choices. The average of all the sunfish records plotted, as in figure 16, fails to give a learning curve for two reasons: (1) there is at first an instinctive avoidance of the bright red plate; this gives a high initial percentage of correct or blue choices; (2) although the curve of SS_2 is similar in shape to that of the other fish, its successive high and low points occur at different values of red light intensity. The composite curve shown in figure 16 is, therefore, not a curve of learning; it shows merely that under the conditions of the experiment there is, at each intensity of red, some individual in the group that discriminates, so that the composite curve never drops to the 70 per cent level.

When the composite sunfish graph is compared with that of the dace it is seen (1) that the percentage of correct choices in the region of matched brightness for the fish is, on the average, higher for sunfish than for dace (compare figs. 14 and 16); (2) that the range of slit-widths where discrimination is less accurate is shorter for the sunfish than for the dace. Discrimination fails for sunfish at slit-widths 2-0.9 mm. and for dace at widths 5-0.9 mm. This is in accord with the greater capability of sunfish to discriminate white light intensities. The more exact aim of the sunfish in capturing their food is perhaps evidence of their greater visual acuity.

D. *Tests of the Apparatus and its Manipulation.*

In the preceding account of this experimental work it is assumed that the fish are guided in their choice of stimulus patches solely by the patches themselves. But the operator must frequently shift filters and slit from side to side and must at each test pull the door-string and operate the electric switch while looking through the peep-hole. It is, therefore, possible that the fish were guided to a correct choice by some one of these manipulations. It is possible that some difference in food-bars or filters of the

two sides may have aided the fish. Since the slit was used chiefly on the red side, on which the fish were never fed, they may have learned by seeing the reflection of the slit on the lens to go to the opposite side for food. Check tests were, therefore, made in order to learn whether anything else than the stimulus patch served to guide the fish.

1. Check Tests by Changes in Manipulation

a. *Shifts of slit and filters as a clue.*—The fish were invariably shut into the retention compartment before the apparatus was adjusted for the day's trials. Since they were then unable to see the stimulus plates or other parts of the apparatus, these could afford them no clue in making their first choice for the day. To see whether their choice in subsequent trials was possibly influenced by the shifting of filter and slits from side to side, I often introduced "make believe" shifts. These were interpolated in the course of the regular series of the day at times when the fish were discriminating accurately, and consisted in going through the manipulation of shifting slits or filters but without actually making the change. The responses of the fish were in no way affected.

b. *Position of the experimenter as a clue.*—To learn whether a possible clue was afforded by the movement of the string or curtain or of my eyes, when I was in the usual position at the peek-hole outside the curtain, I frequently made tests while inside the curtain or in some other unusual position. None of these altered the responses of the fish.

2. Check Tests by Change in the Apparatus

a. *Food-bar.*—Although, as already stated (p. 11), both ends of the food-bar were kept as nearly alike in appearance and position as possible, nevertheless, new food-bars were introduced from time to time, or the bar was occasionally removed and the fish were fed by hand if they remained before the blue plate. These changes made no difference in the percentage of correct responses of the fish.

b. *Lenses.*—At the close of the red-blue series I slipped out the lenses and tested the fish with only the red and blue filters in place. This reduced the intensity of the red and blue plates and changed the distribution of the light. Although the fish acted uneasy, they continued to discriminate.

c. *Filters.*—Because the blue filter showed some irregularities in transmission, which might be the sign by which the fish knew where to come for food, a new filter was obtained. The red filter was changed several times, but these changes did not affect behavior.

d. *Slits.*—In the experiments described a slit was used to regulate the light on the red side only. A mirror was used to determine the distance at which the image of the slit on the cylindrical lens was visible. The curtain already mentioned was used to hide the lenses from the fish (p. 14.)

After the experiments had been completed a further test was made on untrained fish to learn whether by any possibility the difference in the appearance of the lenses could have influenced the behavior of the fish. This consisted in extending the vertical partition *C*, fig. 1, to the doorway *D*. The fish thus chose while still within the discrimination compartment at a point from which there was no possibility of their seeing the lenses. It was found that the fish could be trained to go to the blue plate after the partition was introduced. The fish had not been guided by the reflection of the slit on the lens above the red stimulus patch.

As a further check a suspension of a very fine bone-black in a glycerine-water mixture was substituted for the slit. This suspension in different concentrations was placed in a glass-bottomed container above the red plate. By this arrangement there was no slit on either side. The blue patch remained rectangular and sharp bordered, but, owing to reflections from the carbon particles, the borders of the red patch were now indefinite. The small sunfish swam up to the blue at all intensities of red, including those which matched the blue for the human dark-adapted eye, as did also the dace *H*. The dace *Yl* circled about and gave indefinite responses, while *YP* went to the red plate.

The difference in the appearance of the red plate might easily account for the behavior of *Yl* and *YP*, while the discrimination of *H* and the sunfish showed that they were not depending upon the presence of the slit in order to reach their food.

Further evidence was furnished when a "new" blue filter was put into use. This let through the same range of wave-lengths as the old, or standard blue filter, but transmitted more light. In order to reduce the intensity of its color patch to match the standard blue, it was necessary to use a slit. The seven trained fish were tested with this "new" blue with the slit, and the red at maximum value, *i. e.*, without the slit. The result of this arrangement was to transfer the slit to the blue side and leave the red side without a slit. Of 34 trials 30 were to the blue. It was clear that when the colors were not matched in brightness the fish could discriminate with the slit on the blue side quite as well as they had hitherto discriminated when it was on the red side. The slit did not afford them a clue.

A short time after this the same fish were tested again, by the use of the slit with the new blue filter as in the last tests. To reduce the intensity of the red without the aid of a slit three separate means were used; the carbon suspension already mentioned, a solution of saffranin, or a solution of potassium sulfocyanide with ferric chloride. By use of the flicker photometer the new blue with the slit, and red reduced by one of the solutions were matched by varying the amount of the solution above the red plate. By this arrangement the slit was on the blue side while the red was without a slit. The experiment differs from the other experiment only in that the colored plates were matched in brightness. The distribution of the light over the two stimulus plates was again different because of reflections from the surface of the solutions employed on the red side. The results obtained are presented in Table I.

The dace *YP* and *Yl* failed to discriminate. The record of *H* may also show lack of discrimination. In the case of the sunfish the definite straight lines of their paths to

TABLE I

Table showing the blue and red responses of four dace and three sunfish when solutions were used to reduce the intensity of the red stimulus patches. The color chosen is indicated by x. Whether the response was to the left (L) or right (R) is also indicated.

Dace																Sunfish											
YP				Y1				Md				H				Large				Small				SS2			
Blue		Red		Blue		Red		Blue		Red		Blue		Red		Blue		Red		Blue		Red		Blue		Red	
L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
x	..	..	..	x	..	..	..	..	x	..	..	x	..	..	..	x	..	..	..	x	..	..	..	..	..	x	...
x	..	..	..	..	x	..	..	x	..	..	..	..	..	..	x	x	..	..	..	x	..	..	..	x	..	..	...
..	..	x	..	..	..	x	..	..	..	..	x	..	..	..	x	x	..	..	..	x	..	..	..	..	x	..	...
..	..	..	x	..	..	..	x	..	..	..	x	..	..	..	x	..	x	..	..	x	..	..	..	..	x	..	...
..	..	..	x	..	x	..	..	..	x	..	..	..	..	..	x	..	..	..	x	..	x	..	..	..	x	..	...
..	x	..	..	..	..	..	x	x	x	..	..	..	x	..	..	x	..	..	..	x	..	..	..	..	x	..	...
..	..	..	x	..	x	..	..	..	x	..	..	..	..	..	x	..	..	..	x	x	..	..	..	..	..	..	x
..	..	..	x	..	..	..	x	..	..	..	..	..	x	..	..	x	..	..	..	x	..	..	..	x	..	..	...
..	..	..	x	..	x	..	..	..	x	..	..	..	..	..	x	..	..	..	x	..	..	x	..	x	..	..	...
x	..	..	..	..	..	..	x	..	..	..	x	..	x	..	..	..	x	..	..	..	x	..	..	x	..	..	...
..	..	..	x	..	..	..	x	x	..	..	..	..	..	..	x	x	..	..	..	..	x	..	..	..	..	..	...
x	..	..	..	..	..	..	x	..	x	..	..	..	..	..	x	x	..	..	..	x	..	..	..	..	..	..	...
x	..	..	..	x	..	..	..	..	..	..	x	x	..	..	..	x	..	..	..	..	..	x	..	..	..	..	...
..	x	..	..	x	..	..	..	..	x	..	..	x	..	..	..	..	x	..	..	..	..	x	..	..	..	..	...
..	..	x	..	..	x	..	..	..	x	..	..	x	..	..	..	..	x	..	..	x	..	..	..	..	..	..	...
..	..	..	x	..	..	..	x	..	..	..	x	..	..	x	..	..	x	..	..	..	..	..	..	..	..	..	...
..	..	..	x	..	..	..	x	..	..	..	x	..	x	..	..	x	..	..	..	..	..	..	..	..	..	..	...
..	..	..	..	x	..	..	..	..	..	..	..	..	..	x	..	..	x	..	..	..	..	..	..	..	..	..	...
..	..	..	..	..	x	..	..	..	x	..	..	..	..	..	x	..	x	..	..	..	..	..	..	..	..	..	...
..	..	..	..	..	x	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	...
..	..	..	..	x	..	..	..	..	..	x	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	...
..	..	..	..	..	..	..	x	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	...
..	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	...
7		10		12		10		16		7		8		14		16		3		12		2		8		2	

the blue, as well as the number of correct choices of the three (35 blue to 7 red) made it plain that they discriminated without the aid of the slit on the red side when brightnesses match for human dark-adapted eyes. For the dace the record shows 41 red and 41 blue choices. These fish had long since ceased to avoid red. If their high percentage of blue choices in the preceding tests had been merely choices of the no-slit side, they should, in the series now described, have made a high percentage of no-slit choices, and in that case would have chosen red. Taken alone this set of data certainly indicates lack of ability on the part of dace to discriminate patches of light which for man match in brightness. The results, however, show that the slit was not the means for discrimination by these trained fish.

In some of these check tests the slit was not present on either side, in others it was transferred to the blue side. In the later procedure the fish did not show by high red choice that they were avoiding the slit and so using it as a guide. Further evidence that they were not guided by the slit appears in the section of this paper dealing with equated energy values (p. 53).

The changes in the sharpness of outline of the red stimulus patches may account for the tendency of the dace to go toward it to investigate the unusual, Table I. In other words, changes in the appearance of the stimulation patches were sufficient to inhibit temporarily the association in those individuals in which it was weakest. The series was not long enough to re-establish the habitual response.

E. *Tests with changed quality of light.*

A further attempt was made to determine whether the quality of the light of the stimulus patches was the means for the discrimination shown by the fish in the red-blue series. The red variable had been presented at all intensities from very bright to very dull as described in section *C*. In the last tests (described in section *C*) the changes in intensity were rapid. It was thought that substituting a patch of light of moderate intensity but of different quality for this red variable might show the significance of wave-length for fish.

Therefore the red filter was removed and in its place was put the photographic negative already referred to. By means of this negative there was obtained a dull patch of mixed (gray) light which was then matched to the blue with the aid of a flicker photometer by varying the width of the slit. The two patches were thus made alike in brightness for the human eye dark-adapted. The dace *H* and *Md* and three sunfish were presented, each separately, with the matched patches, and were fed before the blue plate. The behavior of the fish was so significant that this discussion might be placed in the division of this paper on Unlearned Responses but is placed here to preserve the chronological order so that the previous experience of the fish may be clearly in mind.[8]

The results are shown in Table II. Large Sunfish, Small Sunfish, and SS_2 chose the blue plate seventeen times and the gray plate but three times. The record for dace *H* shows 76 per cent of blue choices, not a high percentage. Of the 43 choices made by the five fish used 72 per cent were to be blue. These records are similar to those in which matched blue and red were used. As in that series the percentage of blue choices increased when the red was held at matched intensity, so here a longer series might have shown increase of percentage of blue choices. However, the number of tests made was relatively few. Further work will doubtless show what significance the percentage of choices may have as evidence that blue and gray are different for fish. That red was different from gray was evident from the behavior of the fish, for both delayed response and peculiar behavior occurred.

a. *Delayed Response.*—On the first trial each sunfish swam rather quickly up to the blue, but for the succeeding trials the time of response was either greatly increased or there was no response, and the fish remained lurking in

[8] Chronological Summary for *H*, *Md*, and *Large Sunfish*. 1914, Oct. 13 Introduced into Experiment Aquarium. 1. Blue-red Experiment. Oct. 13-Jan. 1, Red Maximum (A few early tests with decreased red). 1915, Jan. 1-March 20, Red Decreasing. 2. Check tests. Mar. 20-Apr. 2, With solutions. April 3-5, Blue-Gray Experiment. April 8-10, Equated Energy.

The data of introduction of *Y'*, *YP*, also *Small Sunfish* and SS^2 was the last of November 1914. Their dates differ in that the Blue-red series is shorter but in the following experiments the dates are the same.

TABLE II

Table recording the responses of two dace and three sunfish when blue and gray stimulus patches which matched for human dark-adapted eyes were presented. These fish had been fed before the blue plate for some months when it had been presented with red. (See graphs, figs. 13, 16.)

Md					H					Large					Small					SS_2				
Time in sec.	Blue L	Blue R	Grey L	Grey R	Time in sec.	Blue L	Blue R	Grey L	Grey R	Time in sec.	Blue L	Blue R	Grey L	Grey R	Time in sec.	Blue L	Blue R	Grey L	Grey R	Time in sec.	Blue L	Blue R	Grey L	Grey R
70				x	5				x	19			x		60	x				3	x			
230				x	8	x				31	x	x			480			x		10		x		
420	not	out	of	2	7			x		nottaken	x				660	not	out	of	2	25		x		
8				x	8		x			23	x				30	x				57		x		
10				x	6	x				120	x				360	not	out	of	2	5		x		
6	x				5	x					not	out	of	2		x				9		x		
17				x	4		x			20				x						6	x			
					6	x				30										nottaken	x			
					6	x				120										8				x
					6	x				120	x													
					10		x																	
								x																
					7		x																	
					6	x																		
					7		x																	
					19		x																	
					9	x			x															
					10	x																		
	1		5			13		4			6		1			3		1			8		1	

the discrimination compartment (2 fig. 1). They remained for perhaps six to ten minutes quite motionless. Table II in the column marked "time in seconds" shows these delayed responses. "Not out of 2," in the table indicates no response.

In the case of Small Sunfish the usual time for response in the blue-red series was eight to twenty seconds. In the series described on page 38ff, I have records of 30 to 50 seconds, but none of 480 seconds and none of failure to leave the discrimination compartment.

Before testing *Md* with this blue-gray I had tested her three times with red-gray, twice with this same gray against very bright red, and once with the gray against a duller red. She had gone each time to the gray and been fed. The time for these successive responses was 20, 10, and 6 seconds. Her delay (70 and 230 seconds and refusal to respond) when gray was substituted for the red, convinced me that for this fish red differed from a matched gray. The fact that this fish had just been fed before the gray may explain the continued gray response shown in Table II. A somewhat lengthened time for response often occurred in the blue-red series. This was more frequent on the third or fourth test for the day than on the first, apparently because hunger prevented delay in the first response. By delay in response these fish showed that the change from light of longer wave-length to mixed light had been effective in stimulating them. The light was evidently the means of discrimination, and quality rather than intensity was the effective stimulus.

b. *Peculiar Behavior.*—When the blue-gray patches were exposed to the three sunfish, each advanced toward them, halted, retreated, and acted now as Large Sunfish had acted when the blue and red were first presented. The behavior of *Md* when the blue-gray patches were first presented was like her behavior when the *bright* red and blue were first presented, some six months earlier. She now, as then, swam back and forth across the discrimination compartment before the door and finally up toward the gray patch where she had just fed.

To summarize, the sunfish by peculiar behavior and

delayed response clearly showed that the change from red to gray light of presumably equal brightness was effective in modifying behavior. The dace *Md* showed the same modifications of behavior, but the dace *H* did not. Just before these tests were made, this fish had been presented once with a dull red and gray. After going up to the gray, he shied off from it as if frightened. It was plain that the gray stimulated. The lack of uniformity in the response made by the different individuals at any one time and shown by these fish is characteristic of fish.

F. *Tests with Energy Equated.*—It has been held (Laurens 1911) that animals are able to differentiate between various light stimuli, not by difference in luminosity or subjective value as measured by the eye, but by difference in radiant energy, *i. e.*, by mechanical value as measured by physical instruments. The possibility, therefore, that the radiant energy differences of the stimuli might account for the discrimination already described, must be tested. If the radiant energy reaching the two stimulus plates were made equal, and the fish, especially the sunfish, could still discriminate, then the possibility that they discriminate by radiant energy would be eliminated. In order to equate the energies on the stimulus plates a bismuth-silver thermopile was used (Coblentz 1913). It was placed in the center of a heavy glass container, fitted into a cardboard support. This made it possible to place the thermopile beneath the lenses above the edges of the stimulus plates. The thermopile was connected with a sensitive galvanometer. On one side were placed a water-cell, a slit, and a new blue filter; on the other was the red filter and a solution of potassium sulfo-cyanide and ferric chloride. The energy passing through the red filter was altered by adjusting the depth of the solution above it until the galvanometer deflections were the same when the *bi-ag* thermopile was shifted from one side to the other. The energy of the two plates was also equated by means of a slit on the red side, while a water cell and slit were used with the blue. The relative brightness of the energy-equated plates varied for the human eye according to the method used. When the red solution was used, the red plate was some-

what the duller at equated energy, but with the slit on the red side, and water cell and slit on the blue side it was

TABLE III

Table showing percentages of red and blue choices for four dace and three sunfish when the radiant energy of the two stimulus patches was equated.

	Dace				Sunfish			
	YP	YL	Md	H	Large	Small	SS_2	Totals
Red choices	6	2	5	0	7	0	2	22
Blue choices	3	8	13	10	12	15	17	78
Per cent of blue choices	33	80	72	100	63	100	84	78

possible to so adjust them that the red was brighter or duller than the blue or matched it at equated energy values.

When the energies of the two plates had been equated, the fish were tested by feeding before the blue plate as in the red-blue series. The results are shown in Table III.

The record of Large Sunfish is difficult to interpret. For the first six tests this fish went to the blue. Then while keeping the energies equated, I increased the brightness of the red; the six following trials were to the red, then one to the blue, one to the red, and again five to the blue. The conditions were duplicated some days later, and when this fish was retested, discrimination was accurate. In the record of *YP* of nine trials, six choices were red and three were blue. The curve for this fish (fig. 13) shows that there were abrupt changes in the slit widths during its series of red-blue trials, and that in the region of matched brightness no trials were made. The fish apparently had not retained the blue-food association. The remaining fish show percentages of correct choices ranging from 72 to 100.

It appears that when the energy is equated, the fish can still discriminate, and that consequently relative energies do not condition the discrimination. (See postscript.)

During these tests the intensity of the blue light was changed so that there was added evidence that the choice of blue by the small sunfish (p. 42) was not merely a response to light of a given constant intensity. But the disturbances in the behavior of Large Sunfish and *YP* did not occur when the blue intensity was changed, hence cannot be attributed to that cause. Since the slit was used in a part of these trials on the blue side only and in a part of them on both sides, the series affords additional evidence that the position of the slit did not guide the fish in their choice (see p. 46).

G. *Results of Experimental Work with the use of Food-Association.*

In the foregoing experiments with stimulus patches of different wave-length it is believed that the responses of the fish were made to the light on the stimulus plates and were not dependent on any other part of the apparatus nor on its manipulation. The radiant energy of the plates, as measured by physical instruments does not appear to have been a controlling factor. The fish were therefore responding either to the wave-length difference between the plates or to a brightness difference. At one point in the series the colored plates were matched in brightness for the human dark-adapted eye and the behavior of the fish indicated that they were matched in brightness for them. Since it is possible that fish have a capacity to discriminate very small intensity differences between stimulus patches of like quality, a capacity even greater than that of man, it became necessary to test them with respect to this. When thus tested the dace failed, under the conditions of the experiments, to learn to discriminate intensities of white light which differed as 1:4 while sunfish did not discriminate intensity differences of 1:2. As it is certain that the intensity difference between the colored patches discriminated by the fish are far less than these, it follows that this discrimination is based on a difference in the wave-lengths of light of the two plates.

At the critical value of the red variable (slit width of about 0.9 mm. in most of the graphs) there is temporary

failure to discriminate with return of discrimination as the tests are continued at this value. This temporary lapse of discrimination and its subsequent recovery are held to be evidence of matched brightness of the stimulus patches.

The evidence for discrimination of the stimulus patches by a quality difference between them is quite uniform and is most readily appreciated in the graphs figs. 13 and 15. A fuller discussion of the whole question is reserved for the final section of this paper—but attention is here called to the case of failure to discriminate at matched brightness that appeared in the training experiments. In this case the slit was removed from above the red filter and was replaced by solutions which reduced the intensity of the red to that of the blue. The result was a change in the distribution of the light on the red plate. The dace failed to discriminate. (Table I.) Two explanations of this failure are suggested. Either with matched brightness of red and blue discrimination must be maintained by *constant* use when the red has become familiar, and this had not been done, or the fish in this case were tending to go to the modified red plate, changed enough in appearance by the solutions to awaken their "curiosity." As Bauer (1910) has shown, they often go toward an unusual object. Of course, there are those who will be apt to call attention to the fact that here a psychic factor is resorted to in order to account for what will appear to them to be proof of inability to distinguish differences in color as shown in response of a particular fish. It appears, however, that a psychic factor is continuously resorted to in this problem; namely, *brightness discrimination.* The change in the appearance of the red plate by the use of solutions modified response, in that after the first responses another psychic factor dominated behavior. But Table I shows that all *first responses*, even with a modified red plate, except that of SS_2, were to the blue. After a bite or two, hunger did not inhibit the tendency of dace *YP* and *Yl* to go frequently to the slightly modified red plate. In view of the uniformly positive results obtained in other experiments, little importance is attached to this single failure and it

is not doubted that a longer series of tests would have re-established the response to blue

Besides the percentage of correct choices in the two series of training experiments, there is the incidental evidence in delayed response and in peculiar behavior shown by the fish when gray was substituted for the red to which they were accustomed. But in the next section further evidence of innate differential response to light of different wave-length will be presented, which gains weight from the results obtained by the training method.

H. *Unlearned Responses of Fish.*

a. *Modified breathing rate of fish subjected to light of long wave-length.*—That the longer wave-lengths of light have a peculiar stimulating effect on fish has been mentioned on p. 2. Parker (1903) found that he could use the respiration rate as a means of detecting effective sound stimuli for fish and I have twice noted a change in breathing rate following exposure to light of long wave-length.

(1) A mud minnow, *Umbra limi*, had grown quite tame during a year's careful feeding. The fish was somewhat used to a tungsten lamp above the aquarium. One morning the breathing rate was counted with daylight illumination, before the lamp was turned on, and after the lamp was turned on the rate was again counted. There was no change. A piece of ruby glass was placed under this lamp and it was then left for some days with the light turned off so that the fish might become used to the ruby glass. On the morning of the test the breathing rate was normal, about 30 per minute. I turned on the red light while experimenting with another fish. When I looked to observe the *Umbra* after the red light was turned off, the fish had changed position. It had settled closer to the bottom of the aquarium and was trembling and panting in such a peculiar fashion that I forgot to count the breathing. It seemed that it was more than twice as fast as when counted just before the red had been thrown on it.

(2) A black lined box with a 16 candle power incandescent carbon lamp inside it was placed with an open end against an aquarium containing a number of shiners (*No-*

tropis cornutus), 7-10 cm. in length. The apparatus was in a room illuminated by daylight.

Counts of respiration rate in diffused daylight gave about 60 per minute. The respiration rate of a quiescent fish was then taken while the artificial light in the box was shining upon it, and gave 85 per minute. A ruby glass was then placed in front of the carbon lamp. The effect of this was to change the quality of the light to which the fish was exposed but to lessen its intensity. The respiration rate in this less intense illumination by red light was found to be increased to 150.

b. *Other characteristic behavior of fish in the presence of stimulus patches of unfamiliar light of long wave-length.*

(1) *Sunfish.* In describing the red-blue training experiments I have already referred to the peculiar avoidance of red shown by sunfish unaccustomed to it. During the first weeks of the experiments in which the blue and red

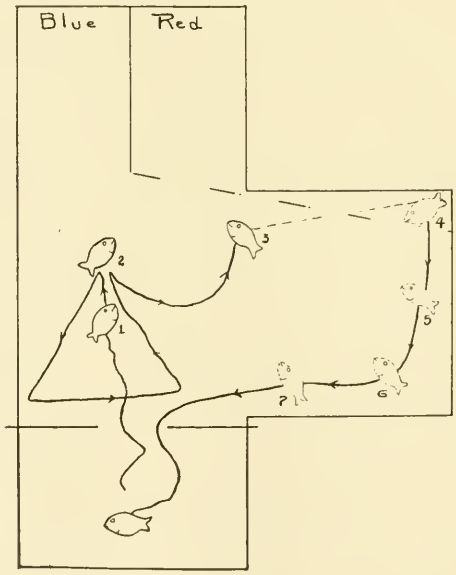

FIG. 17

Path of Large Sunfish in the experiment aquarium to show the effect of red light on its movements. The red illuminated region is bounded above by the straight broken line. For explanation see text.

stimulus patches were presented to Large Sunfish there were many records of peculiar behavior. One such record from my notes follows (see fig. 17):

"As the slide-door went up, the sunfish made straight for the opening, went about one-third the distance to the stimulus patches; halted six seconds (position 1), then went up toward the blue (position 2). Food was released and fell close in front of its mouth. The fish did not snap at it. It was a piece of angle worm and nearly white against the black floor. Then followed a movement of retreat to the further end of the stimulus compartment in front of the door. The same fish then returned nearly to its former position (2) in front of the blue. I let a piece of worm fall through the water, but it was not touched. The fish circled around to the red side (position 3). There followed a swift dart toward position 4 indicated by the dotted line in figure 17. This was not like the usual slow swimming up toward the stimulus patches, nor like the retreat around the outer edge of the retention compartment which followed it and is indicated in the figure (positions 5, 6, and 7). During all these movements except the swift dart from 3 to 4 and in all positions except 4 the head was toward the red plates."

Avoiding reactions toward red were observed with all widths of slit, even those so narrow that the light transmitted was very weak. They were not so vigorous with weak red light as the reaction just described, but they showed, at least, that intensity was not the only factor in their conditioning. Besides this peculiar response to red there was noted an equally interesting mode of behavior of the sunfish toward blue. Large Sunfish, even in the same tests in which it was giving this vigorous avoidance reaction toward red, repeatedly came close to the margin of the blue patch of light and remained there, sometimes with the head just above the margin of the stimulus plate. Often at such times the body of the sunfish was turned slightly on one side so that the sagittal plane formed an angle of about 30° with the vertical. My notes frequently record, "Cocked its eye at the blue." This was frequent behavior for the other sunfish also.

(2) *Minnows.*—Peculiar behavior toward red was less marked in minnows than in sunfish but was occasionally quite striking.

Pimephales.—Some nearly full-grown minnows which had been one week in a stock aquarium, and were not yet tame, were tested as to first responses toward blue-red and also toward blue-gray patches which were matched in brightness. Seven *Pimephales notatus* were tested. Each fish was presented with the matched blue-gray patches

without being fed. There were 28 approaches to the patches, 14 of them to the blue. The two patches were approached by all the fish in the same way and with equal frequency; the time of approach varied from three seconds to three and one-half minutes. When identical matched patches were presented immediately afterward except that one was now red, the other blue, the behavior changed. Two of the fish, after watching for a time at the doorway, slipped out of the discrimination compartment, went an inch or two into the stimulus compartment, and then returned by backing out of the stimulus compartments. They repeated this manoeuver. One did not leave the discrimination compartment for seven minutes; another still lurked in the discrimination compartment after fifteen minutes.

Semotilus.—A horned dace, an untrained fish from the same stock as the *Pimephales*, was placed in the experiment aquarium one noon. The ceiling light was turned on. At 3:15 that afternoon the sliding door was raised and *matched* blue and red plates were exposed. For a time the fish was quiet, then it went slowly a short distance into the stimulus compartment, then lay in the doorway across the shadow of partition *A*. It then swam back into the discrimination compartment and circled around the back of the compartment facing the lights. After 295 seconds the fish went up to the blue plate. It was closed back into the discrimination compartment by use of partition *A*, and after fifteen minutes the sliding door was again raised to expose the matched blue-red patches. Five times the fish upon coming to the door-way turned with its head away from the stimulus patches so that the posterior half of the body projected out of the door into the stimulus compartment, then swung its head across the doorway and moved back into the discrimination compartment. It then circled across the end of the aquarium and after 340 seconds swam to the blue plate.

This dace was tested with matched blue and gray patches, two hours later. Twenty seconds after the slide door was raised the fish was at the gray plate, and 30 seconds was the time for its second trial. Three hours later the blue

and red were again used. When the door was raised the fish stood in the doorway three minutes, then went forward an inch into the stimulus compartment and backed away. It next turned straight toward the red plate and darted forward to within 20 cm. of it, then drew back and darted up to the blue stimulus patch. It is to be noted that the waiting in the discrimination compartment of the untrained minnows and their circling across the doorway in the presence of the red-blue patches are exactly the sort of behavior that the dace, habituated to blue-red stimulus patches, gave when the blue-gray was presented to them. When the matched blue and gray were presented to the untrained minnows, all the fish tested swam promptly to these plates. They went an equal number of times to each plate. They often swam from one plate to the other. I could detect no differential behavior toward either, but these same untrained minnows, when presented with the red and blue, often remained at a distance from the red or turned from it or swam vigorously toward it. In other words, the introduction of red in place of gray brought about a differential response in those untrained fish. This took place when no part of the apparatus was modified in appearance except the stimulus patch. Without the evidence of the long blue-red training series the tendency of fish to change their behavior when the red plate is first exposed might be attributed to brightness differences, although the plates matched in brightness for human eyes. But in the red-blue food association series with the variable red intensity, the *least* discrimination was shown by experienced fish when the red and blue first approached matched brightness for the human eye. Therefore, if untrained fish showed a differential response when the red plate was first exposed at this matched brightness, this could scarcely be due to its brightness.

When untrained fish were presented with blue-gray patches that matched for the human dark-adapted eye, they showed no preference for either plate and gave no indication that the two patches were in any way different for them. Therefore, it seems clear that a difference in brightness was not the reason for the peculiar behavior

noted when the fish used to blue-red patches were shown patches matched in brightness but with the gray substituted for the red. The evidence that red differs from gray is emphasized by the differential behavior of untrained fish. It is equally emphasized by similar behavior of the fish which were modified by months of experience, as recorded in the blue-red series. They showed toward gray the same differential response which wild fish showed toward red.

C. *Dark-adaptation and sensitivity to light.*—To test this question I made tests from time to time to determine whether there was a change in the relative brightness of colors when the fish were in strong and weak light. These tests were made during the red-blue training experiments. They were never long continued but merely interpolated in the red-blue series, when a point had been reached in the adjustment of the red at which its brightness for the fish was judged to be equal to that of the blue. The fish were then tested at night after two hours dark-adaptation. This dark-adaptation did not greatly change the accuracy of the response. There were no marked changes in behavior even when the two stimulus patches were of the intensities to which the fish had responded by similar behavior before the food association was established. This seemed to show either that there *was* no shift in relative brightness, or that the response was to color rather than to light intensity. It was too dark for the fish to secure the food as it fell. Only when it fell through the water between the fish and the colored plate was it ever seized. As there was danger under these conditions of breaking up the reaction of the fish to the positive stimulus plate, the experiments were not carried further with the trained fish. The work was continued with red and white stimulus plates and with untrained dace, sunfish, and blunt nosed minnows (*Pimephales*). While these were light-adapted, they were presented with the stimulus patches until red avoidance disappeared, and the intensity of the plates was then adjusted until the fish went to the two with equal frequency and in the same manner. The fish were then allowed to become dark-adapted. No marked change

could be seen in the method or in the frequency of approach to either of the two plates.

Although I obtained no evidence of a shift in relative brightness of the red and blue used, or in that of red and white, there was evidence with both dace and sunfish of an increased sensitiveness to light after dark-adaptation. If the intensities of the red and blue plates were so adjusted that fish adapted to the illumination from a tungsten lamp went without hesitation to either plate and visited the two plates with equal frequency, and if the fish were then allowed to become dark-adapted and the plates again presented, they no longer went close to the plates but halted at some distance from them. Their sensitivity to light had increased, but my evidence does not show that the relative brightness of the plates had changed for them.

III. REVIEW OF THE LITERATURE

It is not uninteresting to note that the early workers in this field used a variety of methods which involved both (1) training of the fish and (2) their unlearned responses. But the discordant results obtained are not correlated with the type of method employed.

Graber (1885) was one of the first to test the color vision of fish by the method of response. He illuminated different parts of the aquarium simultaneously with lights of different sorts, and he noted in which of them the fish gathered. He found a difference in the behavior of *Gasterosteus spinachia* toward darkness as compared with their behavior toward light, and a difference in their behavior toward red as compared with their behavior toward blue.

Zolotnitsky (1901) fed fish with red *Chironomus* larvae until they were accustomed to this food. He then put against the glass aquarium wall a cardboard, upon which were pasted bits of wool of various colors and of the size and shape of the larvae. The fish jumped most frequently for the red pieces. He decided that fish could distinguish red from other colors. He did not consider the brightness values of the colors used.

Washburn and Bentley (1906) attacked the problem by a method which involved more exact discrimination by

the fish. They fed a single horned dace, *Semotilus atromaculatus*, from forceps, two pairs of which were fastened to a wooden bar so that they could be lowered into the water simultaneously. One pair of the forceps had small red sticks fastened to the legs with rubber bands, while the other was equipped with green sticks. Food was placed in the red forceps to form an association red-food. When the association was formed, both pairs of forceps were presented empty; the fish selected the red, and continued to do so even when a much lighter red was used.

The conclusion reached by Washburn and Bentley is that the fish can associate food with pigment color and discriminate between red and green even when the shade of the red is changed.

Reighard (1908) studied color vision in the gray snapper. The primary purpose of his work was the investigation of warning coloration, not of color vision. If the fish upon which he worked should be shown to be color blind, his conclusions that the coloration of coral reef fishes does not serve as warning, would be strengthened. He describes a school of gray snappers (*Lutianus griseus*) which were fed in the open sea with blue and red bait. The fish showed an instinctive avoidance of red. When they had become accustomed to the feeding, the red bait was presented together with the blue. The fish avoided the red. They also gave preference to white when offered with blue. The brightness of the blue, red, and white were measured by the color wheel and found to be in the order white, red, blue. Professor Reighard concludes that since the snappers preferred the white to the blue, and the blue to the red, they chose in the first case the brighter bait and in the second the duller one of a pair. They were, therefore, guided not by the brightness of the bait but by the color. The quickness and accuracy of the fish in forming associations show, in this experiment and in others, the advantage of working with fish in a natural environment.

Since Zolotnitsky did not determine the relative brightnesses used by him for either the fish eye or the human eye, it is clear that these may have been such that the fish were able to select the red yarn by its brightness alone.

Washburn and Bentley used a brighter red in non-food tests to detect a possible brightness discrimination by the fish.

Reighard varied the brightness of one of the two colors so that one was used both lighter and darker than the other color. Following the practice current at the time and finding that the fish discriminate between two similar objects when one is used both brighter and less bright than the other for the human eye, he infers the presence of color vision. The brightness values of the color used should have been determined with dark-adapted eye but since in no case was the attempt made to obtain matched brightness, but rather to insure a considerable *difference* in brightness, this criticism has little force. The conclusions of the writers so far considered are based on the assumption that the brightness values of the colors used are approximately the same for the fish eye, as for the human eye, light-adapted. For this assumption there was no evidence. Had they conducted a long series of experiments in which one of the two colors was changed in intensity by small degrees, they might have found a region in which the two colors matched for the fish eye. This region might have made itself known by temporary failure of the fish to discriminate. A recovery of ability to discriminate in this region of matched brightness would have been evidence of color vision. A persistent failure to discriminate at these matched values would have been evidence of color-blindness.

Hess (1909) held the proofs of color vision so far offered to be inconclusive. When he illuminated an aquarium placed *in a dark room*, half with blue light and half with red by the use of colored glasses, young (15 cm.) *Atherina hepsetus* gathered in the blue, even when it appeared to his light-adapted eye somewhat darker than the red. When the red was made sufficiently bright, the fish gathered in the red instead of in the blue. By properly adjusting the relative brightness of the blue and the red he succeeded in getting the fish distributed evenly in both halves of the aquarium. These results indicated to him that the fish were responding to intensity differences rather than to wave-lengths. He observed that these young fish swam

toward the light and in a dark room gave this response to light of very low intensity. They went to the brighter of two white plates which differed in illumination as 1 to 1.23. Taking advantage of this phototactic behavior, he found that fish gathered in the yellow-green of a spectral band thrown into the aquarium. By using a piece of cardboard he slowly cut off the successive portions of the spectral band from the violet end until only red was left. The fish gathered in whatever part of the spectrum remained except in the extreme red. If the spectrum was shortened from the red end, they continued to gather in it until they were finally in the violet. Since the fish did not gather in the red of longest wave-length, Hess decided that it stimulated them very little. For them the red end of the spectrum appeared to be shortened as it is for the totally color blind.

By means of their brightness response Hess determined the relative brightness of different parts of the spectrum for fish. To do this he used monochromatic light on one side of the aquarium and a white light of variable intensity on the other, and found intensities of the variable at which the fish distributed themselves equally on both sides. He decided that for fish the yellow-green was the brightest part of the spectrum, that blue, yellow, and orange were less bright; that red was the darkest; and that for fish orange and red have little brightness value. These determinations of brightness values of the spectrum were so like those already found by others for the human color-blind that Hess was led to conclude that fish are color-blind.

The first work of Hess seems to be open to criticism on several grounds:

(1) He used very young fish. The condition of the retinal cones of young fish has been shown by Shafer (1900) to be quite different from that of adults. It is not impossible that their color vision is different. Whether this is the case must always be difficult to determine, for such young fish cannot well be used in training experiments because their behavior is too mechanical. They feed on minute plankton animals and have perhaps little need to

exercise discrimination in the choice of their food. Goldsmith (1914) has shown that when the fish are very small they do not chase their prey. The need for discrimination grows as the fish develop and change their food habits.

(2) The experiment in which the fish are found to show no differential response toward red and blue when the relative brightness of the two is suitably adjusted, is taken as evidence for the lack of wave-length discrimination. The fish are here not responding to a difference in wave-lengths of light, but it does not follow that they are *unable* to respond to such differences. The experiment shows only that under the conditions they *do not* respond differentially to the wave-length differences. Training experiments might show a capacity not revealed by this method. It is further possible that during the time required for adjustment of the blue and red lights the fish became accustomed to the red so that they no longer avoided it. When the adjustment was completed they might then distribute themselves equally in lights of the two colors. My own experiments contain much evidence of such rapid " getting used " to red. In such work on response to light of different wave-length it is the initial responses that have greatest value.

(3) Hess' experiments show that the fish do not gather in the red of a spectral band, and this is taken to mean that the red has little stimulating power. The experiment could, however, be explained by supposing that the red affords a stronger stimulus than other rays and is avoided. My own observations as well as those of Reighard, Bauer, Mast, and Goldsmith show an avoidance of red.

(4) The experiments in which Hess determines the relative brightness of different parts of the spectrum for these young fish in the dark is of interest but seems to me to have no bearing on the question of wave-length discrimination. That the brightness values of the different colors are the same for fish as for the color-blind may be thus established. Hess' work with the pupilloscope is confirmatory (Hess 1917). My own work adds to this evidence. It does not necessarily follow that fish are color blind. Von Kries (1896) shows that for the periphery of the human

retina the brightness values of different regions of the gas-spectrum are the same as for the central area of the retina of the normal eye in daylight. It should then follow, if Hess' mode of reasoning is sound, that the periphery has color vision, but it is well known that it is color-blind. But if the periphery of the human retina has the same brightness values of the spectrum as the normal eye in daylight but is color blind, may not the fish eye have the same brightness values as the human color-blind and yet the fish distinguish colors? With more knowledge of the color discrimination possible in lower vertebrates, theories of human color vision may be enriched and improved.

Bauer (1910), noting that the results of Hess were at variance with those of other writers decided that the fact that the work of Hess had been done with fish in the dark rather than in the light might account for some of these differences. Accordingly he placed above the aquarium in which he kept his fish a light, which furnished a constant moderate light intensity for those experiments in which the fish were light-adapted. The stimulus light reached the narrow, black-lined glass aquarium through a clear rectangular area in one of its ends. When two colored glasses, used as filters, were placed so as to divide this opening through the center, the halves of the aquarium were illuminated by light of two colors. When different thicknesses of white paper or ground glass were before the halves of this opening, the two parts of the aquarium were illuminated by white light of different intensities. When white light was used, Bauer was not able to cause a gathering of the fish in either half by differences in the intensity of the two sides. But with red and blue filters in place certain light-adapted fish tended to gather in the blue half. With the *Charax* and *Atherina* tested, he found, in contradiction to Hess, no brightnesses of these two colored lights at which the fish were equally distributed in both halves. When spectral bands were substituted for the filters, the light-adapted fish went into the blue green or yellow area. When the orange or red (between 620 $\mu\mu$ and 630 $\mu\mu$) were presented to the fish, they rushed to the unilluminated end of the aquarium as though frightened. When tested with

the white light, no such behavior was observed, and with different intensities of white light no avoidance of a definite moderate brightness appeared. Bauer concluded that when light-adapted, the fish have color vision, a conclusion reached both from his observations that the fish avoided red, and from the fact that he was unable so to equate the brightnesses of red and blue that the light-adapted fish responded to them similarly. When the same fish were dark-adapted, they entered the red and orange lighted portions which they had avoided when light-adapted. He regarded this as evidence that when dark-adapted, they might be color blind. He presented evidence for a "Purkinje phenomenon."

Hess (1911), stimulated by the work of Bauer, tested the relative sensitivity of fish to light when dark-adapted and when light-adapted. He used carp between 8 and 9 mm. long. He put the fish in their containers in the sun to get them light-adapted and then rapidly moved the container into the dark room, in which the tests of both light- and dark-adapted fish were made. He noted the strength of the stimulus necessary to call forth a phototactic response in light-adapted fish and compared that with the strength of stimulus for fish which had been for some time undisturbed in the dark. He found their sensitivity increased more than 1,000 times by 15 minutes dark-adaptation. By varying the intensities of the light used he, like Bauer, was able to make *dark-adapted* fish distribute themselves uniformly in the red and blue halves of an aquarium illuminated by filtered light. When these fish were *light-adapted*, it was necessary to increase the intensity of the blue illumination six to eight fold, in order again to secure uniformity of distribution. The relative brightness of red and blue for the fish had been changed by light adaptation, but whether light- or dark-adapted, they showed no preference for red or blue.

One factor seems to have affected unfavorably the determinations of Hess concerning the relative sensitivity of fish after dark-adaptation. It appears that for certain, experiments with light-adapted fish the aquarium containing the fish was removed from a lighted window to a dark

room. For experiments with dark-adaptation the aquarium was not shifted. I have found fish more sensitive to light after dark-adaptation although I have not worked with such young fish as Hess used. It is certainly to be expected that fish, whether dark-adapted or light-adapted, would more readily respond to light after being quiet for 15 minutes as in the case with Hess' dark-adapted fish than after the earthquake-like experience of being moved about a room, as were his light-adapted fish. It therefore seems to me that the relative lack of sensitiveness of Hess' light-adapted fish may be due quite as much to inhibition of response through mechanical disturbance as to light-adaptation. Certainly dependable comparative results are to be expected only when the light- and dark-adapted fish are handled in the same way.

Hess repeated some of the experiments of Zolotnitsky. He fed light-adapted fish upon red *Chironomus* larvae. He then offered them at the same time bits of red and gray yarn that for his dark-adapted eye matched the larvae in brightness, and he found that the fish snapped with equal frequency at both the red and the gray yarn. When the imitation larvae matched the background in brightness but not in color, the same fish passed them without trying to eat them, quite regardless of their color. Again areas of red light of the size and shape of the red larvae were projected against a green-lighted area and were snapped at by the fish when they were darker or lighter than the background, but not when they matched it in brightness for his dark-adapted eye. These tests seemed to show that fish are color blind.

Bauer shows that after dark-adaptation fish go into a red which they avoided when light-adapted when this red is presented along with a blue. Hess shows that a blue which matched a given red for dark-adapted fish must be increased in brightness to match the red for the fish after light-adaptation. It is probable that both men are dealing with the same fact, namely that the stimulus afforded by the blue is increased by dark adaptation. It is not impossible that the real brightness of the red has remained little changed with changed adaptation. But

the blue, according to Hess' explanation, is greatly reduced in its effect by being absorbed by the pigment which in the light-adapted eye has drawn forward and therefore must absorb the light before it reaches the ends of the rods and cones. In Bauer's work the dark-adapted fish in entering the red may have been giving a negative response to a too brilliant blue, a blue past the optimum because of the retractions of the retinal pigment. The red, however, had not so increased in brightness and was entered. The dark-adaptation had increased sensitivity to brilliant blue light. The fact that fish tend to go to an optimum light will equally well explain the behavior of the fish used by Hess when they are recorded as going to a red after light adaptation and entering the blue half of the container when the blue was increased in brightness six to eight times. This would be expected for fish where red avoidance is absent as it is in Mugil according to Bauer.

Frisch (1912) placed fish in glass-bottomed dishes with colored papers beneath them and found that they became of a brightness and color like the background upon which they rested. The stimulus for this matching is received through the eye.[9] He found that the fish changed their brightness tone before they changed color. When he used at the same time papers of different colors he found that with properly selected colors the fish could be shifted from one to another without change in their brightness tone. Such colors were thought to be of matched brightness for the fish. After a time these fish changed color to match the background, thus indicating that the color change is a response to wave-length and not to brightness. In other experiments Frisch fed his fish from the upper end of a glass tube lined with a certain color. This tube was placed in an aquarium as a member of a series of tubes with linings varying from white, through a series of grays, to black. To make impossible a choice by position the order of the colored tube in the series was changed from time to time. When the fish had learned to seek food only in the colored tube, one similar in color but empty was substituted. The fish continued to seek food in the colored tube. As they

[9] See Parker 1909, Mast 1916.

did not confuse with the color any intensity of a long series of grays varying from white to black, he decided that their response had been to wave-length and not to brightness. He further tested their color vision by seeing whether the fish trained to go to a given color would respond to it positively when other colors of matched brightness were presented. He found that blue and green were discriminated from each other and from other colors as well as from the grays of the series, but that the fish confused yellow and red with each other though not with grays or with black.

Uhlenhuth (1911) after a critical and illuminating review of the literature, accepts as conclusive Frisch's evidence that fish react differently by color change to lights of different quality but of equal brightness. It does not follow that they are aware of the color differences in their backgrounds. Where a method of choice is used, as in my own work, it becomes probable that the fish are stimulated by quality and not intensity alone and that the quality determines their choice. (cf. Mast 1916.)

Frisch (1913) fed fish upon yellow-colored meat until the habit of approaching it was fixed; then he tested them by substituting colored papers for the meat. For these tests small pieces of yellow paper were pasted upon sheets of gray of the same texture. These gray backgrounds included one the brightness of which matched that of the yellow paper for his dark-adapted eye. Upon each gray background, in addition to the yellow bit of paper, was pasted one of similar shape of a darker gray and another of a lighter gray. When these sheets of gray were placed against the walls of the aquarium, the fish that were used to the yellow food swam more frequently to the yellow bits, while fish that had not been fed with yellow meat swam with equal frequency to all three pieces of paper. From this Frisch maintained his previous conclusions, that for fish yellow and red light are different from white and from other colors.

Hess (1912) resumed his attack on the problem and followed the method used by Frisch. He placed his fish in a rectangular aquarium and fed them on yellow meat,

which he allowed to fall through the water while a gray back ground was placed against the outside of the aquarium. He also fastened pieces of yellow meat and pieces of colored wool of similar shape upon one side of a glass plate which could be lowered into the water, so that the colored bits were visible to the fish against the same gray background but the glass surface which separated them from these pieces was invisible. The fish went with equal frequency to all the bits of color as the glass was sunk into the water. Next a glass was used to cut off a small space along one side of the aquarium. For one week yellow food was allowed to fall on the side of this glass plate where the fish might reach it. Then for two weeks, while yellow food was given on the same side, where it could be seized, blue food was allowed to fall at the same time on the reverse side of the plate, where it was visible but inaccessible to the fish. After the three weeks of feeding of yellow meat, with or without the inaccessible blue, bits of yellow, blue, gray, red, and green were dropped into the aquarium behind the glass plate; the fish swam at them freely and showed no preference for yellow. Again Hess insists that fish are color blind.

In this work of Hess, in which he used training methods, he allowed the food masses to fall through the water and found that the fish rushed to a mass of any color, though they had previously been fed upon yellow-colored food only.

Hess has here adapted the well known experiment of Möbius (1873) with pike, afterward confirmed by Triplet (1901) with perch. Möbius found that when a pike in an aquarium was separated from minnows by a glass plate, the pike at first dashed at the small fish and received a bump on the nose whenever it did so. After a time the pike stopped rushing at the minnows, and when the glass plate had been removed, the minnows were not at first seized by the pike. A severe bump had become associated with trying-to-seize-minnows. Had Hess, while feeding his fish on food of quite other form and appearance, first succeeded by punishment in establishing an immunity for his blue food masses so that they were not seized when

made accessible, and had he then offered the fish, along with the blue, masses of equal brightness but of other colors, and found all of them refused, he might then have concluded that the fish did not discriminate them by color. What he did was to establish an association with yellow by feeding the fish on it. He then offered this yellow along with blue, but without showing that the blue had been made immune. The fish showed no differential choice, and there was no reason to expect it.

This experiment, used to prove the lack of ability on the part of fish to discriminate on the basis of wave-length, illustrates the difficulty of trying to prove a negative. Fish are keen in detecting movement. There was apparently no severe bumping against the glass when blue bits were falling through the water with only a plate of glass between them and the fish. The accessible yellow meat dropped near the plate satisfied the hunger of the fish. The yellow food served only to form the association " falling bits-food. ' But the inhibition against reacting to blue was not established.

Hess (1913) argues against the view that the red color of the belly of the breeding " Saibling " may be observed by other " Saibling " and is therefore an indication of color vision. As evidence that red rays do not reach the spawning grounds of the brilliantly colored Königseesaibling he tested the penetration of red rays into water by a simple experiment. He used a brass tube 4 m. long. On the side of this at one end was a window 4 cm. in diameter, and within the tube facing the window was placed a mirror set at an angle of 45° with the axis of the tube. Attached to the lower end of the tube opposite the window and at a distance of 20 cm. was a red plate 12 by 20 cm. which could be set at various angles to the window. The end of the tube to which the red plate was attached was immersed in the water to a depth of 4 meters, and the reflection of the plate was observed in the mirror through the upper end of the tube. When thus observed, the plate appeared yellow or brown but not red. I have repeated the experiment in air in diffused daylight. When the light is sufficiently reduced, the results are as Hess states. This

does not mean that the surface of the plate does not appear red if observed directly. In Hess' experiment only a small fraction of the light waves reaching the mirror are those reflected from the plate. Inside of the tube, which apparently was not blackened, the light waves were probably reflected back and forth. The illumination of the mirror is weak, and the visual angle for its surface at 4 m. distance is small. Conditions are unfavorable for observing the image of the red surface in the mirror, but not because red rays are lacking. Hess recalls that many fish spawn at 20 m., that this especially brilliant variety may spawn at 60 m. and, because of the absorption of red at this great depth, the red of their lower surfaces can have no biological significance. There are few data as to the absorption of light of different wave-lengths in fresh water lakes. It has been determined, however, by Murry and Hjort (1912) by photographic methods that in the ocean at 100 meters there are many rays of all kinds, though fewest of the red. From data of v. Henri et Larguier des Bancels it is determined that the eye is about 3,000 times as sensitive, as the most rapid photographic plate. Although the red rays are absorbed with increasing depth in shallow water, on the other hand, spectral colors abound. This is shown by v. Aufsess (1913) who placed a mirror beneath the water of an Alpine lake and in it viewed the terrestrial landscape. The branches of trees and all other external objects then appeared fringed with spectral color, ranging from red near the horizon to blue higher up. Most young fish live in such water but may retire to deeper water as they grow larger. Hess' evidence does not satisfactorily show that no red rays reach the spawning grounds. But if none do, that does not prove the absence of color sensitivity in fish. If the absence of a particular stimulus in the normal environment of an animal were to be accepted as evidence of the lack of response to it, we should be forced to hold that Paramoecium is not affected by the electric current. Experiment shows it to be sensitive to the electric current, and experiment alone can decide the response of any animal to a particular stimulus, whether that stimulus is or is not normal to the environment. I have shown that the

color of the male probably plays no rôle in selection by the female *Etheostoma coeruleum* (Reeves 1907), but that displays of the male may nevertheless play a part in the breeding activities. The color of the breeding fish need not indicate the presence or absence of color vision in a given species, but the absence of ability to distinguish wave-length can not be demonstrated by assuming or by proving that the red wave-lengths do not penetrate to the breeding grounds of any species. (See also postscript.)

Hess (1913) showed that if the integument of young eels is subjected to the action of violet light, a peculiar fluorescence appears. He did not find this when he used older fish. I found that a certain very large sunfish (not the one whose graph is shown in fig. 15) failed to learn to discriminate a blue and red which the smaller sunfish, SS_2, discriminated. This may have been due to a difference in effect of light on the retinas of young and old sunfish comparable to the difference in effect of light on the integument of young and old eels. It may also have been due to greater readiness of the younger fish in forming a sensory habit.

Before leaving the work of Hess, it may be well to characterize it in more general terms. The conditions of his first work, which was carried out in the dark, were unfavorable for observing small differences in behavior. His subsequent failure to find color vision is in part due to the earlier failure, in part to the fact that he worked often in the dark, and in part to his method of handling the fish. Small differences in behavior are difficult if not impossible to observe under the conditions of illumination he used. His method of handling his fish introduces too many disturbing factors. Fish picked up and put into the light and then put into the dark will show excitation or inhibition effects because they are especially sensitive to jarring and shifting of the aquaria. But differences between response to red and other colors exist; and Hess found these and misinterpreted them. His work in establishing the similarity in brightness values of different spectral regions for fish and for the totally color-blind will probably be confirmed.

Goldsmith (1914) in a most suggestive paper gives the results of a study of the perception and memory of colored objects by fish. Her work shows differences in this respect in the various species used. While *Gobius* avoided red, the stickle-back came to rest over red and approached the red objects presented.

Freytag (1914) reports work to determine whether fish become colored like their surroundings. The fish were usually placed for a few hours in a glass dish above a given background. Twenty-four hours seems to be the maximum time. He finds no proof for color vision in the *Phoxinus laevis* used. The fact that there is in his specimens a tendency to match the background in brightness leaves one in doubt as to whether with as much time for color adaptation as was allowed by Mast for flounders these fish would not also have shown consistent color changes.

Mast (1916) has published evidence of color vision and of the avoidance of red by fish. In experiments on change of color to conform to background, he used red, yellow, green and blue paints. He had boxes painted half with one color and half with another one of the four colors used, so that all possible pairs of these colors were provided. Fish (flounders, *Paralichthys* and *Amylopsetia*) were allowed to become adapted for six weeks or more, to each of these colors in boxes painted of one color. Colored photographs show that they became colored like the background. They were then released above the dividing line of a two-colored box in order to see toward which half they would swim. It appears from an examination of Mast's data that fish adapted to blue showed 88 per cent of blue choices, those adapted to green 70 per cent of green choices, but those kept in the red box and then released in the two-colored boxes went to the red in only 26 per cent of the choices. Of the 120 times when *red* and *blue* were the pair of colors presented to the red-adapted fish, it went but five times to the red. This record, given by Mast, of natural differential response in avoiding red has added value from the fact that his experiments were not performed for the purpose of testing the existence of a differential response to that color.

IV. DISCUSSION

A. Analysis of Methods Employed

In the study of color vision in fish, investigators have availed themselves of three methods—that of training (formation of a food association), that of instinctive response, and that of change of color of the fish with change of background. The second and third of these methods might, of course, be considered together since both involve instinctive response, but it is convenient for purposes of discussion to separate them.

a. The *method of response* has been used chiefly by Reighard, Bauer, and Hess, and results obtained by it are included in this paper. No attempt is made by this method to form a food association, but the fish are presented with light stimuli of different intensities and qualities, and their behavior is noted. Two patches of light of restricted wave-length, or one of restricted wave-length and one of white light, may be presented together or a considerable part of the spectrum or the whole of it may be shown at one time. Where two qualities of light are used, the fish may show by difference in frequency or method of approach or by tendency to avoid one of them, that the lights differ for it. The intensity of one light is then varied (Bauer and Hess). If at any intensity of the variable, behavior of the fish toward the two lights is found to be the same, it is concluded that their past differential responses toward the lights have been due to a difference in brightness; the cessation of these responses is taken as evidence of matched brightness. If the fish do not, under the conditions of the experiment, show differential response at this matched brightness, they are regarded as color-blind. The evidence, failure to respond at matched brightness, thus leads to a negative conclusion. It has been pointed out that responses of this sort are evanescent. The response may be given when the stimulus is first presented, but may not appear on repetition of the experiment: because the fish may have become "adapted" to the unwonted stimulus and no longer respond (see adaptation to red in figs. 13, 15 and discussion p. 33). Failure to respond may also result from

inhibition by other stimuli (delayed response in sunfish p. 50). For these reasons a *negative* conclusion based wholly on evidence from the method of response seems unwarranted. The method may answer for lower organisms, but animals as highly organized as fish may be quite capable of responses that do not appear under it. Those who use it need to take particular pains that they are not relying upon innate responses which have disappeared through adaptation or which are inhibited by uncontrolled stimuli.

If on the other hand, when positive results are obtained by the response method (Reighard, Bauer), they appear to have the greater value. Here, at least, it is certain that response is not lacking through adaptation to the stimulus or through inhibition. Positive results are obtained when the fish show differential response toward light-stimuli of different quality at all intensities of the variable used. Owing to the evanescence of the response (adaptation) it is not practicable to repeat the experiments at *many* intensities of the variable. It is, therefore, possible that *matched* brightness for the fish is *never* secured by this method. But if, at various intensities of the variable, the fish continue to show a differential behavior toward the two stimuli of different quality and do not show this toward stimuli of the same quality at presumably like intensities, then we have evidence of color vision. Such evidence we get, for instance, from the peculiar behavior of fish toward red obtained by Reighard, Bauer and myself. Hess' failure to obtain similar differential behavior is merely lack of evidence, and as already pointed out, permits of other explanation than inability of fish to respond differentially to red.

b. The *method of training* gets rid of the difficulty involved in evanescence under the response method, for it insures response over long periods of time and makes it possible to use the variable at many intensities in the effort to secure matched brightness At the same time the fact that the fish take food during experimentation shows that their responses are not inhibited. In work that has been done hitherto on color vision of fish by training methods, three procedures have been used in the attempt

to determine whether the fish were guided by brightness differences rather than by quality of light.

In the *first* of these procedures (Washburn and Bentley) no attempt is made to secure matched brightness of the two colored objects presented to the fish as stimuli. One of them is kept constant in brightness value and is presented to the fish in contrast to the other colored stimulus, which is used at two values, one brighter and one duller than the first. The relative brightness of the two stimuli is judged by the human eye either light- or dark-adapted. The method is probably adequate to insure the end sought, namely, that the variable stimulus be used both distinctly brighter and distinctly duller than the constant. When, under these conditions, the fish learns to avoid the constant stimulus in contrast to both a brighter and a duller variable, he chooses in the one case the duller object and in the other case the brighter, and it has been assumed that the discrimination is, therefore, made by means of a quality difference between the two stimuli. Since considerable brightness differences for the human eye always exist under this procedure, it is possible that they exist for the fish eye also, and it follows that the fish may discriminate the constant stimulus from the variable by brightness difference only. A totally color blind person might so discriminate them by avoiding the stimulus of definite constant brightness, with preference for one either brighter or duller.

The *second training procedure* referred to above attempts to make the two stimuli of equal brightness for the fish. To this end a colored stimulus object is matched with another colored object or with a gray by means of the human dark-adapted eye. The two objects may be identical except for color and may be offered to fish as food, or one may be offered as food and the other form a background against which the food is seen by the fish. If the fish learns to distinguish the two objects assumed to be matched in brightness for it, the conclusion is drawn that quality differences in the light are the basis of discrimination. However probable it may be that colors matched in brightness for the human dark-adapted eye are also

matched for the fish, the method under discussion affords no proof that this is so. If it is not so, the fish may distinguish the two stimulus objects because of brightness difference, although to the human eye they appear equally bright.

The *third training procedure* hitherto employed attempts to meet the difficulty of the first two by varying the intensity of one of the two stimuli while the other is held at constant intensity. It assumes that some intensity of the variable will be used at which its brightness equals, for the fish, that of the constant. If at this intensity the fish continue to discriminate, they must do so by means of quality differences, and they, therefore, have color vision; if they fail to discriminate, they are color-blind. Frisch used this method when he offered his fish food concealed in a colored tube, which was one of a series of gray tubes. On the assumption that the colored tube is of the same brightness as one or more of the gray tubes, a fish that learns to go to it and continues to go to it when it is empty, must distinguish it by the quality of light coming from it, and has, therefore, color vision. A fish that is capable of learning, but cannot distinguish the colored tube amongst the grays is color-blind. The danger in the employment of this method lies in the assumption that the colored tube is matched in brightness for the fish by one or more of the gray tubes. If a long series of closely approximated gray tubes is used, it is probable that one of them matches the colored tube, but it always remains possible that none of them matches for the fish. There may remain a brightness difference between the colored tube and any of the grays great enough to enable the fish to discriminate them. To obviate this, the brightness limen must first be found. It cannot be too often pointed out that brightness is not measurable by physical means, but is a psychical or physiological quality, so that colors matched in brightness for one animal may or may not be matched for another. What is brighter or duller each of us can know directly only for himself. It is, therefore, important to use a training method in which the behavior of the fish affords a means of judging when the two color stimuli are matched in brightness.

The training procedure used in my own work belongs in the third category outlined. It resembles the procedure of Frisch with the colored and gray tubes, in that a positive stimulus of constant intensity is presented to the fish along with a variable. In Frisch's work the constant was a colored tube, while the variable was a series of gray or colored tubes, all of which were shown at the same time with the constant. In my own experiments the constant is a patch of blue light, the variable is a series of like patches of red light of different intensities shown one at a time in contrast to the constant. The intensity of the illumination used for the patches is known, and in the case of the variable the intensities form a series the members of which are close together. At one point in this series, usually at the intensity of the variable corresponding to slit width 0.9 mm., the fish temporarily fail to discriminate (cf. graphs figs. 13 and 15). This failure is believed to indicate the region of matched brightness of the two stimuli for the fish. If this is true, the fish themselves show by their behavior when the colored patches are matched in brightness for them. As the variable is held at this matched brightness, the fish again come to discriminate the two patches. The conclusion seems inescapable that the quality of the light is the basis of the discrimination. The method thus appears to meet the difficulties encountered in the other training methods, in that it affords a behavior-indicator for matched brightness. It has not hitherto been used in training experiments on fish.

c. *Change of color in fish* in response to background was long ago shown by Pouchet (1876) to be response to stimulation received through the eye. It does not occur in blinded fish (see also Mast, 1916). The use of this method to afford evidence of color vision in fish has been discussed. Compared with the time required for discrimination of colored stimuli by trained fish, a relatively very long time is required for these color changes in the integument to occur. While Mast's experiments with blinded flounders show that the color changes are mediated through the eye, Frisch has shown that in the minnow, *Phoxinus*, they are influenced by illumination of the integument of the pineal

region. In eyeless Amblystoma Laurens (1917) has shown that the melanophores contract in light and expand in darkness. It may then be suspected that the mechanism by which the changes in the melanophores are controlled is more complicated than we know. The slowness of these changes and the fact that they may not be wholly mediated through the eye make it difficult to draw conclusions from them with regard to color *vision*, and especially difficult to compare such conclusions with those derived from training experiments. In the one case we have a slow reaction to background, while in the other we have, if my results be accepted, instantaneous choice of one of two stimuli which differ only in quality of light. In the latter case we may speak of color vision, or wave-length discrimination. In the former it is doubtful whether either discrimination or vision is involved. The *choice* by Mast's flounders of a background of the same color as that to which they had been previously adapted affords evidence more nearly comparable to that obtained by training.

B. Sources of Error

From the foregoing review of the literature it appears that workers have used many methods of experimental attack on the problem of color vision in fish. All workers except Hess conclude that fish have the capacity to discriminate wave-lengths of light. My own results support this conclusion, but before discussing them further I shall take up, on the basis of my own experience and from a study of the literature, the sources of error involved in such work.

a. *Errors may arise from lack of proper environment and care.*—The need of keeping the fish in normal physiological conditions has already been referred to. The chemical contents of the water, the size of the containers (Franz, 1910, 1911), the tameness or wildness of the fish, are all factors to be considered in judging of the effectiveness of environment in modifying appearance and behavior. Through neglect of these factors Hess seems greatly to have lessened the value of his experiments. He tells us (1913) that while he was experimenting two of his twelve

fish died. This indicates that his other fish were not in normal condition. They may have failed to give responses that could have been obtained from normal fish.

b. *Errors may arise during experiment from uncontrolled environmental factors.*—The procedure of Hess (1909) in comparing the sensitivity of dark- and light-adapted fish has been already described. The aquarium containing the light-adapted fish was moved just before testing them, while that containing the dark-adapted fish was not moved. To compare the responses of the two sets of fish under these conditions cannot be regarded as a sound procedure. Again, Hess (1913) in studying the influence of the background in modifying the colors of fish puts several into the same containers or into separate containers so near together that the fish are visible to each other. He thus ignores the fact that the colors of one fish may be influenced by the presence of another fish. I have several times observed the colors of fish when two are in one container. If one chases the other, the pursuer, as observed, may become lighter in color and the pursued darker or at times a reversed change may take place. In the breeding season, I have found the male rainbow darter to change strikingly in color from second to second and without change of background (Reeves 1907). Colors flash out with the incidence of various stimuli, such as the presence of other fish or the movement of the observer. Similar changes may be seen at other seasons. Yet it appears that both Hess (1913) and Frisch (1911), in some of their experiments, went to the aquarium and stood over the fish to observe whether they changed to match the background. This procedure in itself would cause color change in some of the species with which I have worked. (See also Freytag, 1914). Through neglect of these factors Hess seems greatly to have lessened the value of his earlier experiments. Frisch appears to have avoided putting a number of fish into one container without running water and into such poorly adjusted conditions as to cause the death of his fish, but for the control of all the complex physiological and psychological factors that cause response, his methods are not entirely satisfactory. The recent work of Mast (1916)

gives evidence that some fish can and do change color to match the background upon which they are resting. Mast presents pictures made by color photography of fish which have become like the background. These were taken after three months of adaptation.

c. *Errors may arise from inhibition of response.*—Hess (1911) shows that fish fail to eat when red light is thrown upon them. Of his experiments in which a worm was upon white sand on the bottom of the aquarium illuminated by a Nernst lamp with a red glass filter in front of it, he says, in effect, that more convincing than all else to the lay mind is the fact that the fish left the worm undisturbed, but on illuminating with blue light, the fish snatched the worm at once though it was then less conspicuous to the human eye. Here Hess observed the same response that Bauer got and called "Rotscheu," but Hess misinterprets and says that the red was of low illuminating value. He adds that when brightness of the red was *slowly* increased, the worm was seized and eaten. Many times my fish have failed to feed upon a bit of white worm when it lay wriggling on the black aquarium bottom in front of the colored plates, but when I turned off the lights for the stimulus plates and left only the general illumination from the ceiling light the fish have fed at once, though the total illumination was reduced. The fact was, the colored patches so stimulated the fish that the feeding behavior was inhibited. When Hess slowly increased his red, it is not stated how long the fish was allowed to become used to the red illumination. It may be that the time required for the slow increase in the red sufficed for the fish to become used to it, if fear of red was originally present.

d. *Errors may arise through lack of training at matched brightness.*—When stimuli of different wave-lengths are employed in training experiments, it is always essential to vary the brightness of one of the two, for the purpose of finding a point at which the two stimuli match in brightness. If at this point discrimination fails, it may be argued that the discrimination shown in other parts of the series has been due to brightness difference and that such a series, therefore, affords no evidence of color vision. If discrim-

ination occurs at matched brightness for the fish, it may be taken as evidence of color vision. This general form of experiment was used by Frisch (1911) in the experiments in which the fish discriminated a colored food tube in a series of grays or colored tubes. The results were rightly judged to be an indication of color vision. Had discrimination not taken place in this case, the result would ordinarily have been taken to indicate a lack of color vision. This conclusion could be accepted only in case the trials were long enough continued at matched brightness of the two colors to make it certain that failure to discriminate persisted. In other words, in such a series temporary failure to discriminate at matched brightness is not conclusive. This source of error has not appeared in previous work with fish. A reference to the graphs (fig. 13) shows how it might appear. If in the case of Small Sunfish, upon failure to discriminate at slit-width 0.9 mm., (matched brightness) the slit width had been at once considerably reduced, discrimination would have been re-established. The curve might then have been interpreted as evidence of brightness discrimination with failure at matched brightness. Only by continuing the trials at matched brightness and securing return of discrimination at this slit width does it give evidence of discrimination of wave-lengths.

e. *Error may arise from exclusive use of the method of response.*—This method does not accurately test the potentiality for discrimination for fish. It shows not inability but merely *failure* to respond under the conditions of the experiment. Only a method which necessitates the formation of a definite habit of response to a definite sensory stimulus can be expected to show the *ability* of the fish to respond.

C. General Considerations

a. *Difference in species of fish investigated.*—All fish that have been used in investigations on color vision belong to the group *Pisces*, one of the three classes of vertebrates popularly referred to as fish. Few species have been investigated. It has been pointed out that the capacity to discriminate by means of wave-lengths is not the same in

the two species chiefly investigated by me and that the capacity of individuals of the same species is not necessarily the same. Even a single individual may be expected to show responses varying with age or condition. That the conflicting results obtained by different investigators may in some cases have arisen from difference in species used, in individuals, or in ages, is possible. It is also to be expected that color blindness occurs among fish as among men.

b. *The responses to wave-length mediated through the eyes.*—The question may be raised whether the responses to wave-length are conditioned through the eye. Parker (1909) has shown that in the species of fish (dogfish, *Mustelus canis*; eel, *Anguilla chrysops*; killifish, *Fundulus heteroclitus*; scup, *Stenotomus chrysops*; cunner, *Tautogolabrus adspersus*; tautog, *Tautoga onitis*; puffer, *Chilomycterus schoepfi*; toadfish, *Opsanus tau*; tomcod, *Microgadus tomcod*) investigated by him, the skin is not sensitive to white light even when of great intensity. The eyes remain as the only possible mediating sense organ. Mast (1916) found that flounders " with both eyes removed do not simulate the background either in shade, color, or pattern." The evidence that with the eyes functioning these fish become colored like the background upon which they rest has been mentioned. With the sunfish there never was reason to doubt that the behavior toward light of different wave-lengths is governed by stimuli received through the eye. The eye movements toward the source of light are striking, and occur at all intensities of red light.

c. *Peculiarities of the teleostean retina.*—Hess suggests that fish do not necessarily have color vision because men can see how it would be of use to them if present. With equal reason it may be said that fish do not necessarily lack color vision because men cannot see how it would be of use to them if present. Yet Hess argues the lack of red vision on the ground that red rays do not reach the environment of certain fish. The truth is that only experimental evidence can determine whether color vision exists in fish. This evidence has been considered and the conclusion drawn that the fish used in my experiments

and probably those used by others have color vision, but certain peculiarities of the eyes of fish make it probable that their color vision differs from that of terrestrial forms. The fish eye shows peculiarities of the visual purple and of the cones which suggest that the longer wave-lengths of light may have more marked effect upon them than upon man. These peculiarities are as follows:

(1) Köttgen and Abelsdorff (1896) have published curves showing the relative absorption of light of different wave-lengths by the visual purple of different animals. These show the maximum absorption for fish at wave-length 540 $\mu\mu$, while for mammals, birds, and Amphibia it is at 500 $\mu\mu$.

(2) According to Ewald u. Kühne (1878) this visual purple in fish has not the true purple color found in terrestrial vertebrates but is somewhat reddish-violet. This is significant, for researches[10] on organic compounds show that the farther their absorption band lies toward the red, the more sensitive is the chemical to light. From the differences in color and absorptive power between the visual purple in fish and higher vertebrates, we should expect to find the relative sensitivity for light of longer and shorter wave-lengths different from that in terrestrial vertebrates. We might even predict from the work of Köttgen and Abelsdorf that fish would show the greater sensitivity to red subsequently found by Bauer and others.

(3) In another respect the retina of fish differs from that of higher vertebrates. It possesses (Eigenmann and Shafer 1900) large cones and peculiar twin cones, structures which may have advantages in the reception of the reduced number of red rays of light. Whether wave-length discrimination is confined to the cones (Schultze 1866 and v. Kries, 1896) or is in part the function of the rods and the visual purple (Kühne 1879, Siven and Wendt 1903), the fish eye has modified anatomical structures which may be the basis for differences in the functioning of the eye as compared with the human eye, and for increased sensitivity to red.

[10] Reported by Bayless from Luther and Nikolopoulos.

D. Final Statement of Results

This paper embodies an attempt to learn whether fish are capable of responding differentially to lights of longer and shorter wave-lengths. The experimental evidence presented is of two sorts—that in which the fish went for food to a patch of light of shorter wave-length when presented at the same time with a patch of longer wave-length, and that in which the unlearned responses of the fish to light of different wave-length were observed.

By the first method all the seven fish used learned to go to the patch of blue light of constant intensity before which they were fed, when this was presented at the same time with a red patch. There was then established a food association or sensory-motor habit. When the intensity of the red patch was gradually reduced the fish continued to go to the blue until the brightness of the red was approximately that of the blue for the human dark-adapted eye. At this value of the red most of the fish at first failed to discriminate the two patches and went about as often to the one as to the other. But as the trials were continued at this matched brightness the fish again discriminated and continued to do so with further reduction in the intensity of the red. The value of the red variable at which temporary failure to discriminate and subsequent recovery take place is believed to be that at which the red and blue are of matched brightness for the fish. The behavior of the fish at this value thus becomes an indicator for matched brightness. The fish then learned to discriminate the red from the blue at all values of the red variable used including one of matched brightness for them. (See graphs figs. 13 to 16 and discussion of them elsewhere). Check tests of the apparatus used and of the method of manipulating it seem to have excluded the possibility that the fish were guided in their discrimination by anything else than the stimulus patches, and at matched brightness these patches differed for the fish and for man only in the wave-length of light coming from them.

This evidence from training experiments is reinforced by that obtained from a study of the unlearned response of the fish. From this evidence it appears that in the

training experiments the fish show an initial avoidance of red and that they rapidly become adapted to red and then no longer avoid it. (Graphs 13 and 15 and discussion of these in text.) It appears further that when first presented with red and blue patches of matched brightness for the human eye fish show without training, by manner and frequency of approach to the patches, that the stimulus value of the two is not the same for them. When in experiments they have become adapted to red and blue patches, their behavior is greatly altered when a gray patch of matched brightness is substituted for the red. Many innate responses indicate the different stimulus values for the fish that lights of longer and shorter wave-lengths have.

In spite of the fact that the fish discriminated red and blue stimulus patches when they were matched in brightness for the human eye and when the behavior of the fish indicated that they were matched in brightness for them; it is possible to postulate extraordinary powers of brightness discrimination for the fish, powers far beyond those of man, and to explain the results obtained with the use of food association on that basis. Thus, postulating high capacity to differentiate slight brightness differences, we might explain the graph in figure 13 on the basis of such discrimination. Failure to discriminate at slit width of 0.9 mm. would then be due to the fact that the stimulus patches were nearly but not quite matched in brightness for the fish. Recovery of discrimination at this slit-width could be attributed to continued training at these slightly differing brightnesses. To determine whether the fish possesses extreme powers of brightness discrimination tests were made to find by how much two white stimulus patches must differ in intensity in order that the fish may learn to go to the duller patch for food. It was found that intensity differences of white light of 1 to 4 were necessary for discrimination in the case of dace and of 1 to 3 in the case of sunfish. The fish do not therefore under the conditions of the experiments show powers of accurate brightness discrimination sufficient to explain the graphs shown in figures 13 and 15, nor sufficient to explain their innate dif-

ferential responses toward patches of light of different wave-length but of presumably matched brightness.

It is *a priori* not impossible that the responses of the fish to the stimulus plates are determined by the total energy reaching the fish from them, as measured by physical instruments, rather than by the stimulus value of the light rays alone. Tests were therefore made to determine this point but no relation could be detected between total energies and the responses of the fish. (p. 53.)

Throughout the work the attempt has been made to escape the sources of error enumerated in the last section. The fish have been kept in normal physiological state and it is believed that environmental factors likely to modify normal response or to inhibit it have been detected and eliminated.

The conclusion is reached that the fish used are capable of responding differentially to light of longer and shorter wave-lengths. This capacity is made evident by the use of a food association. In the absence of modifying or inhibiting environmental factors differential response may be apparent in the unlearned responses of the fish of some species. The two sources of evidence thus supplement each other. Evidence is collated to show that the response to light of longer and shorter wave-lengths is mediated through the eye. We may therefore speak of color vision in fish, but attention is called to the differences found by others between the retinal structures and visual purple of fish and higher vertebrates, differences which indicate that the stimulus value of the longer and shorter wave-lengths of light may not be the same in the two cases.

The evidence presented in this paper that the longer wave-lengths of light have a physiological or psychological effect upon some fish different from that produced by the shorter rays is, I think, sufficient, even in the sense demanded by Watson (1914, p. 354) when he writes,

> "Ordinarily we mean when we say that an animal is sensitive to difference in wave-lengths that such stimuli play a role in the adjustment of the animal to food, sexual objects, shelter, escape from enemies, etc., *i. e.* that such stimuli initiate activity in arcs which end in striped muscle."

I prefer to designate what I have found as difference in stimulating value of the longer and shorter wave-lengths

of light not entirely dependent upon the intensity of the light.

V. SUMMARY OF EXPERIMENTS

A. Apparatus

1. A T-shaped experiment aquarium of galvanized iron supplied with running filtered water was used, and in this the fish remained not only during experiments but in the intervals between them. p. 9, figs. 1, 2.
2. The aquarium was divided into compartments. The first of these contained two stimulus plates of opal ground glass, which could be exposed to the fish to be immediately tested by lifting a sliding door separating it from a second compartment. The third compartment contained fish not being tested. p. 5, fig. 1.
3. The partitions between the compartments were movable, and by manipulating them the fish could be shifted from compartment to compartment without causing fear reactions. p. 9, figs. 1, 2, 6.
4. The stimulus plates were illuminated by lamps in fixed positions, contained in a light-tight house. pp. 7, 10, fig. 2.
5. The intensities of the illumination on the plates were varied by means of adjustable slits beneath the lamps. pp. 7, 12, fig. 2.
6. Well defined areas of light of practically uniform distribution were secured upon the stimulus plates by the use of cylindrical lenses. pp. 7, 12, fig. 2.
7. Red and blue filters were used to secure light of restricted wave-lengths,

and by shifting the filters a red or a blue light could be secured on either plate.

8. By use of slits the intensities could be varied. The aquarium was illuminated by a ceiling light of constant intensity, and other light was excluded from it by a light-tight enclosure.

9. A curtain was hung about the aquarium within the light-tight enclosure in such a way as to conceal the experimenter from the fish.

10. Food was released before one of the stimulus plates (blue or white) by means of a device operated by an electro-magnet controlled by a switch, which could be manipulated from outside the curtain. The sliding door by means of which the stimulus plates were exposed to the fish could also be controlled from outside the curtain.

B. Method of experimentation

11. Training methods were used in which a food association was established by feeding the fish before a stimulus-patch of constant intensity in contrast to one of variable intensity. By shifting filters and adjusting slits the positions of constant and variable stimuli were irregularly interchanged. In experiments with light of restricted wave-length, blue was used as the constant and was the positive stimulus.

12. The unlearned differential responses of the fish toward lights of different wave-lengths and different intensities were studied by the use of the same apparatus.

C. Care of the fish

13. The fish used in experiments with food association were horned dace (*Semotilus atromaculatus*, Mitchell) and Common Sunfish (*Eupomotis gibbosus Linnaeus*). Individuals of these species as well as of the blunt-nosed minnow, *Pimephales notatus*, Rafinesque, the Common Shiner, *Notropis cornutus*, Mitchill, and the mud minnow, *Umbra limi*, Kirtland, were used in experiments on differential response.

14. When not in the experiment aquarium, the stock fish were kept in separate aquaria. When needed for experiment, they were transferred to the experiment aquarium, where they lived often for months together. During more than two years these fish have shown by feeding regularly, by lack of fear, by continued growth, and by breeding behavior that the conditions were normal for them.

D. Experiments with food association

I. *Intensity discrimination of white light*

15. Three full-grown individuals of the horned dace were given an aggregate of 307 trials in an attempt to form a food-association with the duller of two white plates, the intensities of which were as 1:4. They failed to discriminate these plates although they learned to discriminate plates of greater intensity difference. (p. 20.)

16. Three sunfish, 4 cm. long, were tested for intensity discrimination without training by noting their behavior toward two white plates. When the

intensities of the two plates were in a ratio somewhat greater than 1:2, the fish showed differential response toward them by a difference in frequency or method of approach to them. With less intensity difference no differential response was observed. (p. 37.)

17. A single sunfish, 8 cm. long, was given 160 trials before two white plates of different intensities, and was fed before the duller plate. The fish discriminated at once plates differing as 1 to 4. In an attempt to use the food association thus established the fish discriminated plates differing in intensity as 1:3 poorly but not those that differed less. (p. 38.)

II. *Discrimination of light of different wave-lengths*

a. White-red

18. Fifty trials were given to each of two horned dace by feeding before a white plate presented at the same time with a red of different intensity. These fish were accustomed to red and were not red-shy. After 30 trials each fish made 80% to 90% of correct or white choices, and each finally gave 10 successive correct choices. (p. 23.)
19. By means of a peculiar unlearned response of the dace of section 18 to red and white plates these plates were matched in brightness for them. (p. 24.)
20. Twenty trials were then given to each of the horned-dace of section 18 before these red and white matched plates, while the fish were fed before the white. Seventy per cent of correct or white choices were obtained. (p. 25.)

b. Blue-red

21. Four untrained but tame horned dace were tested before a brilliant red and duller blue plate in order to learn whether these plates were effective stimuli. There was an initial avoidance of the bright red plate but this soon ceased and the behavior of the fish showed that both plates were effective stimuli. (p. 26.)
22. Four horned dace were given 420 trials before blue and red plates with the red varied in intensity so as to include an intensity equal to the blue. They were fed before the blue. The results are plotted in the graphs, figure 13, p. 31, in average percentage of correct choices at different intensities of red. At an intensity of the red obtained by a slit-width of about 1 mm. the percentage of blue choices diminishes and the curve falls to near the 50% level. This is believed to be the region of matched brightness of red and blue for the fish. As the trials are continued with the red held at this brightness, the percentage of blue choices again increases as is shown by the rise in the curve. With subsequent lessening of the intensity of the red the percentage of correct choices continues to be high. The fish then discriminates the red and blue patches at all intensities of the red. (p. 30 also figs. 13 and 14.)
23. Three sunfish were given 680 trials before a blue in contrast to a red plate as in the preceding experiment; they were fed before the blue. The graphs showing the percentage of correct

choices at various red intensities are shown in figure 15, p. 39. The graphs have the same general form as those of the dace so that the statements of sec. 22 apply to them.

c. Blue-gray

24. A brief series of trials was made before blue and gray plates of matched brightness for the human eye, with blue as the positive plate, with two horned dace. One went to the gray and blue with about equal frequency; the other chose blue in 13 out of 17 trials. (p. 49 and Table II.)

25. A brief series of trials was made before blue and gray plates of matched brightness, with the blue as positive plate, with three sunfish previously trained to go to blue for food. Seventeen out of twenty choices were to the blue plate. (p. 49 and Table II.)

E. Unlearned responses

1 Breathing rate

a. *Umbra limi*

26. After stimulation with red light a mudminnow, *Umbra limi*, was found panting rapidly. The red was the only unusual factor in the environment. (p. 57.)

b. *Notropis cornutus*

27. The breathing rate of a shiner, *Notropis cornutus*, increased by one-fourth when the illumination of white light to which it was accustomed was increased by the addition of a carbon lamp. But when this increased illumination was lessened by a red filter the breathing rate more than doubled. (p. 58.)

2. Red avoidance and behavior toward blue

a. *Eupomotis gibbosus*

28. One sunfish circled about the red lighted area as far from it as possible and with her head toward the light. This fish often seemed to bask in the blue light, remaining with the direct rays of light shining upon her and with one side turned so as to receive more light than when in a vertical position. (p. 58.)

b. *Pimephales notatus*

29. When matched blue and gray plates were presented to several untrained *Pimephales notatus*, they promptly approached them; but when a red plate was substituted for the blue, they remained at a distance. (p. 59.)

c. *Semotilus atromaculatus*

30. When an untrained fish was tested with matched blue and gray patches, one-third to one-half of a minute was sufficient for the fish to swim up to the lighted areas, but when the same blue patch was matched with red, approach was completely inhibited or was inhibited for five or six minutes

3. Delayed Response

31. Two dace and three sunfish, fed before the blue plate from October to March, in the blue-red series, usually reached the stimulus patches three to twelve seconds after the opening of the door *D* (fig. 2). They were shown the blue with a matched gray. They failed to leave the discrimination compartment or left after a long wait. The average time of response was over 100 seconds for the four fish showing the best dis-

crimination. Instead of the usual direct approach there was a weaving back and forth in front of the door or circling around the end of the discrimination compartment or remaining still in a corner.

F. Experiments with equated energies.

32. When in the blue-red discrimination experiments the energies reaching the two stimulus plates were equated by the use of a silver-bismuth thermopile the percentage of correct choices continued to be significantly high. (p. 53 and postscript.)

G. Tests of apparatus and manipulations

33. Check tests to determine whether shifting of slits and filters, changes in the position of the experimenter, or difference in appearance of any part of the apparatus on the positive and negative sides might afford the fish a clue gave negative results.

VI. CONCLUSIONS

Sunfish (*Eupomotis gibbosus L.*), horned-dace (*Semotilus atromaculatus*, Mitchill) discriminate light of longer wave-length from light of shorter wave-length and from white light. This is shown not only by innate differential reaction but by the results of experiments in which a feeding response was associated with a stimulus of restricted wave-length.

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Postscript

While this paper was being made ready for the press in the fall of 1917, Doctor Reeves took up her residence at Ginling College, Nanking, China. War has delayed the publication. Owing to Dr. Reeves' absence and the lapse of time I am venturing to add the following notes for which I alone am responsible.

1. The absorption of rays of the visible spectrum by the water of Wisconsin Lakes has been recently studied by Pietenpol (Trans. Wis. Acad. Sci., XIXI (1918), 562–593). In connection with the discussion on pp. 74–75, it seems best to record here a recent simple experiment of my own on the visibility of red through lake water. In February, 1919, when Winan's Lake in Livingstone Co., Mich., was covered by about eight inches of clear ice, without snow, I suspended through a hole in the ice and at a distance of three feet below the surface a cylindrical tin can covered with red paper (Klinksieck's color code No. 56). At a distance of thirteen feet from this hole was a small spear-house which shut off a good part of the light from a second hole cut through the ice which formed its floor. By means of a mirror immersed to a depth of a foot through this hole I was able to view the can. Its color, as thus viewed, was unmistakably bright red, merely a little duller than when seen through air. The red rays which reached my eye had travelled a distance of 16 feet through water. With the great sensitivity of fish to red I have no doubt that it stimulates them through this lake water at much greater distances.

2. Miss Gertrude Marean White (Jour. Exp. Zool. Vol. 27, pp. 443–498, 1919) has recently published an account of ingenious experiments on color vision in sticklebacks and mud-minnows. The methods used were those of the third training procedure (this paper p. 81) and the results reached are those of other investigators except Hess and are in accord with those of Doctor Reeves. They do not involve the equation of brightness through the behavior of the fish and are therefore open to the same criticism as other experiments of their type. Miss White also reports experiments on the inability of these fish to discriminate grays of very unequal brightness and in this respect confirms Doctor Reeves (this paper pp. 20 and 37).

3. In all her measurements of the energy reaching the two colored stimulus plates (pp. 53–54) Dr. Reeves used a new blue filter. Since the filter transmitted more light than the old filter, a slit was used with it to reduce the intensity of the blue to that obtained with the old filter to which the fish were accustomed. The width of the slit, once adjusted, was not varied. A water-cell on the blue side served as an infra-red filter, if indeed such a filter were needed, since no such rays should have been let through by the blue filter. The energy which reached the blue plate during the measurements with the thermopile is therefore the same as that which reached the fish from the blue plate during their tests. The two might differ somewhat on account of the unequal thickness of the strata of water involved but in both long rays should be wholly excluded.

But in measuring the energy reaching the red plate two methods were used to vary the intensity of the red light—a red solution alone and a slit alone. Since red solution and aquarium water both act as infra-red filters in greater or less degree, whatever energy reached the red plate through the one should reach the fish through the other though in less intensity. Infra-red was presumably reduced under the two conditions. When a slit alone was used to vary the red intensity there was no infra-red or long-ray filter present on the red side in the energy-equation measurements. By this method infra-red rays would reach the red plate unhindered. When the energies had been thus equated and the fish were then tested the aquarium water served as an infra-red filter on *both sides*. The energies presumably equated with water cell on one side only would then no longer be equated for the fish.

It appears that both methods of varying the intensity of the red permit the energies of the two plates to be equated but that only one of them, that in which a red solution was used, retains approximately those equated energies in the stimuli which reach the fish through the aquarium water.

Table IV, p. 54, presumably includes trials in which both methods of equating energy were used. The table

shows that two out of three sunfish *discriminated* while from the text it appears that the third, large sunfish, discriminated accurately in later trials not included in the table. Three dace discriminated, but one did not. Its failure is perhaps adequately explained on p. 54. The table might be interpreted as showing response to unequal energies if only the slit method of varying the red had been used in equating. Since both methods were used, energies were equated in a considerable but unknown number of trials and in these the fish should have failed if they were reacting to energy differences. The high percentage of correct choices for five (or six) of the fish indicates that Doctor Reeves is right in holding that they were not responding to total energy differences.

Undoubtedly the tests should be repeated and in equating energies of the red and blue plates the light for *both* should be passed through filters of the identical water used in the experimental aquaria and as thick as the layer of water through which the fish ordinarily see the stimulus patches.

The recent work of Pietenpol gives reliable data on the absorption of rays of different wave-lengths by the waters of Wisconsin lakes. It is clear that absorption is unequal and that either the red or the blue or both may be absorbed more rapidly than other rays. The total-energy ratio of two stimuli of unequal wave length probably could not be constant for a fish unless its choice is made always at the same distance from the stimulus plates. This was by no means the case in Doctor Reeves' experiments. As judged by the behavior of the fish (change of direction) choices were made at all possible distances and with all possible variation in the energy ratios. This seems to me to show that choices could not have been made on the basis of energy differences nor of brightness differences, but only as the result of quality difference. But the truth is that *no value* of the red variable was found at which the fish did not *learn* to discriminate the longer and shorter wave lengths. Amongst the values tried was one which showed temporary failure of the fish (slit width 0.9–1.0 mm. for red). Whether we assume that at this point we have to do with matched brightness or equated energies

is immaterial—for even here the fish *learned* to discriminate and could have been guided only by quality differences.

JACOB REIGHARD.

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Ann Arbor, Michigon.
May 23, 1919

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Visual Perception of the Chick

BY

HAROLD C. BINGHAM

A dissertation submitted to the Board of University Studies of the Johns Hopkins University in conformity with the requirements for the degree of Doctor of Philosophy.

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CONTENTS

Part I. Historical

Part II. Experimental

PREFACE

The observations on which the experimental portion of the following pages is based were made upon four different groups of Plymouth Rock chicks. Work with the first three groups was conducted in the Harvard Psychological Laboratory during 1911–1912 when the visual factors in space perception described in Chapters V and VI were studied. The data on flicker perception reported in Chapter VII and the greater portion of the material on problem learning, presented in Chapter VIII, were gathered in the same laboratory during 1915–1916. The results on relativity and specificity of reactions reported in Chapter IX were obtained quite incidentally during the two years of research.

In this Monograph there is presented an account of the results as written in 1916. A preliminary report had been published in 1913 in the *Journal of Animal Behavior*, following which there were several published comments relative to certain questions raised in the paper. Cognizance of these discussions and the related literature was taken at the time the manuscript was prepared. Rather than isolate the unpublished portion, it now seems advisable to present the entire study in the form it had taken before the United States became a participant in The World War. A revision of the manuscript to make it strictly current is not deemed worth while.

The problem in spatial perception was proposed by Professor Robert M. Yerkes, under whose guidance the entire study was made. During the year preceding my initial work on this problem, he completed in the Harvard Psychological Laboratory the construction of the apparatus which has been described in a Monograph[1] on "Methods of studying vision in animals." For the use of this apparatus, for his numerous suggestions in method, for his precise formulation of problems, and above all for his continued and sympathetic encouragement, I wish to

[1] *Behavior Monographs*, Vol. 1, No. 2.

express sincere appreciation. My only contribution to the apparatus is the simple mechanism described in Chapter VII, yet in the development of this device his helpful suggestions always were at my command. Likewise, my only contribution to the main problem of visual perception in the chick is that represented by the preliminary data on the reactions to flicker stimuli. Gladly I acknowledge my indebtedness to Professor Yerkes for his patience in starting me on this experimental task and for his kindly interest throughout the study.

This opportunity is also taken to express my obligations to Miss Doris M. Wood, who generously read the entire manuscript, and to my wife, who assisted in various ways with the preparation of the manuscript.

HAROLD C. BINGHAM.

Washington, D. C., January 25, 1922.

PART I. HISTORICAL

CHAPTER I

Origin and History of the Domestic Fowl

In the jungles of southern Asia lives a species of birds known, from the nature of its habitat, as the Jungle Fowl. As the name suggests, it is a wild type of *Gallus*, the comb fowl, to which our domestic chick belongs. Several varieties of these little wild fowls are to be found in India and the Malay regions, but all have general characteristics in common. Four groups are generally recognized, namely, the Bankiva Fowl, the Sonnerat Fowl, the Ceylon Jungle Fowl, and the Fork-tailed Jungle Fowl or Gangegar. These jungle fowls are commonly regarded as the ancestors of all the present breeds of domestic fowl.

Gallus bankiva, the wild type which seems to be most closely related to our domestic fowl, is found throughout India, in the Malay Islands, and in the Philippines. It closely resembles the domestic Black-Red Game Bantam. The feathers of the head and neck, including the long hanging feathers at the back of the head, possess a glistening golden hue. The golden hue of the collar is matched with the long supra-tail feathers, but the shorter straight tail feathers beneath are all black. The middle feathers of the wings are a lively brown, the remainder, in the male, being dark gray with pale borders. The iris is orange red, the head dress red, the bill brown, and the foot slate black. The body length reaches 56 cm., the wing length 22 cm., and the tail length 27 cm.

The tail of the smaller female stands more erect, her comb and wattles are barely noticeable, and her long neck feathers—black with yellowish borders—add brownish black spots to the mantle plumage. The dorsal side is cream colored. The tail and supra-tail feathers are a brownish black.

Gallus sonnerati was the first of the wild breeds to become known. It occurs in west, south, and central India. The long slender feathers on the head, neck, and upper back of the male

are black with gray edges and white tips; near the end they bear an ornamental yellowish spot. The other feathers of the dorsal side are narrowly striped with white. The ventral side of the body is black, dotted with little white lines, and becomes almost white at the median line.

Domestication of the Sonnerat Fowl is more difficult than that of Bankiva. We are told that these two wild species will cross but the hybrids are said to be sterile. The sterility of the hybrids and the characteristic differences between tamed Bankiva and Sonnerat fowls have frequently been urged as evidence that the latter is not the ancestor of our domestic chick.

The Ceylon Jungle Fowl, *Gallus lafayetti*, closely resembles Bankiva. The male is distinguished from Bankiva by the orange-red breast, the long black-striped yellow neck feathers, and the glistening blue-black throat and supra-tail feathers. The slightly notched red comb, bearing on the lower part a large oval yellow spot, is also distinctive. The Ceylon and Bankiva females differ with respect to voice. According to a report of the National Poultry Conference, Reading, England, (cited by Houwink), Lafayetti has been crossed with common fowls and fertile hybrids were obtained.

The extreme shyness of the Fork-tailed Gangegar, *Gallus varius*, is a characteristic phase of its behavior indicating that it would not be readily domesticated. At the least noise, it hides in the alang-alang thickets, which makes close observation of this fowl in its natural habitat very difficult. Were it not for the male's noisy voice it would scarcely be noticed. Early morning is the best time to observe it, for it then leaves the thickets for the open places in search of food.

Gangegar seems to be very remotely related to the three preceding classes. It differs from them in the number of supra-tail feathers, the untoothed comb, and single neck lobe. It also has certain characteristic differences in coloring.

Of these four groups of wild fowl, Bankiva is most generally regarded as the ancestor of the common chick. Darwin, basing his conclusions chiefly upon structural evidence, is inclined to regard Bankiva as the original stock. "Having kept," he says, "nearly all the English breeds of the fowl alive, having bred and crossed them and examined their skeletons, it appears to me almost certain that all are the descendants of the wild Indian

fowl, Gallus bankiva." Others think that the jungle and domestic fowls sprang from a common ancestor of intermediate size which has since become extinct, but Houwink thinks it is improbable that the domestic fowl has an extinct ancestor, for it, like the known wild poultry races which have maintained themselves in the midst of the oldest and most populous Indian towns, surely have been preserved somewhere in Central Asia.

The behavior of Bankiva, as reported by certain naturalistic observers, would lead one to regard it as the most probable ancestor of the domestic fowl. Guillemard is cited in Brehm's Tierleben to the effect that captive Bankiva fowls on the island of Sulu are very tame and are easily crossed with domestic fowls. In the same source, but in a different citation, it is asserted that in the mountainous regions of Pegu, where the Bankiva abound, they come into the villages and yards of the natives where they mix with the tame fowls. Another citation has it that crossing with the domestic chick is a common occurrence in Ceylon and that the male hybrids resulting are far more spirited and have sharper spurs than the parent males.

At the present time there are domestic fowls which are very similar in structure to the wild Bankiva. It has been found that modifications in food and environment may cause changes in the general form and color of poultry, if we may believe Houwink on this point. It is rather resonable that the breeds resembling Bankiva have descended from that origin. Natural and scientific selection might readily account for the variations and further development that have resulted.

From discoveries in mounds and other ancient settlements of man, it appears that the chick has long been domesticated. Along with the duck and the goose, the chick could have been taken and held in captivity with comparative ease. On this fact is based the assumption that the origin of the fowl's history dates back to ancient times. Robinson deems it quite probable that it was domesticated before any of the mammals. Houwink on the contrary, reasons that it was not kept by man until population took on a permanent aspect. Unlike the dog, its domestication would have been neglected by the hunter. Such animals as the cow and the horse would naturally be first tamed by the nomads.

Turning to evidences which ancient literature furnishes, the

first reference to the domestic fowl is probably made in the great Chinese Encyclopedia which was prepared about the fourteenth or fifteenth century before Christ. This book suggests that the chick was brought from the West and from India into China. This would indicate that it is an old domestic animal with the Chinese and Japanese. It is possible, of course, that this account is based upon nothing more reliable than tradition.

The Egyptians are also said to have had domestic chickens at an early date. It is thought that they were received from the Orient. It is probable that the fowls were transported from Egypt or Persia to southern Europe, Greece, and Rome. The chick is not mentioned by the Old Testament, Homer, and Hesiod, but it was to be found in Babylonia as early as the seventh and sixth centuries before Christ. It was surely known to the Greeks as early as the fifth century before Christ, for Socrates, after taking the poison which caused his death, reminds Crito that he owes a cock to Asclepius and asks him to pay the debt. Darwin is of the opinion that the domestic fowl appeared in Europe about 600 B.C.

The early history of the chick is thus quite uncertain, despite the fact that a number of students have given it their attention. Numerous theories have been advanced, evidence more or less convincing has been submitted in favor of them, yet the available facts are not conclusive. The evidence thus far furnished does little more than provide a basis for theories, and in consequence the statements which occur in the literature must be accepted with caution. For the most part it seems probable that *Gallus bankiva* is the common ancestor of the numerous breeds of domestic chicks which we now possess. It is quite reasonable to conclude that man caught the wild fowl, domesticated and developed it for cock fighting, fortune telling, or domestic use according to his peculiar interests. Chickens used for fighting tended to remain fighters; those accustomed to domestic life tended to retain their utilitarian characteristics; and from some of the deviations which have occasionally occurred the numerous breeds which we possess today have been developed.

Thus the wild fowl, after its domestication, has been permanently adopted by man. In a general way, its distribution over the earth seems to have followed the migrations of the

Aryan peoples. The Chinese record, however, if its reliability be not questioned, suggests an important exception. At any rate, the life of the chick has been so long connected with human activities that it has become quite dependent upon man. If left to itself, it is no longer able to maintain an existence. Since becoming domesticated, it has changed in form and has been bred toward gigantic or dwarfish structure according to climatic conditions and the influence of natural and artificial selection.

As a result of these variations, there were in the year 1911 over 160 breeds of domestic fowl. Five of these are recognized as distinctly American breeds, of which the most typical is the Barred Plymouth Rock. An accurate knowledge of the Plymouth Rock's blood heritage is impossible, for in the duplication of the original stocks and in the perfection of the breed numerous elements were intermingled. It is generally believed that the original stock was secured by crossing the American Dominique with black Javas or Cochins. Light Brahma, Dark Brahma, and Pit Game are said to have been used in its making. This breed was briefly known as Plymouth Rock until the white variety appeared, after which it became known as Barred Plymouth Rock.

This particular type of fowl appeared about the middle of the 19th century. Some of the more intelligent poultry breeders conceived the idea of a breed of chicks particularly adapted to American conditions. Accordingly, they set about developing birds with the desired characteristics. As a result of this activity there were exhibited in 1869 the first Plymouth Rocks. These birds were so favorably received that they soon became more numerous in America than all the other standard bred birds combined. The observations reported in Part II were made upon this strain of chick.

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CHAPTER II

Experimental Literature on Vision in the Chick

During the course of the investigation which is reported in Part II, the question was asked by a Harvard undergraduate: Why is it that a chicken always wants to get on the other side of the road when it sees an automobile? The question has nothing in common with my investigation but it is suggestive of a prevalent notion regarding the stupidity of the domestic fowl. The chick seems to rank low in intelligence according to unscientific observers. Eulogistic literature, in which anecdotes and remarkable stories abound, often contains accounts of exceptional and almost incredible behavior of dogs, cats, horses, parrots and the like, but in such collections of stories and incidents, it is noteworthy that the chick has been generally neglected.

One may incidentally hear of such stories as that of a hen finding her way through an open window to a bedroom in a farm house and selecting the top of the old-fashioned bureau on which to make a nest. In her efforts to collect all of the articles that might be used in a hen's nest, she knocked from the bureau a kerosene lamp and made use of a doily on which the lamp had been standing. In this extraordinary nest, composed of pincushions, ribbons, laces, doilies, and handerchiefs, she laid an egg.

The above anecdote was related to me by people who personally observed "biddy's stolen nest" and the results. Though trivial to the extent of absurdity in science, it is nevertheless typical of much that one may read about cats and dogs in the eulogies of the anecdotists. Chicken anecodotes of this sort seldom appear in print, but let one cat claw at the knob of a door supposedly as a singnal to be let out, and she becomes (see Thorndike (30)) "the representative of the cat-mind in all the books." It seems that no chicken has performed any act which might furnish the aspiring eulogist with a representation of the chick-mind.

Considering the apparent delight of the naturalists and semi-experimentalists in repeating animal stories of an exceptional

type, it is rather surprising that so little chick behavior has found its way into print. Apparently the animal anecdotists saw in the behavior of the chicken only acts of *stupidity*, rather than *intelligence*, and as a result of their eulogistic inclinations they neglected to report such facts. The chick does not fill the place of a household pet; hence the stock of chick stories like that related above has generally been unknown to the reporters of animal anecdotes.

Despite the tendency of Aristotle to report unusual facts about animals, he has said very little about the chick. The brief description of it is typical of his usual method of describing animal behavior. He naïvely says:

> Young hens are the first to lay, and they do so at the beginning of spring and lay more eggs than the older hens, but the eggs of the younger hens are comparatively small. As a general rule, if hens get no brooding they pine and sicken. After copulation hens shiver and shake themselves, and often kick rubbish about all around them—and this, by the way, they do sometimes after laying. . . . (1).

With such generalization, Aristotle's description of chick behavior ends. His metaphysical interests did not encourage intensive observations that would lead to a description of the fowl's perceptions.

Offering little or nothing for the pure naturalists to eulogize, therefore, chick behavior is not reported until the scientific spirit spreads to the field of animal behavior. Naturally, then, the first publications involving the chick are those of the semi-experimentalists. Stimulated, as they must have been, by the theory of natural selection, one might well expect these first observations to be turned upon the instincts. From a consideration of inherited types of behavior, it is a logical step to individual modifiability. And the investigation of habit formation, involving the sensory equipment of the organism, finally leads to studies of perceptual discrimination.

Early reference to the chick's vision is incidentally made by Spaulding (28), representing the semi-experimental group, whose observations were primarily centered upon the nature of the pecking and drinking reactions. In a general way, Preyer (25) observes that the perfection of sight in newly hatched fowls is astonishing when compared with the imperfection of this sense in newly born humans. The work of Romanes (26),

Eimer (8), Mills (22), and Morgan (23) also primarily involves the instincts. There is a tendency for this transitional group to become controversial over the problem of instinct and acquisition. No definite experimental data are produced to settle the disputed questions. Mills loosely reports some of his observations in diary form. The diary method also appears a few years later in reports by Hunt (12) and Kline (19) in each of which certain visual discriminative ability is described.

Irritated by the controversies of this transition group and the failure to answer on empirical grounds the disputed questions, Thorndike (30) sets out on a procedure distinctively experimental. However, he barely touches the problem of visual acuity in the chick and, for the most part, his observations are confined to crude studies of the chick's space and color perceptions.

Nearly ten years later, Hess (9–11) takes up the problem of the chick's color vision as well as light and dark adaptation. The method of Hess involves for the first time the use of the dark room for studying visual acuity in the chick. Although he greatly improves on the method of Thorndike and deserves praise for introducing the controllable method of the dark room which has later been highly refined, Hess nevertheless often leaves the reader uncertain of the experimental conditions. He should be credited with ingenuity and alertness, but his method in certain details is too crude for the problems with which he deals.

A study, certainly deserving more severe criticism than the work of Hess, has been jointly reported by Katz and Révész (18). These authors have hastily considered a variety of topics relative to the chick's visual discriminative ability. Their crude "Klebmethode" has been applied to several phases of the problem, including the topics of size and form perception as well as color discrimination in "unsuppressed daylight."

In its simpler form, the "Klebmethode" of Katz and Révész consists in pasting on a cardboard kernels of grain at which the chick's pecking response is to become inhibited. Among these "glued" kernels is scattered a different kind of grain which the bird is allowed to pick up. To illustrate, it was found by the experimenters that the chicks preferred rice to wheat. The bird was classed as "Fehlerfrei" when it had picked up the loose

wheat without pecking at the glued rice. The observers had two quantitative measurements for the rapidity of learning: (1) The number of series necessary for a perfect habit; (2) the number of reactions to rice. To make sure that the errorless chicks did not avoid the rice by means of the glue which might be visible on the pasted kernels, the rice was scattered loosely upon the cardboard in the same manner as the wheat. The wheat was again eaten by the errorless chicks and the rice was left. The discrimination, the authors concluded, was between wheat and rice.

Having found that the chick could pick up wheat and avoid rice, Katz and Révész sought an answer to the question: By what means does the chick discriminate the grains? Accordingly they turned to a study of size and form discrimination. Because the chicks could be trained to eat only half grains of rice when scattered among whole grains, the authors were convinced that there was discrimination of size and form. Further observation leads them to conclude that the chick discriminates squares and triangles. They say:

> Knowledge of this fact we secured through a variation of the experimental procedure. Out of green peas (some of which had been readily eaten), we cut three and four cornered pieces. On account of their moisture, they could not be glued down, so we laid the four sided pieces upon a glass plate and the three sided pieces under it. The chick found that the three sided pieces could not be reached and soon ceased to peck at them. Then if we laid both forms upon the glass plate, only the squares were picked up. By means of the same method we found that the chick discriminates between triangles and circles as well as squares and triangles.

The report of Katz and Révész leaves the reader too often uncertain of the experimental conditions. They have tried to do too much and have not treated any one task intensively. Their report indicates carelessness and indifference to details. No doubt the assertion that the chick discriminates squares and triangles as well as triangles and circles is true for the conditions under which the experiment was made. But from the written account, one cannot tell what the conditions were. One does not know, for example, the relative sizes of the different forms. Were they equal in area? Was the square an inscription or a circumscription of the circle? Was the diameter of the circle equal to the side of the square or the altitude of the triangle?

Was the third dimension constant? These are some of the factors which must be known before one can safely say that the chick perceives form. One could truthfully state that an animal discriminates between a circle and a triangle if it regularly chooses the former even though the triangle be twice as large as the circle, but it is improbable that the basis of discrimination in such a case would be anything other than size. Since such points are ignored in the report by Katz and Révész, one suspects of the experimenters carelessness in technique.

Furthermore, no information is offered as to the method of cutting these forms. It is a difficult matter to cut green peas with regularity. Can we be certain that the chicks discriminated on the basis of form rather than irregularity of surface? No mention is made of controls to eliminate this possibility. Because the authors leave vital points like these unmentioned and apparently unnoticed, one is inclined to regard the experiment as quite superficial.

A definite answer to the controversy of the semi-experimental school over the nature of the chick's instinctive reactions is offered for the first time by Breed (4).[1] His study of the instincts is supplemented by his study of certain habits, out of which grew the problem of accurately determining the nature of the color, form, and size stimuli in response to which a chick is able to acquire a habit of reaction (5). The chief significance of Breed's later study appears in his contribution to the development of the dark-room method. For testing the chick's perception of colors, Breed combines the Yerkes discrimination method (34) with the Hess (9–11) dark-room method. The next step is the adaptation of the combined methods to investigations of size and form perception. The stimuli were presented to the chicks by means of the illumination of two plates of opal flashed glass over which were set mats of tin or cardboard containing the desired openings. Thus the chick was given an opportunity of selecting a circle when appearing with a square, or of discriminating a larger from a smaller stimulus.

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[1] Certain instincts have later been carefully observed by Pearl (24). The instincts considered relate primarily to behavior having practical significance for the poultry keeper. In the single reference cited at the close of this chapter, there appears a selected bibliography referring to a number of other papers on related subjects.

For testing size discrimination, two circular areas—one 5 cm. in diameter, the other 8 cm.—were presented to the chick. Evidence of a perfect habit appeared at approximately two hundred trials. Controls were introduced throughout the training to eliminate "difference in brightness of the lighted areas" and "difference in brightness of the right and left sides of the experiment box." In spite of ambiguity in the use of "brightness" Breed's conception is fairly obvious.

In the study of form perception, Breed used three chicks, one of which, he declares, "learned to discriminate two optical stimuli on the basis of difference of form." The forms were a circle and a square equal in area. Because his studies of the reactions of other chicks to similar stimuli yielded negative results, he attributes the positive reactions of this particular chick to fortune in the choice of animal. In this connection, it is significant that the chick was credited with a perfect record in the fifth training series or after only forty trials. A perfect habit is clearly evident after one hundred trials. For space stimuli differing in form alone this rate of habit formation appears, in the light of later results, unusually rapid and suggests that the successful chick may have discovered some easy cue other than the form difference. This possibility suggests itself rather forcefully when one considers that Breed was using a mechanism only partially standardized; it rises to the level of probability when one notes that he does not report controls for varying the relative positions of the stimuli within the sliding frame.[2]

It is unfortunate that Breed also failed to make control tests to determine whether the distribution of light on the chick's retina was the basis of discrimination. Such a control is easily made in the case of a triangle by inverting the stimulus. The inversion of a square would cause no change in the distribution of light, but such a change might be produced by turning the square through 45 degrees. Even had there been no possibility of an unsuspected cue furnishing the chick with a discriminable factor, there remained this second possibility which Breed did not consider.

[2] A discussion of controls in which this possibility was found to be a reality appears in the *Journal of Animal Behavior*, 1913, vol. 3, pp. 86–90.

A study of the relation of strength of stimulus to rate of learning in the chick, though subsequent to Breed's work, is reported by Cole (7) prior to Breed's account (5) of his dark room work. Cole presented brightness stimuli to his chicks, using the same apparatus as Breed.

A further stage in the development of the combined "dark-room-discrimination" method is indicated in a joint report by Yerkes and Watson (35), on methods of studying vision. They have greatly refined the apparatus used by Breed and Cole and limited its use to studying *light* vision. In addition, they have developed a special apparatus for studying color vision.

The first use of the Yerkes light vision apparatus with chicks is my study of size and form perception (2). The aim of this study was to locate thresholds for standardized forms and sizes. With a standard circle 6 cm. in diameter, the threshold was found to be one-fourth to one-sixth. But instead of determining a limit in form perception, the question became chiefly whether the chick perceives forms. It was found that the chick could discriminate between a circle and an upright triangle of equal area, but the evidence of discrimination disappeared when the triangle was inverted. Since Breed failed to make a similar control, his statement that one chick "learned to discriminate two optical stimuli on the basis of form" may be questioned. A safer conclusion seems to be that the chick reacts to unequal stimulation of different parts of the retina.

With reference to this interpretation of the reactions to form stimuli, Watson (33) says:

> Bingham has raised the whole question as to what is meant by form.[3] . . . . While the chick can apparently respond to the difference in form between the circle and the square, and the circle and the triangle, when they are equal in area, yet such responses, after all, are really nothing more than keen perception of size differences. He draws this conclusion from the fact that after the chick has learned the circle-triangle habit with the base of the triangle down, the habit will disintegrate if the apex is placed down. (p. 366).

Quite naturally, this interpretation of form perception has called forth considerable comment. Hunter's contribution (13)

[3] For this suggestion I hasten to acknowledge my indebtedness to Professor Yerkes who proposed this question as a part of my experimental task. Because he conceived the possibility, however, it does not follow that he agrees with my view. All responsibility for subsequent use of the conception as an explanation of the facts, I alone assume.

to the discussion which has ensued consists in calling attention to the need of sharper distinction between the study of form discrimination and pattern discrimination. He argues that we should not expect the child to discriminate forms in the sense of my definition. He theorizes that infrahuman animals "have only a more or less crude pattern vision." As a means of testing the validity of his theory he proposes that the surroundings of the discriminable forms be changed, since the form, seen with its surroundings, must be considered as part of a pattern. Even if no other objects are in the visual field the stimulus "is seen surrounded by the more or less irregular outline of the field of vision, and so is again part of a pattern."

To demonstrate experimentally whether the animal is reacting to forms or patterns, Hunter proposes that the electric chambers of the experiment box be fitted, after a perfect habit has been established, with hollow cylinders or hollow triangular prisms through which the stimuli may be seen by the reacting subject. He presents diagrams which, he declares, represent the discrimination situation in my experiment and in Lashley's study (20) of form perception in the rat.

> Both series of experiments are concerned with *patterns* not forms. . . . . In problem boxes such as those described by Lashley and Bingham . . . . the animal tested is confronted *not* by two "*forms*" corresponding to the configurations of the opal glass, but by such designs as are suggested in figure 1. The squares drawn in the figure represent the rectangular tunnels down which the animal goes in making his responses. What the animal sees is a triangle or a circle each in more or less of a square setting.

Designs 4 and 5 represent Laskley's "forms."

Johnson (14) points out that Hunter's proposed method of control would introduce new olfactory stimuli and probably new tactile stimuli. Is there any means of deciding, he asks, whether failure to discriminate, after making such a change, resulted from the change of pattern or from the simultaneous introduction of other novelties? Furthermore, Johnson believes the change of a form stimulus from the right to the left compartment of the experiment box actually changes the background and foreground. This would therefore make the pattern a variable and the form a constant.

In addition to Johnson's reply to Hunter's contention, I have pointed out (3) the impossibility of pattern, in Hunter's sense,

serving as the discriminable factor. The conditions of control leave the rectangular tunnel constant but wholly change, if not destroy, the perceptibility of the environment.

That the animals could not see the environment is attested by the fact that they were frequently observed to walk blindly into the confining walls. Not all of the time was the environment "darkened," but the control tests were always made to determine whether, among other factors, setting was a factor in discrimination.

Figure 1, as presented by Hunter, does not accurately illustrate the condition of the stimulus areas. With the introduction of a screen as a means of control between the general illumination and the electric boxes and with the reduction of the intensity of the source lights, a similar condition to that illustrated in figure 2 appears. In the compartment where the triangle appears, the source light fails to illuminate the corners

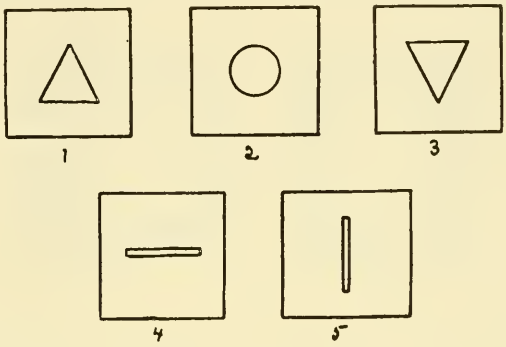

Fig. 1.
Reprinted from *Jour. Animal Behavior*, vol. 3, no. 5, p. 331.

of the tunnel, and so the perceptible portion of the setting changes to a sort of circular form as in diagram 1. About the circular stimulus, the visible setting is more nearly a perfect circle as is shown in diagram 2. Even if my apparatus offered a possibility of pattern discrimination, my plan of control (2: p. 98) would have made so variable the patterns confronting the animal that they never could have served as a basis of discrimination.

Hunter has apparently overlooked one of the essential features of the apparatus used in my study. The dark-room apparatus allows the experimenter to control the visibility of surroundings by means of artificial illumination. His criticism

would be valid for similar experiments conducted in natural and uncontrolled light. With the discrimination of stimuli continued under a varied visibility of surroundings the perception could not have been of patterns.

In a brief review, Washburn (32) dissents from my interpretation of form perception, declaring that she would conclude that the chick is not possessed of an abstract idea of triangularity. She says:

> A triangle with apex up is a different form from a triangle with apex down: the two have in common only the abstract quality of three-sideness. The perception of form, as distinct from an abstract idea of form, is based precisely on the unequal stimulation of different parts of the retina.

A portion of my later paper involves this lack of agreement in defining form (3). In that paper it is maintained that my

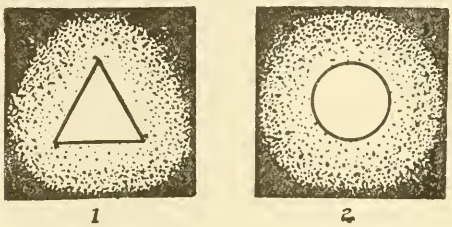

Fig. 2
Reprinted from *Journal Animal Behavior*, vol. 4, p. 137.

conception of form is in keeping with the ordinary usage of the term, and that we should not depart from the usual meaning in an effort to have it included in an animal's stock of perceptual experiences. If we find that our animals have a power of discrimination which approaches form perception, but which is not form perception in the strict sense of the term, we should adopt a terminology to fit the special case; we should not attempt to enlarge the scope of the old term to cover the special case.

Perhaps a more or less crude pattern vision is the nearest approach to form perception that animals possess. At any rate, Hunter has done well in calling attention to the distinction between patterns and forms. But our definition should not stop here. Two forms may be identical, but even in the ab-

sence of an orienting background or environment (pattern), as in the dark room studies, there may yet be a fundamental difference. This difference has been arbitrarily called "shape." An illustration of form similarities having shape differences is furnished in the experimental setting of Lashley's study. He used two identical forms in that both were rectangles 2 mm. by 60 mm. In his use, however, they differ in this respect: one is extended laterally thirty times as far as its vertical extension; the other is extended vertically thirty times longer than laterally. This has been defined as a difference in shape of two identical forms.

It is not to be denied that a triangle with vertex up differs from a triangle with vertex down, but one can scarcely say that they are different forms. They are both triangles, and more; they are equilateral triangles. Obviously it is desirable to adhere as far as possible to an explanation of the difference between these patternless stimuli in perceptual terms instead of resorting to ideational content. It seems useful to employ a term like "shape," therefore, which may differ in forms that are otherwise identical. When the extended base of the triangle is so placed as to stimulate the region of the retina which was formerly stimulated by the vertex of the triangle, a condition occurs similar to that pointed out regarding Lashley's forms: the forms remain identical, but the lines of maximum and minimum extension become interchanged. This fact led me to conclude in my paper (2: p. 110) that the apparent reactions to form are the result of keen perception of size differences. It seems probable that they are due to the perception of these so-called shape differences. The inversion of the triangle causes certain particular size changes—vertex or point interchanged with base or line—which introduces a change in shape, but no general change of size since the area remains constant. Similarly, the factor of triangularity remains constant and the form is unchanged. Not "the perception of form," therefore, but the perception of shape "is based precisely on the unequal stimulation of different parts of the retina."

Our definition, then, as separate from the distinction between forms and patterns, should distinguish between forms and shapes. Referring to the retinal area stimulated, there is form which is general, for example a triangle. But there is a partic-

ular feature about this general distribution of light—it is equilateral, or isosceles, or right angled—which is called shape. Forms are identical when their areas are equal and their general retinal distribution is similar. Shapes of forms are identical when all extension of the identical forms are equal and in corresponding directions. Thus, the area remaining constant, either or both form and shape may change. The form remaining constant, the shape may change. Change in form must always be accompanied by change in shape.

Unquestionably the test of form perception by inversion of the triangle is a severe one. But if this test of inversion is found to interrupt the discrimination, form perception in the strict sense of the term can scarcely be said to prevail. Moreover, there is evidence that form perception regarded not as an abstract idea but as perceptual phenomena does not exist.

More in line with Washburn's inclination to regard my interpretation of form as "an abstract idea of triangularity" (32) is my incidental observation (2) of reactions to relative stimulus difference. Because a few chicks showed ability to carry the correct large-small reactions from a 6–4 training to a 4–3 or 9–6 test situation, it would seem that the chick has some sort of ideational content. Watson, having been informed by Johnson that the latter failed to secure positive evidence in this relative stimulus problem with a single adult game bantam, hastily remarks (33): "From experiments now in progress at Nela Physical Laboratory (Johnson) it would seem that this observation cannot be confirmed." Johnson, however, is more conservative and disclaims Watson's unguarded remark by suggesting that the variation is due to individual differences particularly because it was found that not all of my subjects reacted positively to this problem. Moreover, I found only one chick that reacted positively and perfectly to *both* of the unfamiliar combinations. Doubtless, the amount of training has much to do with the nature of the reaction.

One of the best controlled studies employing the dark room-discrimination method is reported by Johnson (15–16). His report, appearing as two papers, is on the detail vision of the dog, the monkey, and the chick. The first paper deals with standardization of method in which he presents certain improvements upon the Yerkes-Watson apparatus. He commendably

points out that my discussion of controls (2) is ambiguous through my synonymous use of the words "intensity" and "brightness." The luminous intensity of a source, he declares, involves the total number of candles presented, but the brightness is the luminous intensity divided by the area of the source. The brightness, then, is measured in terms of candles per unit of area. In the light of this definition, Breed's use of the term "brightness" (5) is also open to criticism.

Regarding Johnson's assertion (15) that I reported "no control tests to show that discrimination was on the basis of size, rather than of luminous intensity of the stimuli," it is sufficient to note that variation of source distances would vary both brightness and luminosity. Independent variation of these two factors would be unnecessary so long as neither was allowed to remain constant. This control is adequately described in my report (2) on page 98.

Johnson's method consists in presenting striate fields for discrimination, adopting the visual angle subtended by one of the striae as a convenient measure of the animal's visual acuity. In terms of the visual angle subtended by individual striae, the stimulus threshold for the chick was found to be slightly above 4′. The standard individual striae were about 0.11 mm. in width, the assumption being that, at the given distance of 60 cm., "they were too small to be resolved by the eye." The minimum size of the variable individual striae discriminated from the standard striae was accepted for chick 1 as 0.710 mm. and for chick 2 as 0.743 mm. (16).

The refined dark room-color apparatus is used by Lashley (21) in studying the spectrum of the chick. Preliminary to his study of wave length and without using punishment as a motive, he finds that the brightness threshold is approximately three to one. In contrast with earlier work, this difference limen is unusually large. Aside from certain trivial errors in computations, Lashley's work seems to have been carefully done. He thinks that field experimenters may feel confident that differential reactions of birds to colored objects are made on the basis of wave length if the objects do not differ enormously in brightness for the experimenter. He concludes that "the chick can distinguish between monochromatic lights of any intensity between threshold and the Pfund standard, irrespective of the brightness or saturation. The effective stimulus is the wave length."

Finally, the latest paper dealing with chick reactions is by Fletcher, Cowan, and Arlitt (8a).[4] They have made comparative observations of chicks hatched from normal eggs, from alcholized eggs, from eggs with distilled water inserted, and from eggs merely pierced and sealed. Inherited and acquired reactions of these four groups were observed after the manner of Breed (4–5). They have contributed nothing to the topic of visual acuity.

In addition to this chick literature, studies in bird vision have been made by Porter (24a–24b) on the sparrow, cowbird, and pigeon; by Tugman (31) on the sparrow; and by Coburn (6) on the crow. In technique, the work of Porter is similar to that of Katz and Révész (17–18) but it reflects less ingenuity than the German papers. However, Porter's work was done a little earlier than that of Katz and Révész and he seems to have been better acquainted with the historical setting of his task. Coburn's and Tugman's studies have made use of recent available developments in the field of infra-human vision. These papers will receive further consideration in subsequent chapters where the results will be compared with my own results from the chick.

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PART II. EXPERIMENTAL

CHAPTER III

Apparatus

The work on visual acuity, as reviewed in the preceding chapter, has been criticised primarily on the basis of method. One general fact stands out when these experiments on visual perception in the chick are viewed in their historical setting: the methodological aspect has rapidly come to be the central feature of the work. Beginning with loose observations in which accurate description of method was either impossible or ignored, the method has developed into a thoroughgoing scientific procedure. The early naturalistic observers raised questions for the later scientific school to solve. The naturalists have contributed a general orientation; the experimentalists are solving, one by one, the specific tasks involved. The apparatus used in the present experimental study represents an important stage in the development of technique for studying detail vision. Controllability was the primary aim in its construction. It represents a definite standardization which has been previously described in detail, hence my description will be a rapid summary. Supplementary to apparatus, but no less important, is experimental method and technique to which a special chapter will be devoted.

The dark room-discrimination apparatus has been carefully described in the report by Yerkes and Watson. In Chapter II, the origin and development of the method has been set forth. In figure 3 is presented an isometric view of the apparatus showing the skeleton of the various parts when assembled for work. That part of the mechanism labelled I is the *experiment box*. The opposite end, III, is the light or *source box*. Between the experiment box and the source box is the *stimulus shifter*, II.

1. Experiment box

An illustration of the experiment box appears as figure 4. This section of the apparatus is made of one-half inch lumber,

except where stated otherwise, and is painted within and without a dead black. It consists of four main parts: (1) A is an entrance chamber,[1] 20 by 15½ by 22. The floor of *A* is provided with a metal tray containing a layer of wet felt. The entrance

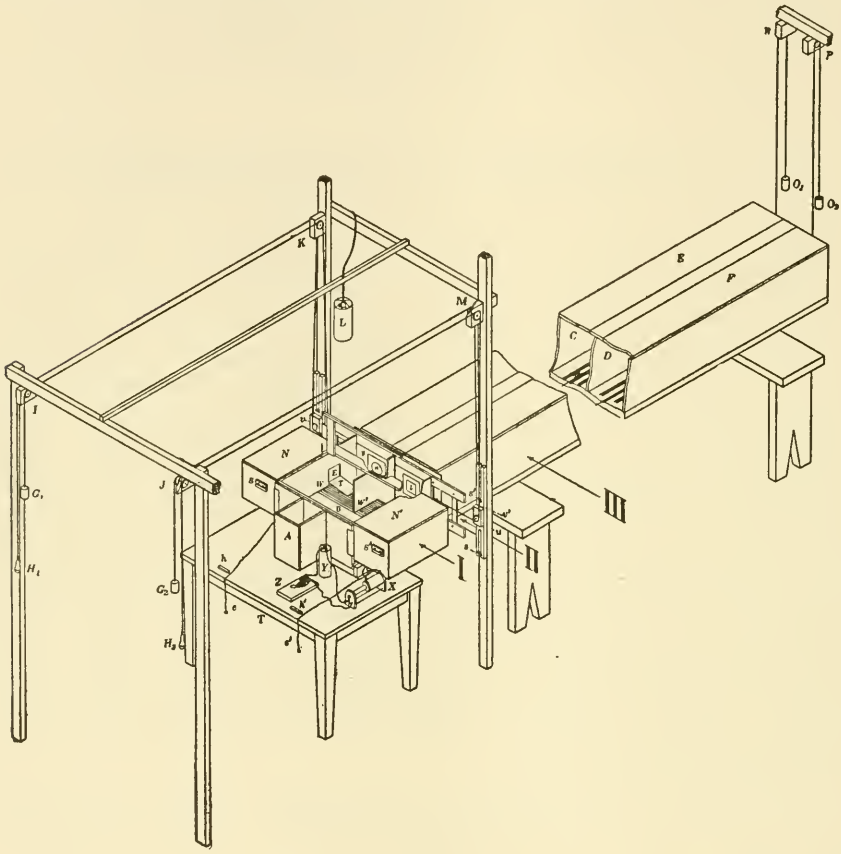

FIG. 3

Isometric view of *light* vision apparatus. Reprinted from *Journal Animal Behavior*, vol. 3, p. 67.

box may be removed by raising out of the iron straps, *C* and *C'*, the board to which it is attached. (2) *B* is a discrimination

[1] Unless otherwise stated, dimensions are given in centimeters and the order of presentation is length, width, and depth—inside measurements.

chamber, 26 by 51 by 22. Leading from *A* to *B* is an entrance, *I*, 8 by 10. The floor of *B*, like that of *A*, is carpeted with wet felt. The tray of either compartment can be easily removed and cleaned. (3) *W* and *W′* are electric boxes separated from each other by the partition *D*. On the floors of *W* and *W′* is a slab of slate carrying electric wires for punishment. By means of the interposed sides, *O O O*, the electric compartments are

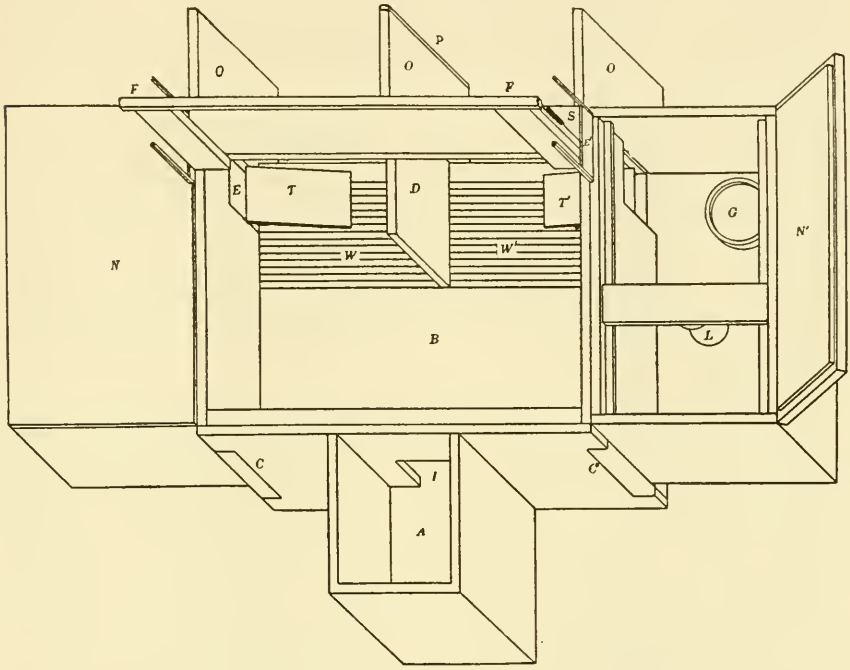

FIG. 4

Experiment box as seen from above. Reprinted from *Journal Animal Behavior*, vol. 3, p. 69.

set back 14 cm. from the stimulus shifter. The floor of this extended portion drops down about 10 cm. below that of *W*-*W′*. The middle *O* presses closely against the shifter so that the exposed stimuli are sharply separated from each other. On the end of *D*-*O* is glued a piece of piano felt, *P*, which rubs snugly against the shifter. (4) *N* and *N′* are nest boxes, 40½ by 22 by 22. Each nest box is covered by a tightly fitting lid, which is

hinged at the outside, and is equipped with a 2 c.p. frosted electric lamp, a watch glass for water, and sand or litter in which food may be scattered. It is also provided on the outer side with hidden holes for ventilation.

Between *W* and *N* is a vertically sliding door, *E* closed and *E′* open, 3 mm. thick which fills an opening 8 by 10. Suspended from an upright frame, *F*, is a coiled spring, *S*, which passes through the walls of the experiment box to the top of E. When *E* is closed, *S* is extended and in a state of torsion, hence when *E* is released *S* tends to return to a state of rest and the doorway is opened.

The method of closing the exits is best illustrated in figure 3. A silk line, *e*, passing up through a wire loop directly under *E*, is attached to the lower part of the door. By pulling on *e*, the experimenter can close *E* which automatically locks when it is closed. By stepping on or striking *T*, the chick can release the lock. The experimenter, however, by catching *e* on the hook, *h*, can prevent the exit from opening when the lock has been released. This automatic release was devised by Professor F. S. Breed.

The construction of this mechanical device for locking and opening *E* appears in figure 5 where *T* is the trip that was seen in the other figures and *t* is a short piece of No. 30 black thread attached to *T* at *a*. Passing down through the floor, *F*, of the electric box, *t* runs over a pulley, *P*, and is fastened to the spring lock, *L*, at *b*. *B* is a block through which *L* passes and against which one end of the spring, *C*, presses. *D* is a stop attached to *L* supporting the opposite end of *C*. This spring tends to force *L* in the direction of *X* and to keep *T* in the position as illustrated. But when sufficient pressure is applied to *T* at any point above *R*, *L* is forced back in spite of the pressure of *C*, *E* is released at *X*, and the recoil of *S* raises *E*. When *E* is drawn down, *L*, by reason of the slanting end surface at *X*, is forced toward *P* until the notch of *E* has passed below the lower side of *L* when the constant pressure of *C* toward *X* forces *L* into the notch of *E* and the door is again locked.

In several respects, figure 5 is a poor representation of this tripping device. *L* is shown as constructed solidly in *B*, when, in reality, it slides freely through *B*. Moreover, *L* is shown in the figure as wide as the floor of the experiment box, but it is

really a delicate latch narrower than the width of *T* or *E* and is released by a slight touch upon *T*.

2. *Source box*

To provide illumination for the two stimuli simultaneously presented to the chick, the source box represented in figure 6,

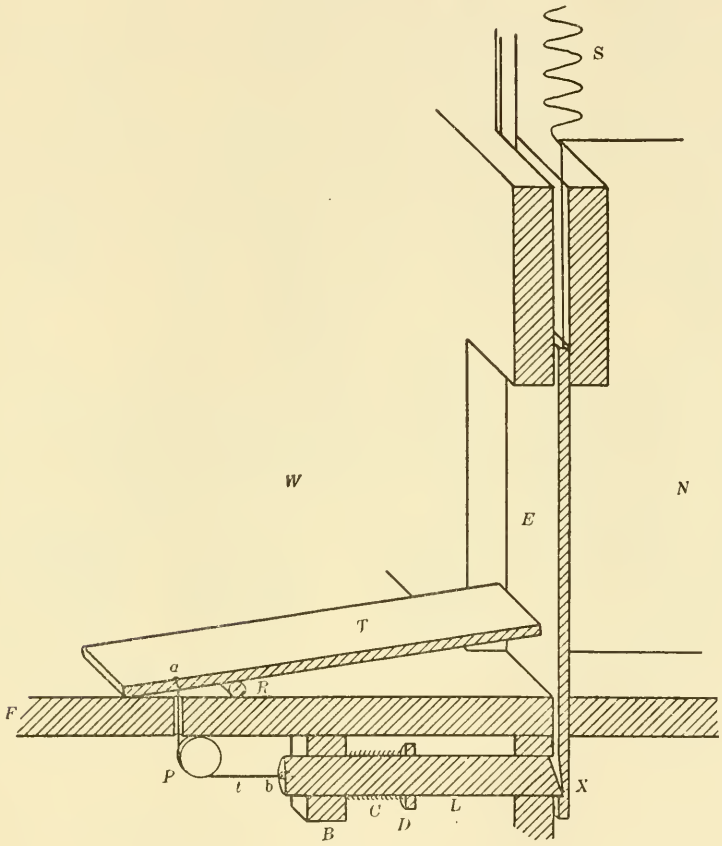

FIG. 5

Automatic tripping device of the experiment box. Reprinted from *Journal Animal Behavior*, vol. 3, p. 70.

—III of figure 3,—was used. A complete description of this part of the mechanism appears in *Behavior Monographs* from which figure 6 is reprinted.

3. Stimulus shifter

Figure 6 also presents a general view of the stimulus shifter, the primary function of which is control of the various visual details. The stimulus shifter or adapter is also described in *Behavior Monographs* along with the description of the source box.

A considerable number of stimulus plates, used for varying the size and form of the stimuli, is required for determining the chick's threshold for these spatial details. The majority of the plates used in this study is included in table 1. Owing to variations in sensitiveness among different subjects, a set which meets the requirements for one animal does not suffice for another, hence, in those cases where the size difference among the plates varies by one millimeter, a safe margin has been allowed by enumerating a few more plates than would ordinarily be required.

4. Accessories

In my report from which figures 3–5 are reprinted, there appears, on page 73 and following, a description of the details designed to aid in the control and manipulation of the mechanism just described. The punishing device and the upper illumination are also described. It is there shown how the experimenter from his position for observation, can control by means of ropes, pulleys, and weights the entire apparatus.

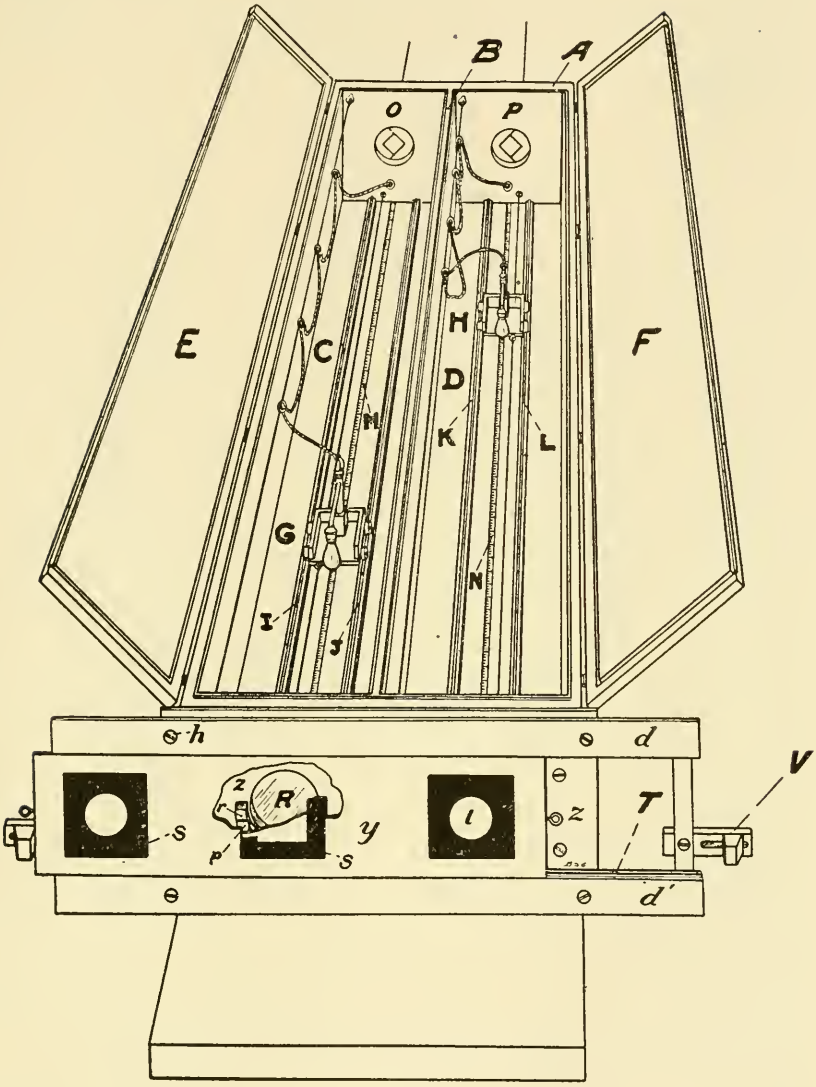

FIG. 6

Reprinted from *Behavior Monographs*, 1911, vol. 1, no. 2, p. 18. "Perspective of *light* or 'brightness' apparatus. *A*, light box; *C*, *D*, compartments of *A*; *B*, partition between *C* and *D*; *E*, *F*, lids of *A*; *G*, *H*, metal carriages carrying tungsten lamps; *IJ* and *KL*, tracks for *G* and *H*; *M*, *N*, Starrett steel millimeter tapes; *O*, *P*, apertures covered by Aubert diaphragms; *R*, Bausch and Lomb cooling cell in light box; *d*, *d'*, metal straps; *y*, aluminum plate sliding between *d* and *d'*; *T*, tracks for *y*; *V*, stop for *y*; *z*, steel plate bolted to wooden end of light box; *h*, screws attaching *d* to *z*; *s*, *s*, standard brass stimulus plates; *p*, brass frame about aperture in *y*; *r*, hard rubber ring screwed to *p*."

TABLE 1

Stimulus Plates

USE	FORM	DIAMETER OR SIDE	AREA	NUMBER PLATES NEEDED
		cm.	*sq. cm.*	
To test Size Perception	Circle	1.8	2.5447	1
"	"	1.9	2.8353	1
"	"	2.0	3.1416	1
"	"	2.1	3.4636	1
"	"	2.2	3.8013	1
"	"	2.3	4.1548	1
"	"	2.4	4.5239	1
"	"	2.5	4.9088	1
"	"	3.0 (standard)	7.0686	2
"	"	3.5	9.6211	1
"	"	4.0	12.5664	1
"	"	4.1	13.2026	1
"	"	4.2	13.8545	1
"	"	4.3	14.5220	1
"	"	4.4	15.2053	1
"	"	4.5	15.9043	1
"	"	4.6	16.6191	1
"	"	4.7	17.3495	1
"	"	4.8	18.0956	1
"	"	4.9	18.8575	1
"	"	5.0	19.6350	1
"	"	5.5	23.7583	1
"	"	6.0 (standard)	28.2744	2
"	"	6.1	29.2247	1
"	"	6.2	30.1908	1
"	"	6.3	31.1725	1
"	"	6.4	32.1700	1
"	"	6.5	33.1832	1
"	"	6.6	34.2120	1
"	"	6.7	35.2566	1
"	"	6.8	36.3169	1
"	"	6.9	37.3929	1
"	"	7.0	38.4846	1
"	"	7.1	39.5920	1
"	"	7.2	40.7151	1
"	"	7.3	41.8540	1
"	"	7.4	43.0085	1
"	"	7.5	44 1787	1
"	"	8.0	50.2656	1
"	"	8.5	56.7455	1
"	"	9.0 (standard)	63.6174	2
				44
		cm.	*sq. cm.*	
To test Form Perception	Circle	6.0 (as above)	28.2744	—
"	"	5.9	27.3397	1
"	"	5.8	26.4208	1
"	"	5.7	25.5176	1
"	"	5.6 and smaller circles used in size perception	24.6301	1
"	Square	5.317 (side)	28.2743	2
"	Equilateral △	8.081 (side)	28.2743	2
		Openings inscribed in circle—28.2744		
"	Square	4.243 (side)	18.003	2
"	Equilateral △	5.196 (side)	11.691	2
				12
Total				56

CHAPTER IV

Problem, Method, and Technique

The experiments reported in the following pages were made with about thirty chicks belonging to four different groups. The first and fourth groups, each consisting of ten chicks, were secured from poultry breeders when the chicks were about two days old. The second and third groups were artificially incubated in the laboratory. The chicks used were Plymouth Rocks and all except two were of the Barred variety. The two exceptions were White Plymouth Rocks but neither contributes importantly to the final results. Properly caring for the chicks and keeping them healthy was one of the most serious difficulties which had to be overcome. On the whole, the laboratory hatched chicks proved more satisfactory.

The most common ills seemed to be due chiefly to improper feeding, irregular temperature, and inadequate ventilation. A few individuals of group 3 survived until the weather became warm enough for them to be out of doors during a few hours on favorable days. When this plan was first tried the birds were in poor condition. Two-thirds of the group had died. But as soon as the survivors were placed out of doors their physical condition began to improve, and it was possible to do nearly three times the amount of experimental work that could be formerly done. Evidently, the requirements for healthy laboratory chicks include an abundance of sunlight and fresh air with the necessity of working for a living.

The disease giving trouble with the first two groups was a type of "leg weakness," so called because the leg joints become enlarged, the toes curl out of shape, the chicks cannot stand, and they move about only with great difficulty. This trouble ultimately carried off nearly all of the birds which did not succumb to bowel disturbances. With one brood it was probably the result of excessive heat in the hover. In other cases it was probably due to overfeeding. More often, perhaps, it was due to a combination of both conditions. The birds which first

showed signs of this weakness were the largest and apparently the strongest of the flock. There was no evidence of it among the chicks of the third and fourth groups, which were fed sparingly and for which the temperature of the brooder was carefully regulated.

The matter of health among the chicks turned out to be a problem which had not been anticipated. However, it did not prevent work toward the solution of the primary problem. The task originally planned was a study of the chick's discriminative ability between sizes, forms, and brightnesses, but, owing chiefly to these unfavorable conditions, little consideration has been given to the third factor. Later tasks added to the original plan involve the perception of flicker and a study of the learning process and ideational content.

The aim has been to make the study intensive and quantitative. The question whether the chick can discriminate between stimuli differing with respect to a single visual detail is only a preliminary aspect of the problem. The primary task has been that of determining the least perceivable difference in detail vision. Breed's work indicates that chicks can discriminate on the bases of size and form. The work of Katz and Révész suggests the same possibility. My original plan, then, was to determine the threshold of difference for each of these factors.

With respect to size, my original plan was carried out with no essential changes, but with form, it was found necessary to abandon the original plan. In a short time it appeared that proper responses to stimuli differing only in form were not so readily acquired as reactions to size differences. After trying in vain for several weeks to train different subjects to discriminate between a circle and a triangle equal in area, the nature of the problem was considerably modified. It was clearly necessary to determine whether the chick, under the conditions of this experiment, could perceive form differences.

The task involving flicker perception, like that with forms, demanded first a preliminary answer. Other than the generally observed fact that birds are highly sensitive to moving stimuli, there were no experimental data at hand to indicate that a three or two to one flicker difference could be perceived. Beyond the study of a two to one discrimination, time and conditions have not permitted me to go.

The studies involving problem learning and ideation arose merely as incidents in connection with the more fundamental tasks. As the time of observing the chick's behavior in the various problems lengthened, there was a proportional increase of interest in the behavior itself. At last I gave in to a persistent desire to record quantitatively the chick's characteristic behavior in learning a particular task. From such an interest it is a natural step to questions pertaining to evidences of ideation in this learning. The problem of relative stimulus difference, incidentally discussed in Chapter IX, represents an initial approach to the study of the imaginal problem.

Finally, another aspect of the problem, also arising quite incidentally, was that of the relative value of the different visual details. My earlier results with forms, largely negative, emphasized the desirability of considering the factors in combination as well as in isolation. In its normal life the chick is not compelled to rely upon a single visual factor, but, on the contrary, it relies upon a natural combination of the visual details, It thus seemed desirable to start with complex stimuli and from this complex gradually to eliminate inequalities until a single visual factor remained. This method might furnish data on the relative value for the chick of the various visual factors.

The plan adopted for solving these various problems was the familiar Yerkes discrimination method. The description of the apparatus sets forth the general features of the method. Conditions both desirable and undesirable are presented to the chick. Either nest box contains those things which the chick wants. It provides food, light, warmth, and companionship. The experiment box is arranged to make the chick seek escape. In the entrance box the chick is closely confined; in both the entrance and discrimination chambers the floors are wet; the entire reaction box provides faint illumination, little warmth, no food, and no companionship. The chick's problem is to learn how to get from the undesirable to the desirable part of the apparatus. The two different stimuli are the signs by means of which the chick may learn which way to escape.

Each chick was taught the way of escape to the nest box by means of 20 preliminary trials. The entrance to the nest box at the side where the *right* stimulus appeared was open; the sliding door closed the entrance from the electric box where the

wrong stimulus was presented. The chick was allowed to go alternately to each nest box 10 times. It was thus made familiar with the nest boxes and the reaction box.

By displaying, always on the side of escape, the stimulus which the chick was later to be trained to choose, the subject was occasionally aided, prior to training, in acquiring a perfect habit.[1] This fact was especially noticeable in the experiments on size discrimination in which a circle 6 cm. in diameter always appeared in that electric compartment by way of which the subject escaped. At the end of the preliminary series a few chicks were responding perfectly to this condition of ⊙ 28 + — ⊙ 7 + discrimination.[2] This perfect ⊙ 28 + — ⊙ 7 + habit, however, may not mean that size was the basis of choice. It is quite probable that the chicks chose the lighter compartment. Precaution was taken to eliminate this possibility before size tests were completed, and control tests were introduced to make certain that it had been eliminated.

This preliminary work was followed by the training series. Both entrances to the nest boxes were now closed, and the only cues that remained to aid the chick in reaching the nest box were the two visual stimuli. Continuing with the example of size discrimination, ⊙ 28 + was the positive sign, ⊙ 7 + was the negative sign of escape from the experiment box. If a chick chose ⊙ 7 + by stepping into that compartment, it was shocked by momentarily closing the key, *Z* of figure 3. A single shock was usually administered but if it were not effective it was repeated. The wet floors of A and B regulated the intensity of the shock. Care in the manipulation of the shock was important for it was essential that it be an effective punishment yet mild enough to avoid frightening the animal. The results of weeks of work could be destroyed in a moment through a blunder in the method of punishment.

In the early stages of training the chicks often went beyond the exit towards the stimulus at the end of the compartment. If the animal were allowed to do this it spent considerable time and energy around this illuminated stimulus. By placing a

[1] A habit is termed perfect when a chick successively makes 20 correct choices.

[2] The stimulus demanding a positive response is named first followed by the stimulus demanding a negative reaction. The dimensions represent the number of square centimeters in the area.

RECORD SHEET

Subject 9 **Date** 12/7/11 – 1/2/12 **Experiment** Form Perception

Tests → / Series ↓	1	2	3	4	5	6	7	8	9	10	R	W	REMARKS Average Time
A	l	r	l	r	l	r	l	r	l	r			
B	r	l	r	l	r	l	r	l	r	l			
1	r E-29	l O-6	r E-59	l O-19	r E-125	l O-120	r E-56	l E-95	r E-65	l O-44	4	6	61.8
2	l O-4	l O-24	r O-36	r O-30	l E-1-62	r O-39	l O-19	l E-2-180	r O-15	r O-33	8	2	44.2
3	r O-67	r O-8	l E-135	r O-28	l O-25	l E-2-141	r E-1-180	l E-1-21	r O-5	l E-1-61	5	5	67.1
4	l O-29	l E-1-42	l E-1-35	r O-55	r O-40	r O-64	l E-2-100	r O-30	r O-32	l E-1-65	6	4	49.2
5	r E-2-84	l O-8	r O-9	l O-12	r O-10	l O 6	r O-18	l O-26	r E-1-43	l E-2-38	7	3	25.4
6	l O-11	l O-14	r E-2-71	l O-21	r O-83	r E-2-41	l O-28	r E-2-110	l O-49	r E-2-118	6	4	54.6
7	r O-45	l O-31	l E-2-70	l O-7	r E-1-8	r E-1-23	r O-25	l O-6	r O-9	l E-1-54	6	4	28.3
8	r E-2-46	r O-62	l O-89	l O-67	r E-2-71	l O-58	r E-1-65	l E-1-56	r O-24	l E-1-29	4	6	56.0
9	r O-4	r O-5	r O-6	l E-1-20	l E-1-7	l O-21	r E-2-42	l E-1-23	r O-15	l E-1-16	5	5	15.9
10	l O-4	l O-9	l O-5	l O-31	r O-106	r O-19	r O-61	r O-5	l O-10	r O-45	0	0	29.5
11	r O-10	l E-2-124	r E-2-125	r O-35	r E-2-75	l O-67	l O-34	l O-26	r O-38	l E-1-88	6	4	60.2
12	r O-6	l O-37	r O-22	l O-10	r O-14	r O-12	l O-8	l O-8	r E-1-36	l E-1-14	8	2	16.7
13	r O-8	l O-7	r O-40	l O-45	l E-1-110	l O-3	r O-1-29	r E-1-20	r O-21	l E-2-44	7	3	32.7
14	l O-12	l E 1-123	l E-1-31	l O-10	r E-1-10	r O-74	r O-12	r E-1-27	l O-8	r E-1-31	5	5	33.8
15	r O-38	l O-11	r O-22	r O-8	r E-1-38	l E-2-54	l E-2-64	l O-16	r E 1-39	l O-5	6	4	29.5
16	l O-18	r O-8	l O-21	l O-30	l O-5	r E-1-46	r E-1-42	r O-33	l O-11	r O-28	8	2	24.2
17	r O-42	r O-37	r O-40	r O-11	l E-1-19	l E-1-50	l O-62	l O-30	r O-28	l E-1-19	7	3	42.8
18	l E-1-60	r E-1-94	l O-25	r E-1 35	r O-20	l E-1-24	l E-1-25	r O-15	l E-1-18	r O-12	4	6	32.8
19	r O-92	l O-40	r E-1-46	l E-1-76	r O-26	l E-1-58	r E 2-43	l O-10	r E-2-27	l E-1-33	4	6	44.7
20	l E-1-12	l O-39	l O-8	r E-2-17	l O-18	r O-25	l O-9	r E-1-60	r O-42	r E-1-103	6	4	33.3
21	r E-1-22	l O-12	l O-13	r E-1-15	r O-17	l E-1-26	l O-11	r E-2-10	r O-19	l E-1-40	5	5	18.5
22	l E-1-65	l O-19	r E-1-40	r E-1-20	l O 7	l O-21	r E-1-22	r E-2-30	l E-1-46	r E-1-25	3	7	29.8
23	r O-12	l O-25	l O-10	l O-8	l O-4	r E-2-41	r E-1-9	r O-2	r E-1-10	l E-1-12	6	4	13.3
24	l O-5	r E-1-49	l E-1-6	l O-3	l O-5	r O-4	r O-4	r O-4	l O-2	r E-1-45	7	3	12.7
25	r O-14	r O-12	r E-1-6	r O-26	l O-25	l O-23	l O-18	l O-15	r O-55	l O-25	9	1	27.8

thin plate of glass across each compartment at a point just beyond the exit, the chicks were stopped near the exit and yet were not prevented from seeing the regular stimulus. As soon as they had learned the way of escape and had ceased trying to reach the stimulus, the glass plates were removed.

After a perfect habit had been acquired, the amount of difference between the two stimuli was decreased. When the ⊙ 28 + — ⊙ 7 + discrimination became perfect, the situation was changed to ⊙ 28 + — ⊙ 9 +. The large circle was thus the standard which remained constant. The smaller circle was the variable which was successively increased in size until the animal could no longer choose correctly. This limit of correct choices was accepted as the chick's threshold of difference. The changes in diameter of the variable, it was found, could be

TEST SHEET

Title of investigation, Form: ⊙28+ — △ 28+
Experimented on, 9
Harvard Psychological Laboratory, December 25, 1912
Record Sheet, 1; Series, 15

TEST	BEHAVIOR	RECORD
1 r	$\overline{//}$ − /// + /// 〃	0–38
2 l	/// + /// 〃	0–11
3 r	$\overline{//}$ + /// 〃	0–22
4 r	// + // 〃	0–8
5 r	/// − // $\triangle^1$ + /// 〃	E–1–38
6 l	/// − /// $\triangle^2$ + // 〃	E–2–54
7 l	// − /// $\triangle^2$ + /// 〃	E–2–64
8 l	// + // 〃	0–16
9 r	// + / $\triangle^1$ + // 〃	E–1–39
10 l	/ + // 〃	0–5

6–4–29.5

REMARKS: Tendency to choose by position, *i.e.*, to go where it last escaped. Usually goes immediately to other compartment when it has been shocked for wrong choice.

as great as 5 mm. between ⊙ 7 + and ⊙ 12 + when presented with a standard ⊙ 28 +. Above ⊙ 12 + the diameter of the variable was successively increased only by 1 mm.

For tabulating results, a *record sheet* which had formerly been used in the laboratory was well suited to my needs. It

provides for a concise summary of results. For the details of behavior, a *test sheet* was adopted. The 10 tests, horizontally arranged on the record page, appear vertically on the test page. After each one is a space for recording the details of the animal's behavior. At the right of the page is a narrow column for recording the results of the test—whether an error was made and the time for choosing. At the bottom is a space for further notes.

The manner of recording the details of the chick's behavior is illustrated in the accompanying *test sheet* which is a record of an actual series of tests. A set of symbols was used in order to follow fairly accurately the movements of an animal while in the discrimination chamber. Herewith is presented the key to the symbols used in these experiments:[3]

1. + = Approach to *right* compartment.
2. – = Approach to *wrong* compartment.
3. /, //, /// = Degree of attention based on behavior and time. A horizontal bar above any one of these symbols indicates unusually long time in this locality. For example,

   a. { + / = Brief consideration of *right* stimulus area.
      – / = Brief consideration of *wrong* stimulus area.

   b. { + // = Longer consideration of *right* stimulus area.
      – // = Longer consideration of *wrong* stimulus area.

   c. { + /// = Close consideration of *right* stimulus area.
      – /// = Close consideration of *wrong* stimulus area.

   d. { + $\overline{///}$ = Long time before and close consideration of *right* stimulus area.
      – $\overline{///}$ = Long time before and close consideration of *wrong* stimulus area.

   e. { + $\overline{/}$ = Long time before but slight consideration of *right* stimulus area.
      – $\overline{/}$ = Long time before but slight consideration of *wrong* stimulus area.
4. $\overline{''''''''''''''}$ = Attention at entrance end; indifference to stimulus areas.
5. ∧ = Approach on wires before *right* stimulus followed by retreat.

[3] The symbols presented in print only approximate, as closely as is convenient, the written symbols actually employed during experimental observations. Printed substitutes, of course, are consistently presented throughout the text. The written symbols used for recording observations were selected as far as possible to represent concisely and accurately the behavior recorded.

6. V = Approach on wires before *right* stimulus followed by wrong turn.
7. △ = Approach on wires before *wrong* stimulus followed by retreat.
   a. $\triangle^1$ = One shock
   b. $\triangle^2$ = Multiple shock.
   c. $\triangle^0$ = No shock.
8. ♀ = Turn around, clockwise; ♂, counter-clockwise.
9. ∾ = Partial turn around, right to left; ∽, left to right.
10. ⌇⌇ = Position directly before division between each compartment; by turning head either stimulus area is visible.
11. ,, = Escape to nest box.
12. E = Error in choosing; this is followed by time in seconds.
13. 0 = Correct choice; this is followed by time in seconds.

For specific behavior in the electric compartments and remote corners of the experiment box, which it was desirable to record in gathering the data presented in Chapter VIII, the following additional symbols were used:

¬, ⌐, ⊔ = Right corner, left corner, or stimulus faced and apparently inspected.
¬̄, ⌐̄, ⊔̄ = Right corner, left corner, or stimulus approached and inspected.
¬̿, ⌐̿, ⊔̿ = Right corner, left corner, or stimulus more closely approached and inspected.
¬̿̇, ⌐̿̇, ⊔̿̇ = Right corner, left corner, or stimulus appropriately approached and inspected.

The preliminary series were begun during the second week, usually when the chicks were 10 days old. The experiments on space perception were conducted during the morning between the hours of eight and twelve. The experiment on flicker perception was conducted with less regularity during the morning and afternoon. On the whole, the early morning is the best time for experimental work with chicks. They are then most active for that is the time they naturally start out for food.

In the matter of rewarding with food, however, caution is necessary. A three-weeks-old chick will "fill up" in a short time if food is abundant. It then becomes sluggish. The plan was adopted of scattering only a few grains in the litter of the nest boxes so that the chick was kept active in working for its meal. This plan, when perfected, made it possible to increase the number of tests considerably above the maximum when the food was scattered less sparingly.

Up to this point considerable emphasis has been laid upon method and technique. Certainly an accurate solution of an

animal problem depends upon the adoption of a favorable method. The experimenter must use an apparatus by means of which he can accurately control the conditions of his study. He must also show alertness by controlling these conditions in such a way that his animals behave normally. Much animal stupidity, so-called, is really a reflection of human ignorance. The experimenter may lack animal intelligence by setting human problems for a lower animal to solve.

An animal frequently shows ingenuity in an unexpected direction, and if the experimenter be not alert he misses the most important part of the behavior. How many times this is the case, we cannot tell, for we only know of the cases where we did not miss the significant fact. A perfect method would make it impossible for the animal to pick up cues that were not intentionally offered by the experimenter. But it is through experience that we approach a perfect method, because there is always the possibility of improvement even in the best standardized methods.

The importance of method was impressed upon me through an incident in my experiments with the first group of chicks. I had inexcusably blundered by making the original conditions of discrimination too difficult for the chicks. They were being tested on ⊙ 28 + — ⊙ 7 + discrimination. The subjects were allowed to go through the discrimination chamber and experiment box during the preliminary tests without regard to the position of the right or wrong stimulus; that is, both exits were open. When the training series were begun the brightnesses of the two stimuli were made markedly unequal and were irregularly varied from the first.

The experiment was begun with six subjects. As a partial result of my initial bungling, I had at the end of a few days only subjects 2 and 3 in suitable condition for further work. At the end of two and one-half weeks No. 2 gave up, but No. 3 persisted. At the end of the 24th series it had successively made three perfect series (see table 2). At the end of four more series it had reacted perfectly to the ⊙ 28 + — ⊙ 9 + discrimination. The diameter of the variable was successively increased by 5 mm. until the variable ⊙ 19 + was reached after which the diameter of the variable was changed by increments of 1 mm. The perfect responses continued with very few exceptions.

TABLE 2

Subject: 3. Hatched: 10/3?/'11. Sex: Undetermined

SERIES*		DATE	RIGHT	WRONG	TIME†
		⊙ 28+ — ⊙ 7+ *Discrimination*			
1–21	(1–21)	Oct. 12–27	..	..	..
22	(22)	" 28	10	0	55
23	(23)	" 30	10	0	41
24	(24)	" 30	10	0	29
		⊙ 28+ — ⊙ 9+ *Discrimination*			
1	(1)	Oct. 30	10	0	62
2	(2)	" 31	9	1	79
3	(3)	" 31	10	0	103
4	(4)	Nov. 1	10	0	55
		⊙ 28+ — ⊙ 12+ *Discrimination*			
1	(6)	Nov. 2	7	3	71
2	(7)	" 3	9	1	93
3	(8)	" 3	10	0	50
4	(9)	" 4	10	0	52
		⊙ 28+ — ⊙ 15+ *Discrimination*			
1	(11)	Nov. 4	6	4	112
2	(12)	" 6	9	1	68
3	(13)	" 6	8	2	44
4	(14)	" 6	8	2	51
5	(15)	" 7	9	1	52
6	(16)	" 7	9	1	40
7	(17)	" 7	8	2	41
8	(18)	" 8	10	0	52
9	(19)	" 8	10	0	62
		⊙ 28+ — ⊙ 19+ *Discrimination*			
1	(21)	Nov. 8	8	2	49
2	(22)	" 9	8	2	49
3	(23)	" 9	8	2	90
4	(24)	" 9	10	0	50
5	(25)	" 10	8	2	78
6	(26)	" 10	10	0	53
7	(27)	" 11	10	0	47
		⊙ 28+ — ⊙ 23+ *Discrimination*			
1	(6)	Nov. 11	8	2	58
2	(7)	" 13	8	2	116
3	(8)	" 14	10	0	41
4	(9)	" 15	8	2	45
5	(10)	" 15	10	0	16
		⊙ 28+ — ⊙ 24+ *Discrimination*			
1	(21)	Nov. 17	10	0	22
2	(22)	" 17	9	1	30
3	(23)	" 18	10	0	16
4	(24)	" 18	10	0	11

* Numbers in parentheses refer to series on record sheet.
† Average time for series given in seconds.

TABLE 2—*Continued*

SERIES*		DATE	RIGHT	WRONG	TIME†
		⊙ 28+ — ⊙ 25+ *Discrimination*			
1	(11)	Nov. 21	9	1	22
2	(12)	" 21	10	0	16
3	(13)	" 21	9	1	17
		⊙ 28+ — ⊙ 26+ *Discrimination*			
1	(16)	Nov. 22	10	0	15
2	(17)	" 22	9	1	24
3	(18)	" 23	7	3	45
4	(19)	" 23	10	0	23
		⊙ 28+ — ⊙ 27+ *Discrimination*			
1	(21)	Nov. 23	8	2	20
2	(22)	" 23	8	2	25
3	(23)	" 24	6	4	33
4	(24)	" 24	10	0	11
5	(25)	" 24	9	1	30
		⊙ 28+ — ⊙ 28+ *Discrimination*			
1	(1)	Nov. 25	10	0	?
2	(2)	" 25	6 (crack closed)	4	?
3	(3)	" 25	0	5	?
		⊙ 28+ — ⊙ 23+ *Discrimination*			
1	(16)	Nov. 27	5	5	62
2	(17)	" 27	5	5	59
		⊙ 28+ — ⊙ 19+ *Discrimination*			
1	(18)	Nov. 28	3	7	71
		⊙ 28+ — ⊙ 15+ *Discrimination*			
1	(19)	Nov. 28	9	1	60
		⊙ 28+ — ⊙ 19+ *Discrimination*			
1	(20)	Nov. 29	6	4	73
2	(21)	" 29	5	5	83
3	(22)	" 30	7	3	31
4	(23)	" 30	7	3	22
5	(24)	" 30	5	5	23
6	(25)	Dec. 1	5	5	27

* Numbers in parentheses refer to series on record sheet.
† Average time for series given in seconds.

Finally the behavior of the chick indicated that it was discriminating between ⊙ 28+ and ⊙ 27+ (see record for November 23 and 24).

The discrimination of such a minute difference was incredible, for the human eye could scarcely detect a difference after the variable reached ⊙ 23+. The next step was to try the chick

when the variable was made equal to the standard. The result was a perfect series (see record 1 for November 25).

With positive evidence that the discrimination was not of size difference, an inventory of possibilities was taken. Among the features noted was a small crack where the outside extension of the electric source box jointed to the experiment box. But a similar crack appeared on both sides in corresponding positions, so it seemed that in this factor there could be no cue by which the chick had been guided in its choice of the proper compartment.

Closer inspection, however, proved that these two minute cracks lay at the bottom of the matter. Where the rabbeted edges of the shifter and tracks rubbed, there was a bright edge, and wherever the shifter rested the bright surface was covered. Thus when the shifter was at the left, the right end of the track was uncovered, and from this uncovered part were reflected some of the light rays from the upper illumination. A small portion of this reflected light could enter the crack on the uncovered side. Now, when the standard circle was presented at the left, the shifter was always moved to the right; when the standard stood at right, the shifter stood at the left. As a result, the crack that was illuminated was always the one where the standard circle was displayed; the other crack, being reached by no reflected light, was comparatively dark.

The effect of closing these small cracks through which the light was reflected is indicated in the records following the first on November 25. The perfect reactions abruptly cease; out of 15 tests there are only 6 correct responses. As the following portion of the table indicates, the experiment with the cracks closed was continued, but the variable had to be reduced to ⊙ 15+ before the correct reactions returned.

The chick, then, had detected a faint streak of light not more than 6 mm. long and less than 1 mm. wide or else the increase in general illumination which resulted. By considering the amount of light that came from the upper illumination, the poor reflecting surface of a steel strap worn only moderately bright, and the narrow surface from which the light was reflected, (not more than 1 cm. in width), the insignificance of this strip of light is emphasized. It was an example of the chick "outguessing" the experimenter.

CHAPTER V

Size Perception

The foregoing discussion of method suggests the difficulties that arise when one's experimental problem becomes limited to a single detail of vision. It emphasizes the uncertainty of earlier work where exacting controls were not employed. In the light of my experience, it seems to be a safe guess that prior studies, presumably of detail vision, were, in fact, studies of reactions to visual complexes the constituents of which were not known to the experimenters. The control, in my study, leading to the discovery of the disturbing crack proves that the results with chick 3, prior to the control, were untrustworthy. In other studies where the possibilities for similar disturbances have been many times greater, results should be accepted with considerable caution.

After the discovery of the light-admitting crack, my results become more reliable. Later experiments with chick 3 indicate that the early positive choices had been made on the basis of a discrimination of size difference, but as the variable became larger, and the discrimination proportionately harder, the chick resorted to a different criterion for choosing. In table 2 one finds evidence of the place where chick 3 ceased to discriminate between the two size stimuli. After the controls, the chick was first tested with a variable ⊙ 23+. The results are clearly negative since chance alone is sufficient to explain the number of correct responses. With the variable reduced to ⊙ 19+, there are only three correct choices in ten tests, but when the variable was changed to ⊙ 15+ the results are clearly positive. The standard was chosen nine times and the variable only once. While the average results of the tests with the ⊙ 19+ are slightly in favor of the larger stimulus, it seems that one should not emphasize the fact for the larger circle was chosen, in a total of 60 tests, only five more times than chance allows.

Table 3 summarizes the results of my study of the chick's perception of size stimuli. In contrast with earlier reports

TABLE 3

Discrimination Between Unequal Circles

SERIES	NO. 3[1]						NO. 6 ♂						NO. 7 ♂						NO. 15 ♂[2]						NO. 16 ♂[2]					
	28+ 7+		28+ 12+		28+ 15+		28+ 7+		28+ 12+		28+ 15+		28+ 7+		28+ 12+		28+ 15+		28+ 7+		28+ 12+		28+ 15+		28+ 7+		28+ 12+		28+ 15+	
	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W
1.....			5	5	9	1	7	3	8	2	8	2	8	2	10	0	7	3	9	1	10	0	7	3	9	1	8	2	10	0
2.....			8	2	[3]		9	1	8	2	[4]		6	4	9	1	7	3					7	3						
3.....			6	4			9	1	8	2			7	3	7	3	[4]						8	2						
4.....			8	2			8	2	6	4			9	1	8	2														
5.....			9	1			10	0	8	2			9	1	9	1														
6.....			6	4			9	1	6	4			9	1	8	2														
7.....			10	0			8	2	8	2			10	0																
8.....							6	4					8	2																
9.....							9	1					10	0																
10.....							10	0					10	0																
11.....							8	2					10	0																
12.....							10	0					10	0																
13.....							10	0					10	0																

[1] Preceded by tests which were ruled out on account of the crack of light.
[2] The record for ⊙ 28+ — ⊙ 7+ was preceded by 13 series in which the light factors were combined; the record given represents the first series after all factors except size were eliminated.
[3] Followed by ⊙ 28+ — ⊙ 19+ in which No. 3 failed.
[4] Tests were hurried on account of physical condition of subject.

TABLE 3—*Continued*
Discrimination Between Unqual Circles

SERIES	NO. 17 ♀[2]						NO. 18 ♂[2]						NO. 20 ♂(?)[2]						NO. 21 ♀[2]					
	28+	7+	28+	12+	28+	15+	28+	7+	28+	12+	28+	15+	28+	7+	28+	12+	28+	15+	28+	7+	28+	12+	28+	15+
	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W
1	10	0	10	0	8	2	8	2	10	0	8	2	9	1	8	2	7	3	7	3	10	0	10	0
2					9	1					5	5					7	3					7	3
3											8	2					[6]						8	2
4											[5]												8	2
5																							6	4
6																							10	0
7																								
8																								
9																								
10																								
11																								
12																								
13																								

[2] The record for ⊙ 28+ – ⊙ 7+ was preceded by 13 series in which the light factors were combined; the record given represents the first series after all factors except size were eliminated.
[5] Became discouraged.
[6] Tests ended on account of physical condition of subject.

which emphasize habit formation my results do not always appear clear cut and definite. Frequently the positive choices that have been allowed to pass as though satisfactory do not exceed 75 per cent of the total, whereas earlier work seems to have been more regularly favored with ultimate perfection. Does this not indicate that my results are untrustworthy?

In general, there are two answers to this possible criticism. I shall refer first to the least important, namely, that my task was not one in habit formation. Perfection of a habit was only incidental to the primary task of sensory acuity. Experience with the first group of chicks indicated that time was wasted by holding rigidly to the perfection requirement. The uncertainty of the chick's health, further, made it advisable to hasten towards the threshold of discrimination without waiting in all cases for perfect habits.

Chicks 6 and 7, representing the first group, were held to the preliminary training, ⊙ 28 + — ⊙ 7 +, until two successive perfect series were obtained. Then the variable was changed to ⊙ 12 +. From the first, there was evidence of discrimination of this new variable but only a single perfect series appeared. After six or seven series, there was no evidence of improvement over the beginning of the ⊙ 12 + discriminations. This suggested that time could have been saved by increasing the variable as soon as there was satisfactory evidence of discrimination, even though positive reactions had not reached 100 per cent.

With the second group, including chicks 15–18, therefore, this suggestion was tried out. The series numbered 1 in table 3, which was the 14th for this group of chicks, represents the final series of the preliminary training. In that series chick 17 is the only one to react perfectly. But the reactions of 15, 16, and 18 were so closely approaching perfection that there was unmistakable evidence of discrimination. Moreover, it was more convenient to present to the other chicks the same stimuli which were presented to chick 17. Without further training, then, all chicks of the group were confronted with the new variable, ⊙ 12 +.

That such haste was justified is indicated in the single ⊙ 28 + — ⊙ 12 + series for each individual of this second group. Chicks 15, 17, and 18 responded perfectly while the positive responses of No. 16 are 8 out of 10. Again, when the variable

was increased to ⊙ 15+, chick 16, the only individual of the group which had failed to make a perfect record in one of the two preceding tests, is the only one in this series to make a perfect record.

Comparing, now, these records of chicks 15–18 with the records of chicks 6 and 7 of the first group, the haste is further justified. Chicks 6 and 7, after continuing in the easy training until the reactions were well perfected, subsequently fail to show up superior to chicks 15–18. Furthermore, the records of chicks 20 and 21, belonging to group 3, are no less clear cut for the variables ◐ 12 + and ⊙ 15 + than the records of chicks 6 and 7.

The second answer to this possible criticism is more theoretical than the first, but the two are closely allied. A review of the actual results indicates that it was not essential to insist upon 100 per cent correctness. In the second place, mine is a study of detail vision in the strict sense; earlier studies, though presuming to present data on visual details, have probably dealt with visual complexes. For this reason, my results cannot be justly estimated by means of the same criteria that have been adopted in connection with earlier work. In studies of detail vision, animals are compelled to react appropriately to a single visual factor. Now, when the remaining factors happen to be so grouped that the complex becomes especially attractive,—and well controlled tests will contain such combinations,—is it surprising that the attractive complex gains the attention of the animal for the time being and causes the animal to ignore the more insignificant single visual detail? In control tests, one is always demanding, in the face of other attractions, responses to this more or less insignificant factor. Due allowance should be made for momentary lapses of the attention of the animal.

Furthermore, as the threshold of the particular visual factor is approached, the single detail becomes less and less significant. It is reasonable to suspect, then, that even before the perceptibility of the discriminable detail wholly vanishes, the animal will be tempted to try out novel reactions. On the analogy of human behavior, it seems reasonable that the animal actually ignores at times the discrimination problem that has been set. This supposition is especially plausible when we consider that the vividness of punishment may decline as the discrimination habit approaches perfection. Making allowance, then, for

these interruptions, which are certainly not indicative of inability to perceive the visual detail in question, wholly perfect responses when the threshold is being approached cannot reasonably be expected.

By considering, in addition to the correct records, the peculiarities of behavior which cannot be presented in tabular form,[1] I am convinced that the largest variable which the chick can distinguish, under the conditions of this study, when presented with a standard ⊙ 28+, lies somewhat above ⊙ 15+. The quantitative measurements on the basis of correct choices supports this conclusion. Every subject, excepting 7 and 20, succeeded in making at least 80 per cent of the choices correct in a series when the ⊙ 15+ variable was used. Even in the responses of 7 and 20, an efficiency of 70 per cent was indicated. But more convincing, perhaps, is the fact that two chicks, 3 and 17, reached 90 per cent and two, 16 and 21, made perfect series.

TABLE 4

Average time for choosing

SUBJECT	⊙ 28+ — ⊙ 7+	⊙ 28+ — ⊙ 12+	⊙ 28+ — ⊙ 15+
6	15″	13″	7″
7	22	59	55
15	8	5	31
16	30	28	11
17	3	8	13
18	4	3	20
20	3	13	11
21	6	2	9
Average for all subjects.....	11″	16″	20″

The time used by the chicks in choosing is a factor which might throw supplementary light on this threshold question. Having kept the time for every choice, and having casually observed changes in time for choosing in the beginning, intermediate, and final stages of discrimination, it is at least interesting to note whether the actual time records confirm this observation. In table 4 appears the average time in seconds consumed by each of eight subjects for choosing under the three different discrimination settings. An average of the

[1] See sample test sheet, page 36, for method of recording these peculiarities of behavior.

averages for the eight subjects gives respectively for these discrimination settings 11, 16, and 20 seconds. These averages indicate that the chicks in the early stage of learning were faster in choosing than in the intermediate stage. However, the reliability of these averages as an index of discriminability is open to question. The frequency of errors indicate that less discrimination underlies the early responses. While the chicks were less acquainted with the conditions of the experiment in the initial training, variable ⊙ 7+, they made many direct choices without showing evidence of comparison such as frequently occurred when the discrimination habit had become well established. Less time naturally was recorded for these direct choices, although errors were more frequent. Apparently the averages of No. 21 as recorded in table 4 are more reliable as an indication of the relative time required for each setting where discrimination underlies the choices. The time of this chick for each of the three variables is respectively 6, 2, and 9 seconds. If it were possible to obtain an average for the time of those responses only in which choice was based on discrimination, it is probable that we would find the time greater in the beginning and final stages than in the intermediate stage. During the intermediate stages the habit would be well established and the discrimination settings would not be extremely difficult.

It might be urged that this time average became relatively longer towards the close of the experiments on account of the physical condition of the chicks. The facts, however, seem to refute such a view. Referring again to the individual record of chick 21 in table 4, one finds evidence that the changes in time averages are not conditioned by the health of the chicks. During the course of these tests No. 21 was given open air range under which conditions it throve and grew normally. This chick continued in good health even at the end of 1500 subsequent tests in form perception. The records of table 4 indicate that chick 21 was slower with the variable ⊙ 7 + when it was learning, the average time was *not* increased when the variablew as changed to ⊙ 12+ because the discrimination remained easy, but the time *was* increased when the more difficult discrimination, variable ⊙ 15+, was required.

The records of chick 21 alone cannot be accepted as reliable on account of the limited number of tests, particularly in the

intermediate stage. On the other hand, one might assume with some justice that, in more than 2000 tests distributed among eight individuals, all irregular fluctuations would tend towards an equal distribution among the different size relations. In this event, the time records represented by the final averages of table 4 might be said to substantiate the preceding conclusion, based upon the number of correct choices, that the maximum which the chick can discriminate under the conditions of this experiment lies somewhat above ⊙ 15+.

Statistically considered, however, the averages of this table have very little significance. The mean variation, for example, from the 11, 16, and 20 seconds averages are respectively 8, 13, and 12 seconds. These mean variations are nearly as great as the averages themselves, and they are, in every case, as great as or greater than the differences between any two of the averages.

These averages of table 4 are even more questionable when one considers the individual records on which the table is based. A notion of these individual records may be derived from Test Sheet 1 and Test Sheet 2 which are presented to illustrate how the behavior respectively differed under easy and difficult discrimination. Taking these two series as examples, we find that the mean variation represented by Test Sheet 1 is 1.88 seconds which is nearly 59 per cent of the average for the ten tests. In the records presented by Test Sheet 2, the mean variation is a little lower being slightly above 51 per cent. This wide variability suggests that the averages for the different individuals are themselves questionable. Combining with this the variability noted within the table itself, these averages appear as doubtful criteria.

A number of things might be mentioned in explanation of the variability between the tests of a single series. Wholly secondary influences, such as a severe shock, the slamming of a door, or a snow slide on the roof, are often responsible for a sudden fluctuation in the reaction time. A more natural difficulty with the chick which is responsible for even greater fluctuations in reaction time is a tendency to go to "roost" in the dark room. It can usually be aroused by blowing lightly against the feathers, but such behavior plays havoc with the reliability of the individual time records.

TEST SHEET 1

Title of investigation, Size: ⊙ 28+ — ⊙ 7+
Experimented on, 21
Harvard Psychological Laboratory, February 28, 1912
Record Sheet; 1; Series, 6

TEST	BEHAVIOR	RECORD
1 l	// + /// "	0–4
2 l	+ $\overline{///}$ "	0–5
3 r	+ $\overline{///}$ "	0–2
4 l	+ $\overline{///}$ "	0–1
5 r	+ $\overline{///}$ "	0–2
6 r	+ $\overline{///}$ "	0–2
7 l	+ $\overline{///}$ "	0–2
8 r	+ $\overline{///}$ "	0–2
9 l	+ $\overline{///}$ "	0–2
10 r	+ $\overline{//}$ $\overline{''''''}$ "	0–10

10–0–3.2

TEST SHEET 2

Title of investigation, Size: ⊙ 28+ — ⊙ 7+
Experimented on, 16
Harvard Psychological Laboratory, March 6, 1912
Record Sheet 1; Series 16

TEST	BEHAVIOR	RECORD
1 l	$\overline{///}$ − // + /// V − $\overline{///}$ + /// "	0–47
2 r	/// − // ○ + /// "	0–38
3 l	$\overline{///}$ + − + // − $\overline{/\Delta^1}$ + − // Δ^1 + // "	E–2–58
4 l	// + $\overline{///}$ ∧ ○ − /// + /// "	0–35
5 l	/// + /// "	0–11
6 r	/// − $\overline{//}$ // Δ^1 + /// "	E–1–21
7 r	// + /// − /// ○ + /// "	0–22
8 r	+ /// "	0–5
9 l	+ /// $\overline{\bigcirc}$ − /// $\overline{\bigcirc}$ + /// "	0–35
10 r	// + /// "	0–10

8–2–28.2

The characteristics of the chicks' behavior offer a less precise basis for determining the location of the threshold. This type of evidence, however, is practically limited to the observer. It can scarcely be conveyed to the reader. Yet, despite the limitations of such evidence, the fact remains that the observer has a qualitative criterion which he may employ in addition to his quantitative measurements. If both agree he naturally feels more certain of his conclusions.

The two test sheets presented illustrate two different types of behavior. Test Sheet 1 shows that chick 21 lost no time on entering the discrimination chamber, but went directly in every test to the correct compartment. Test Sheet 2 presents a different type of behavior, yet it indicates that chick 16 was discriminating between the two stimuli. In the first test the chick was quiet for some time after entering the discrimination box; then it went to the wrong side where it stopped momentarily. It then turned to the left, went close to the left electric compartment, hesitated, and entered but turned to the right and came out. Again it looked closely at the wrong (right side) stimulus, turned back to the correct stimulus (left), and escaped. The behavior was somewhat similar in the second test except that in turning away from the wrong stimulus, which was this time at the left, the chick turned its self completely around, counter clockwise, and came up before the correct stimulus. The third test shows that chick 16 made two errors for both of which it was punished. In test 9 the chick made two complete turns—one counter clockwise from the correct compartment (left side), and one clockwise turn from the other compartment.

These two test sheets have been selected with an idea of showing as marked contrast as possible in order to emphasize the importance of the chick's behavior during each test and series. The first shows that chick 21 had no difficulty in choosing the proper stimulus. The second indicates that chick 16 was comparing the stimuli and using considerable care in choosing, although it made two errors. The choices alone do not indicate as much advancement as the details of the behavior during the choices. These two series cannot be called typical yet they represent fairly well some of the essential principles of behavior in the discrimination problem.

On the basis of choices and behavior—it seems safest to exclude the time factor—it appears that the chick's limit in discrimination from a standard ⊙ 28+ lies somewhere between ⊙ 15+ and ⊙ 19+. To express the relation in terms of centimeters instead of square centimeters, the size in diameter of the variable is above 4.5 but below 5; that of the standard is 6. *The threshold of difference with a standard 6, therefore, is one-fourth to one-sixth.*

To be certain that the reactions of the chicks were not made on the basis of some detail or complex other than size difference, it was necessary to employ various controls. There appear, in the stimuli themselves, three factors other than size that might provide a basis for correct response: (1) luminous intensity of the respective stimuli; (2) brightness of the respective stimuli; and (3) illumination of the respective electric compartments. Without adequate controls, it would be impossible to say definitely whether size or these other characteristics were the bases of the responses which point to the above conclusion.

Supposing the two stimulus areas to be 6 cm. and 3 cm. in diameter, the display surfaces equal in brightness, and a complete image of the larger formed on the retina, it follows that the chick would be stimulated by four times as much light from the larger as from the smaller stimulus. It is conceivable that the chick, under these conditions, might respond on the basis of pain or its physiological concomitant, or even of pupillary reaction. In addition to this possibility, the general illumination of the electric compartment containing the larger stimulus would differ from that of the other compartment. The chick might choose the lighter or darker compartment. Both of these possibilities might occur independently of the matter of brightness.

As a portion of the controls used in this connection, an additional lamp was placed directly above the experiment box. This upper illumination (*L* of figure 3, p. 24), consisting of a 2 c.p. electric lamp enclosed in a vertically suspended cylinder of galvanized iron, was designed to hide the inequalities in the distribution of light in each compartment. It hangs about 120 cm. above the floor of the experiment box so that an equal amount of light is added to each compartment. The diameter of the cylindrical enclosure is 10 cm. and its length is 20 cm.

The upper end is tightly closed. The lower end is fitted with a removable cover in which is centered an Aubert diaphragm for regulating the amount of light falling upon the experiment box. To eliminate shadows in the experiment box and to increase the amount of upper illumination, the diaphragm cover was removed throughout the greater part of the experiment. With the lower end of the cylinder open, the amount of light added to the experiment box was that coming from a 2 c.p. lamp, passing through a circular opening 10 cm. in diameter, and falling a distance of 120 cm. Further variations in the upper illumination were made by substituting for the 2 c.p. lamp, after the chicks had acquired a positive reaction tendency, larger lamps with a maximum of 10 c.p.

The upper illumination thus serves as a control of the inequality of general illumination in the two electric compartments. It can be so arranged as to furnish enough illumination, equally divided between the two compartments, to reduce the proportional difference in illumination to a point below the chick's threshold. The amount of upper illumination should therefore depend upon the degree of difference between the sizes and brightnesses of the two stimulus areas. In a quantitative study, where the difference in size is being continually reduced, and where variations and reversals of brightness are essential features of the vital tests, the possibility of consistent reactions on the basis of difference in general illumination is removable by means of the upper illumination.

Variations and reversals of brightness, as essential parts of the system of control, are easily effected by changing the respective distances of the source lamps from the display surfaces. If the brightness of the respective stimuli be varied by reducing the illumination of the larger, increasing that of the smaller, or *vice versa*, the luminous intensity of the stimuli is at the same time varied. Thus, a proper combination of controls, including the upper illumination and relative changes in distance of the sources, provides a means of determining whether the basis of the chicks' choices lies in size difference or any of the three possibilities (1) luminous intensity, (2) brightness, and (3) general illumination.

The method of adapting these controls to my experiment is concisely stated in table 5. The location of the source lamps

was varied according to the plan of the second and third columns. The illumination of the electric compartments was controlled as indicated by the last two columns. In tests 1 and 2, the + or correct stimulus area was considerably brighter and the corresponding compartment lighter than the other. In

TABLE 5

Control series for ⊙ 28+ — ⊙ 7+ Discrimination

Nos. 15, 16, 17, 18, 20, and 21

March 4, 1912

Record Sheet 1. Series 14

TEST	SOURCE DISTANCE FROM		GENERAL ILLUMINATION OF	
	+ Stimulus	− Stimulus	+ Compartment	− Compartment
	cm.	*cm.*		
1 l	240	125	Uncontrolled except for upper illumination	
2 l	240	125	"	"
3 r	240	125	Much darker: Covered with 2 thicknesses of ground glass	Much lighter: Covered with thin sheet of plain glass
4 l	240	125	Darker: Covered with 1 thickness of ground glass	Lighter: Covered with 1 thickness of plain glass
6 r	240	240	"	"
7 l	180	180	"	"
8 r	180	180	"	"
9 l	180	180	"	"
10 r	180	180	"	"

tests 3 and 4 the general illumination was reversed without changing the brightness or luminous intensity of the stimulus areas. After test 5,[2] the source controls remain unchanged although the relative position of the + or correct stimulus varies from right to left.

This represents the first specific control for ⊙ 28+ — ⊙ 7+ discrimination after a varying amount of preliminary training had been completed. If a chick could not react correctly under these conditions, it was assumed that the preliminary training

[2] In test 5, the source distances were equal and no controls were introduced.

had not been completed. If the previous correct reactions were not noticeably interrupted by this control system, the chick was considered ready for a larger variable. With the exception of the records for chicks 3, 6, and 7 the essentials of this procedure were carried out for every record given in table 3. The results presented in tabular form, therefore, are those of controls; they are not training or learning records.

The significance of having the +compartment darker than the −compartment in most of the tests of this control series appears when the plan of the preliminary training is set forth. In the beginning, the chick was required to choose on the basis of a visual complex consisting of (1) the lighter compartment in which the stimulus area was (2) larger, (3) triangular, and (4) brighter. As soon as consistent choices appeared, the inequalities between the two stimuli, except size difference, were gradually removed by replacing the triangle with a circle, increasing the upper illumination, and gradually bringing the source lamps to an equal distance from the diffusing or display surfaces. Next, the source distances were gradually and irregularly made unequal. Possibility of discriminating on the basis of brightness and luminous intensity, or either, was thus eliminated before reaching the final control stage. In the more thoroughgoing control series, therefore, the most important fact to establish was certainty about the possibility of general illumination. The +compartment was thus made darker after the first two tests while the other variations were continued. In the matter of general illumination, then, the conditions of the final controls were exactly reversed from those of the preceding training series.

This method of preliminary training was adopted after the perplexing experience with chick 3, described in Chapter IV, and the discovery of the crack which admitted reflected light. The incident suggested that the chick which was being trained, preliminary to the primary threshold study, should be aided in this early stage by having the differences between the two visual stimuli emphasized by a combination of light factors.[3] Two stimulus areas, differing from each other with respect to one quality only, present to the chick a problem which is quite

[3] Yerkes, R. M. The discrimination method. *Journal Animal Behavior*, vol. 2, p. 142.

unnatural. Under natural conditions, it probably relies upon combinations of many visual factors. The perception of an isolated visual quality is a technical human problem, not a natural animal problem.

Johnson[4] criticises the use of the visual complex in preliminary training on the ground that one is risking a large waste of time. He says:

> It has happened that an experimenter discovers after several weeks of training that the animal had learned to react to difference of e.g. brightness, and had not been affected by the other stimulus-differences. It would seem that a difference in luminous intensity is especially objectionable since in dark surroundings the animal can choose the brighter or darker alley without attending specifically to the stimulus-forms.

Now the value of the visual complex lies precisely in the fact that the natural inclination of an animal is to attend to some other factor than the one under investigation. A discrimination habit is hastened because the animal may resort to the most conspicuous cue. Whatever this cue may be, it is used as a valuable ally in directing the animal's attention to the proper detail. A patient and alert experimenter can eliminate brightness, luminous intensity, et cetera so gradually that the animal's basis of discrimination is quite simply switched to the detail in question, provided that the detail is perceivable for the animal. The change should not be made abruptly, nor is it necessary to wait for a perfect habit. Slight changes should be commenced as soon as there is evidence of an incipient habit. My results with chick 3, in contrast with later results from other chicks, compel me to favor the use of the visual complex in preliminary training. The success of one method or another evidently depends to a great extent upon the temperament of the experimenter.

Coburn's study (6, Chapter 2) of the vision of the crow furnishes the only available results on size perception in birds that are comparable with my results. His study of the crow's perception of size was not primarily a threshold study, but his preliminary results roughly indicate in centimeters a 3–2, 5–3, 6–4, and 9–6 discrimination of circles. A hasty series of tests towards the close of his observations indicate a discrimination between a 5 cm. circle and a 4.5 cm. circle. He thinks a finished

[4] *Journal Animal Behavior*, vol. 4, p. 324.

threshold study would reveal a discrimination considerably smaller than a 0.5 cm. difference.

Evidently the crow's perception of size is much superior to the ability of the chick in the same task. Although the experimental setting was somewhat different in our studies, it seems that they are sufficiently alike to warrant comparisons. The maximum variable that my chicks were able to discriminate from a standard 6 cm. circle was the same, 4.5 cm. circle, as his crows discriminated from a 5 cm. circle. From the standpoint of size perception, it would seem, therefore, that the ability of the crow is considerably greater than that of the chick.

CHAPTER VI

Form Perception

The development of a definite procedure in the study of form perception in the chick followed, in general, that which has been described in the preceding chapter on size perception. A study of the ability of the chick to discriminate between circles and triangles which are equal in area was made with two of the second group, chicks 9 and 11. The latter became afflicted with "leg weakness" after the 24th series, up to which time it had given no positive results. The results from chick 9 which are presented in table 6 might be regarded as slightly positive.

On the whole, the number of choices of the circle, as shown in table 6, indicate some sort of discrimination. Series 10 was perfect. Series 25 contains 9 correct choices and several series reached 70 per cent or 80 per cent correctness. It is not surprising that the chick became discouraged before a perfect habit was established, for the plan of starting with complex stimuli and working towards the single detail had not yet been adopted. A system of control similar to that described in the preceding chapter was followed throughout the work. The surprising feature is the high percentage of "right" choices on January 4 and 5 when the chick was becoming discouraged and frightened. This discouragement resulted in a rush for one stimulus or the other as though "to get the choice over." It appears that there was some sort of a difference between the two illuminations which tended to attract the rushing chick, but this was not clearly enough perceived for a dependable basis of response. But even though a discrimination between the stimuli be admitted, it does not follow that the chick perceived form. As has been pointed out in Chapter II, the distribution of light on, or the unequal stimulation of, the different parts of the retina may have been the discriminable basis.

The result of this experience with chick 9 convinced me that a better method was necessary to determine with certainty whether the chick actually perceives form. When the study

of form perception was begun with group 3, therefore, the method of the preliminary visual complex was adopted. That is, form, in the beginning, was made only one of other visual factors which were gradually eliminated as the experiment progressed. Only one chick, No. 21, gave anything like positive results. The work with this chick, including considerable train-

TABLE 6

Form Perception: ⊙ 28+ — △ 28+

No. 9. Hatched: December 1, 1911. Sex: ♀

SERIES	DATE	RIGHT	WRONG	TIME
1	Dec. 9	4	6	....
2	11	8	2	44.2
3	12	5	5	47.1
4	13	6	4	49.2
5	14	7	3	24.8
6	15	6	4	54.6
7	16	6	4	28.3
8	18	4	6	56.8
9	19	5	5	15.9
10	19	10	0	29.5
11	20	6	4	60.2
12	21	8	2	16.7
13	22	7	3	42.7
14	23	5	5	32.8
15	25	6	4	29.5
16	26	8	2	24.2
17	27	7	3	42.8
18	27	4	6	32.8
19	28	4	6	44.7
20	28	6	4	33.2
21	28	5	5	22.0
22	29	3	7	29.3
23	29	6	4	13.3
24	30	7	3	12.7
25	Jan. 2	9	1	27.8
1	2	7	3	30.9
2	3	5	5	25.4
3	4	7	3	12.5
4	5	8	2	4.6 (Rushing)
5	6	(Discouraged; rushed blindly and wildly towards either stimulus)		

ing in size and brightness vision, represents more than 1500 tests.

The experiment on form discrimination with chick 21 may be divided into three parts: (1) A preliminary investigation; (2) reactions to the triangle-circle; and (3) reactions to the circle-triangle. The method of the visual complex and the general improvement of my technique enabled me to get much more

work out of this subject, and at the same time, called forth less energy than in the earlier tests. No. 21 knew me quite well by this time. It was perfectly contented to leave its companions in the chick-room and go alone with me to the dark-room for work. The chief reason for this was the fact that it always had its morning feeding in the dark-room. As soon as we reached the experiment room it was given a little chick food and allowed to run freely about until the apparatus was made ready for the tests. During the preparation of the apparatus, the chick would follow me about the room (then lighted) twittering and contented, but if it were left alone for a few minutes its dissatisfaction was made known by loud and ceaseless peeping.

When everything was ready the chick was placed in the apparatus. At this point the note in its voice changed to a slightly modified "hovering twitter." Commonly this peculiar sort of "singing" changed, as the chick entered the discrimination chamber, to the "food twitter" which was continued all the time it was inspecting and comparing the two stimulus areas and, of course, after it had entered the nest box, for there it was rewarded by finding a few grains scattered in the litter. In this manner a series could be completed in about fifteen minutes, after which the chick was taken from the experiment box and given more food and its freedom in the room. This procedure could be carried out until the chick's hunger was satisfied after which the tests went so slowly and with such uncertainity that it was found best to postpone the work until the following morning. As the bird became older this mode of experimentation could be carried on as long as three hours.

While I was preparing test sheets or making notes at my desk between experiments, No. 21 would crowd about my feet and "beg" to be taken up. If it were allowed to perch itself on my arm it would sit there as long as I was quiet, contentedly preening its feathers and occasionally giving a short "hovering twitter." All of this indicates that the chick was quite contented and normal throughout the experiment.

Table 7 shows the results of my first study of form with chick 21 in which it was trained to go to the triangle and to reject the circle or square. While none of the results here recorded are clear cut, there is strong evidence that the chick was discriminating between the two stimuli. This experiment was hurried

lest the chick should not remain in good physical condition, but at its conclusion the bird was in excellent health, having out of doors range, so the work was repeated with more thoroughness.

The last two series (24 and 25) of table 7 were introduced as a different sort of control tests. The circle was larger than the triangle, hence it afforded an opportunity to see if the chick would react to form difference, after this training, rather than size difference. Apparently it was demanding too much of the chick for it became discouraged at this point and the training had to be repeated.

TABLE 7

Form Perception

No. 21. Hatched: February 9, 1912. Sex: ♀

DISCRIMINATION	SERIES	DATE	RIGHT	WRONG	TIME
△ 28+ — ⊙ 7+	6	March 13	7	3	10″
" — ⊙ 12+	7	" 13	9	1	11
" — ⊙ 15+	8	" 14	8	2	18
" — ⊙ 19+	9	" 14	4	6	12
" — "	10	" 14	6	4	8
" — "	11	" 14	8	2	33
" — "	12	" 14	8	2	12
" — "	13	" 14	8	2	12
" — "	14	" 14	8	2	12
" — ⊙ 23+	15	" 14	8	2	13
" — "	16	" 15	8	2	6
" — ⊙ 24+	17	" 15	8	2	13
" — ⊙ 25+	18	" 15	9	1	6
" — ⊙ 26+	19	" 15	6	4	17
" — ⊙ 27+	20	" 15	8	2	18
" — ⊙ 28+	21	" 15	7	3	17
" — "	22	" 16	9	1	8
" — □ 28+	23	" 16	9	1	40
" — ⊙ 63+	24	" 18	6	4	56
" — "	25	" 18	6	4	85

In table 8 are presented the results of the re-training of No. 21. While the record, as shown in the table, indicates that the chick discriminated between the triangle and the circle, it is, nevertheless, equally convincing that the chick did not perceive the form difference. It had reacted properly to the △ 28+ — ⓢ 19+ and — 23+ when the apex of the triangle was at the top, but when the triangle was inverted (series 20, March 25), the animal did not choose the triangle more than half of the time. With the triangle again upright, the correct reactions returned. Proper responses were made when the

areas were equal (series 8 and 9, March 28), but when the inscribed triangle was substituted for the standard, the chick was again confused. Series 13, (March 29), another control where the triangle was inverted, gave more decided negative results which were immediately preceded and followed by almost perfect reactions. As a further test of inverting the triangle, the inversion was made during a regular series, 15, (March 30). The result of the inversion during tests 5–7 was one right choice out of three chances with an average time of

TEST SHEET

Title of investigation, Form: △ 28+ — ⊙ 63+
Experimented on, 21
Harvard Psychological Laboratory, March 18, 1912
Record Sheet, 2; Series, 24

TEST	BEHAVIOR	RECORD
1 l	/// − /// + /// ○ − /// + /// "	0–65
2 r	/// + /// "	0–7
3 l	/// − /// △¹ + /// "	E–1–14
4 l	/// − /// + / \\ + /// "	0–14
5 l	/// − /// △¹ ////// + /// "	E–1–55
6 r	/// − + /// ////// − /// ○ + // − / + // ////// − △² + "	E–2–171
7 r	/// + // − // + // + ////// + // − ////// + /// "	0–94
8 r	// + // \\ − // \\ ////// + // "	0–69
9 l	/// + /// "	0–4
10 r	/// − / ○ + \\ − / + / ////// − // △¹ + // "	E–1–70

6–4–56.3

39 seconds. These three special tests were preceded and followed, during the same series, with *perfect* reactions (triangle upright) the average time of which was somewhat *less than one-sixth* of the average time for the special tests.

In connection with these results, the details of the behavior of No. 21 are presented when it was confronted with △ 28+ — ⊙ 63+ stimuli. These tests are reported in table 7 as series 24 and 25. The test sheets show how utterly confusing to the chick was this condition. The results of this test were verified

in series 10 recorded in table 8 under date of March 28 where the record is the same and the behavior was very similar.

Finally this chick's response to the circle-triangle was tested. The reversion of the condition for discrimination was at first confusing to the chick, and much patience on the part of the

TABLE 8

Form perception: △ 28+ — ⊙ 28+

No. 21. Hatched: February 9, 1912. Sex: ♀

DISCRIMINATION	SERIES	DATE	RIGHT	WRONG	TIME
△ 28+ — ⊙ 9+	9	March 20	10	0	6
" — ⊙ 12+	10	" 20	10	0	14
" — ⊙ 15+ (inscription) of triangle)	11	" 21	9	1	9
" — "	12	" 21	10	0	9
" — "	13	" 21	10	0	8
" — "	14	" 22	10	0	6
" — ⊙ 19+	15	" 22	5	5	15
" — "	16	" 23	9	1	6
" — "	17	" 23	10	0	6
" — ⊙ 23+	18	" 23	9	1	7
" — "	19	" 25	9	1	20
▽ 28+ (inverted) — ⊙ 23+	20	" 25	5	5	92
△ 28+ (upright) — ⊙ 23+	21	" 25	8	2	20
" — ⊙ 23+	22	" 26	10	0	17
" — ⊙ 25+	23	" 26	10	0	12
" — ⊙ 27+	24	" 26	8	2	12
" — "	25	" 26	9	1	6
" — "	5	" 27	8	2	35
" — "	6	" 27	6	4	8
" — ⊙ 28+	7	" 27	8	2	9
" — "	8	" 28	10	0	5
" — "	9	" 28	10	0	9
△ 11+ (inscribed) — ⊙ 28+	10	" 28	6	4	40
△ 28+ — ⊙ 28+	11	" 28	10	0	15
" — "	12	" 29	9	1	5
▽ 28+ (inverted) — ⊙ 28+	13	" 29	2	5	83
△ 28+ (upright) — ⊙ 28+	14	" 29	9	1	7
" — ⊙ 28+	15[1]	" 30	7	0	6
" — ⊙ "	16	" 30	9	1	7
" — ⊙ "	17	" 30	10	0	24
" — ⊙ "	18	April 1	10	0	15

[1] In series 15 the triangle was inverted during tests 5–7; the result was 2 wrong choices with an average time of 39 seconds.

experimenter was necessary. The plan now was to begin with ⊙ 63+ — △ 28+ and gradually to eliminate the size difference by substituting successively smaller circles. In this case the correct stimulus area was the variable and the standard was the sign of "shock" and "no escape." From the summary of these

results, table 9, the early records are omitted since these tests were made only as a means of getting a discrimination between the later forms. The size of the circle was gradually decreased from ⊙ 63+ to ⊙ 38+ at which point the tabulation begins. About 400 tests between April 1st and 20th were necessary to bring the chick to the point in its training at which the records of the table commence.

Table 9 shows that the chick was able to acquire the circle-triangle habit. The plan of controlling the qualities other than

TEST SHEET

Title of investigation, Form: △ 28+ — ⊙ 63+
Experimented on, 21
Harvard Psychological Laboratory, March 18, 1912
Record Sheet, 2; Series, 25

TEST	BEHAVIOR	RECORD
1 r	/// + //−/// ○ \\ − // + // − // ○ + / ○ −/ △⁰ + // 〃	E–0–145
2 r	/// + // ○ − /// + / ○ − // ○ + /// 〃	0–79
3 r	/// + − ○ + // ○ + /// 〃	0–45
4 r	/// ○ + /// ○ − / + /// + /// 〃	0–60
5 l	/// ○ − // + /// − /// + /// − // △¹ + /// 〃	E–1–61
6 l	// + /// − / ○ + /// 〃	0–33
7 l	// + // − /// − /// ○ − // + /// 〃	0–46
8 l	/// + /// − ○ + / − /// △¹ + /// 〃	E–1–35
9 r	/// − /// ○ − // + /// 〃	0–99
10 l	/ − / − △⁰ − △⁰ − △¹ + 〃	E–1–243

6–4–84.6

form was carried out as heretofore explained. After No. 21 had acquired the ⊙ 28+ — △ 28+ reaction, the order shown in in the table was followed to determine whether or not the bird actually depended upon form difference. If it had a perception of form such as has been found to exist for size, then no marked change in the results should have occurred when ⊙ 28+ was replaced by a circle that circumscribed or inscribed the standard

triangle; and if the chick perceived three-sidedness or triangularity on the one hand and circularity on the other hand, there should have been no important modification of its reaction when the triangle was inverted.

TABLE 9

Form perception: ⊙ 28+ — △ 28+ *and* ⊙ 28+ — □ 28+

No. 21. Hatched: February 9, 1912. Sex: ♀

DISCRIMINATION	SERIES	DATE	RIGHT	WRONG	TIME
⊙ 38+ — △ 28+	12	April 20	10	0	4
⊙ 33+ — "	13	" 20	6	4	7
" — "	14	" 20	5	5	7
" — "	15	" 20	7	3	5
" — "	16	" 20	8	2	8
" — "	17	" 20	6	4	6
" — "	18	" 20	10	0	8
⊙ 28+ — "	19	" 20	10	0	5
⊙ 44+ — "	20	" 20	10	0	5
" — ▽ 28+ (△ inverted)	21	" 20	9	1	5
⊙ 28+ — △ 28+ (△ upright)	22	" 21	5	5	6
" — "	23	" 21	6	4	4
" — "	24	" 21	6	4	7
" — "	25	" 21	3	7	6
⊙ 33+ — "	1	" 21	10	0	4
" — "	2	" 21	10	0	4
⊙ 28+ — "	3	" 21	10	0	5
" — ▽ 28+ (△ inverted)	4	" 21	6	4	5
⊙ 15+ — △ 28+ (⊙ inscribed)	5	" 21	4	6	11
⊙ 28+ — "	6	" 22	8	2	10
" — "	7	" 22	8	2	7
" — "	8	" 22	10	0	6
" — "	9	" 23	8	2	5
" — "	10	" 23	8	2	5
" — "	11	" 23	9	1	4
" — "	12	" 23	9	1	7
" — "	13	" 24	9	1	5
" — "	14	" 24	9	1	4
" — □ 28+	16	" 24	5	5	5
" — "	17	" 24	5	5	3
" — "	18	" 25	3	7	4
" — "	19	" 25	6	4	4
" — "	20	" 25	5	5	6
" — "	21	" 25	8	2	6
" — "	22	" 25	5	5	4

The work on form thus indicated that the chick can discriminate between circles and triangles of equal area, and there are indications of a discrimination between circles and squares of equal area (witness series 21, April 25, table 9, and series 23, March 16, table 7), but with the application of control tests we have indications that this discrimination is on some basis

other than form. The results from the inversion of the triangle indicate that the basis of choice depends upon the unequal stimulation of different parts of the retina. When the extended base of the triangle is so placed as to stimulate the region of the retina which was formerly stimulated by the apex of the triangle, the chick becomes confused. Under the conditions of the present experiment, therefore, I am forced to conclude that the apparent reactions to forms are the result of keen perception of relative size differences.

The image formed on the retina of the chick is truly changed when the triangle is inverted by causing certain particular size reversals. The vertex, which was formerly uppermost, becomes interchanged with the base. The portion of the retina which was formerly stimulated by an extended line of light relative to the base of the triangle becomes stimulated by a mere point of light which is related to the vertex of the triangle. Inversion thus causes particular changes in the extension of the stimulated portions of the retina. It would seem, therefore, that the inversion of the triangle, though causing no change in form as such, produces these relative size differences which were evidently a source of confusion to the chick.

This control of inverting the triangle is a severe test, but it affords an excellent basis of comparison between the chick and other birds. Coburn made the same test with his crows without interrupting their correct choices. It therefore seems to be a legitimate and highly desirable procedure in form studies. In addition to circle-triangle discrimination, Coburn's crows discriminated a circle from squares and hexagons.

Coburn's crow study again furnishes from the birds the only results directly comparable with my chick results. Porter tried to study the perception of forms and designs in sparrows by using six form boxes made of poplar boards. He secured negative results but his method was weak. His birds were free to approach all of the boxes in one of which there was always food. There was no strong incentive for the bird to seek the correct box first because it was ultimately rewarded with food regardless of its first approach. Even had the results been positive nothing definite could have been asserted about the detail vision of the birds on account of the lack of any system of control.

Porter finds that the sparrow and cowbird can discriminate three horizontal lines or a black diamond from a blank card or from each other. No more weight can be attached to these results than could be given to his efforts to study form perception. On account of the widely differing method and apparatus a comparison of Porter's results with my own would be quite out of place.

The chick, then appears inferior to the crow in the matter of form perception. Where the crow appears to react by means of a relative form difference, the chick reacts to a circle-triangle situation on the basis of a specific form, or shape, difference. Responses to this specific form relation are much less readily acquired by the chick than responses to size differences.

CHAPTER VII

Flicker Perception

Inasmuch as the preceding studies with the chick indicated unequal visual sensitiveness to the spatial details of size and form, there arose the question of the importance of the rôle played by moving stimuli in the chick's vision. Movement, indicating danger or food, certainly is of great daily importance to the seeing animal. The remarkable ability of birds to discover worms has been plausibly attributed to the visual perception of movement. Might not the chick, then, demonstrate greater perceptual ability if a problem were presented demanding reactions to moving stimuli instead of stationary spatial differences?

To test the chick's sensitiveness to movement, the same dark room-discrimination method was employed. The stimuli presented were two 6 cm. circular openings illuminated as in the preceding experiments. The sources of these illuminations, however, were attached to an interrupting device by means of which the lights could be made to flash at different, though regular, intervals. The positive rate was adopted as once per second. The negative stimulus was a similar illumination flashing more rapidly.

To produce these interruptions a rotating disc of wood, one inch thick and four inches in diameter, was used. Bearing upon the circumference of the disc were two pairs of brass points, each pair being in the circuit of one of the source lamps. When one of these pairs of points bore upon a conducting surface, the circuit was complete; when it bore upon a non-conductor, the circuit was broken. The interruptions of the sources of illumination, then, depended upon an alternation, on the circumference of the disc, between a conductor and an insulator.

The wooden surface itself provided the insulation. For the conduction, thin bands of brass were firmly fitted and screwed to the circumference of the disc. Thus, a brass band extending half way around the circumference of the rotating disc would provide a complete circuit half of the time. In other words, the lamp depending for its illumination upon this band of brass would flash

off and on at regular intervals and the *on* interval would equal the *off* interval.

The brass points were grouped so that one pair bore upon the left, the other upon the right edge of the circumference of the disc. By attaching to the right edge, for example, a single band of brass equal to half the circumference of the disc, and to the left edge two bands of brass each equal to one-fourth of the circumference, the

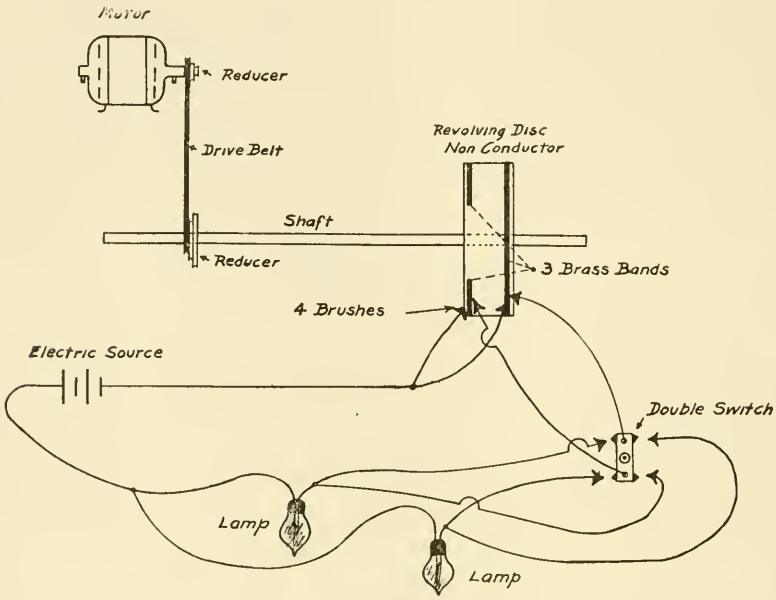

FIG. 7

Flicker apparatus. Schematic diagram showing how flicker stimuli were produced. The lamps were mounted on the movable carriages in the same source compartments described in Chapter III. By means of the double switch shown in the wiring scheme it was possible to alternate between the two lamps the slow and rapid flashes. The revolving disk is illustrated in this figure as much too large when compared with the illustration of the motor. The worm gear reducer, described in the text, is not shown in the illustration.

lamp connected through the right pair of points would have *on* and *off* intervals twice as long as the intervals of the other lamp. But, for any period of time, the total of the *on* or *off* time of the one lamp would equal the same of the other lamp. Similarly, the *on* and *off* flashes of the one lamp could be divided so that the intervals were one-third or one-fourth of the intervals of the other lamp.

A double switch was inserted in the connections so that the relative locations of the slow and rapid flashes could be reversed. The disc was driven by an "A.C." motor having a commercial rating of one-eighth horse power and twelve hundred revolutions per minute. The excessive speed was cut down by means of a worm gear reducer so that the rotation rate of the disc in most of the training tests was approximately once per second. The lamp interrupted by a single insulation, therefore, flashed *on* and *off* once every second. The rate was noted by recording with a stop watch the time elapsing during 50 flashes. Practically no variations were observable during the experiment.

Three driving pulleys of different sizes on the motor and three on the reducer made possible nine different speeds ranging between 50 revolutions of the disc in 162 seconds and 50 revolutions in 39 seconds. The rate of flashing, however, was increased two or more times depending upon the number of breaks on the circumference of the disc.

There is a definite objection to this method of measuring the interruptions, but for the present purpose, rough tests indicate that it may be ignored. Since each *on* interval heats the filament of the illuminating lamp, there is a tendency for the illuminated interval to last longer than the dark interval, and as the alternating intervals become shorter there would be a tendency for the total time of illumination to become greater than the total time of darkness. Yet it seems justifiable to ignore this possibility since the number of alternations is unchanged. Moreover, the glow of a filament after the "flash-off" seemed to be completely swallowed up by the opal flashed glass which served as a diffusing surface. It was also found that the tungsten lamps responded quite promptly to the off and on contacts and more promptly than the carbon lamps.

The training was begun with a one-three discrimination difference. The chick was trained to choose the slower rate. As in the spatial tests, a visual complex consisting of greater brightness added to the slower stimulus was presented at first and gradually changed to the single detail of flicker. Control of the luminous flux was gradually introduced by means of the upper illumination, and, in a few tests, by an additional 2 c.p. lamp located at the middle of the rear of the experiment box. Further controls were made after the habit became established, by irregularly varying

the source distances within a maximum of 40 cm., and by irregularly changing the shifter from left to right.

Chick 27 learned the problem so much more rapidly than the other subjects that it was evidently ready for the one-two relation before the others had acquired the one-three habit. In view of the possibility of the inequality in the two stimuli of the dark-light alternations, it was deemed desirable to reduce the difference rates towards the threshold. This would not only indicate the chick's threshold of difference, but also make less the possibility of different light-dark ratios serving as the basis of discrimination. Since early experience had emphasized the importance of concentrating the work as much as possible while the chicks were in satisfactory condition, further work with the other chicks was abandoned and the mechanism was changed for one-two discrimination. The change seems to have been fortunate, for the other chicks dropped off shortly, and chick 27 did not last long enough to complete more than an elementary phase of this particular task.

The details of the learning of this task by chick 27 are furnished in Chapter VIII where tables 15 and 16 present quantitatively several phases of behavior in addition to the criterion of correct choice per series of ten tests. Table 10 presents the discrimination conditions, reactions of the chick, and the controls employed.

To determine the specific rates of the two stimuli, the method was adopted of recording with a stopwatch the time elapsing during fifty flashes of either stimulus. Thus the time relation is given as 1–3 or 39″ – 13″ for the first twenty series. In series 21 the same relative rate was continued, 1–3, but the specific rates were made slower, the time for 50 flashes being respectively 54 and 18 seconds. The next change, introduced in series 30, January 10th, results in both relative and specific variation. The flicker relation becomes 1–2 and the respective periods for 50 flashes are 36 and 18 seconds. Slight changes were made in series 31, and in series 32 the effect of substituting without additional training, 80–40 and 20–10 periods was observed.

At the close of series 20, the controls had become rigorous enough to indicate that the flicker difference, or some aspect of it, was really perceived. On January 8, at the close of the 26th series, an unusually severe control was introduced. The upper lamp was changed from a 4 c.p. to a 16 c.p. illumination, and in addition,

TABLE 10

Flicker Perception

No. 27. Hatched: December 14, 1916. Sex: ♀

SERIES	TIME RELATION	+ RESPONSES	TIME	REMARKS	DATE
A	1–3 = 39″ – 13″ for 50 flashes	—	—	Preliminary; no regular procedure.	*1915* 12/21
B	"	—	—	Ibid.	12/22
1	"	5	70″	Ibid.	12/23
2	"	6	91	Ibid.	12/25
3	"	9	72	+ source 50; —, 250	12/27
4	"	5	15	+, 70; —, 230. Time taken from start to choice. Weak shock.	
5	"	7	3	+, 80; —, 220.	12/29
6	"	6	3	+, 100; —, 200.	12/29
7	"	7	4	+, 120; —, 200.	12/29
8	"	7	7	+, 130; —, 200.	12/30
9	"	4	?		12/31
10	"	9	16		12/31
11	"	8	15		1/1/16
12	"	5	23		1/1
13	"	8	17	+, 160; —, 200	1/1
14	"	7	15	Irregular variation between 150 and 200.	1/1
15	"	9	11	Ibid.	1/3
16	"	6	12	Right, 160; left, 200.	1/3
17	"	5	8	Right, 200; left, 160.	1/3
18	"	8	22	Right, 160; left, 200.	1/4
19	"	10	23	Ibid.	1/4
20	"	10	65	Right, 200; left, 160. Upper illumination.	1/5
21	1–3 = 54″ – 18″ for 50 flashes	7	14	Ibid. First 5 choices correct; time 12″.	1/5
22	"	6	33	Irregular variation. Upper illumination.	1/6
23	"	10	7	Ibid.	1/6
24	"	8	53	Ibid.	1/7
25	"	10	44	Right, 160; left, 200.	1/7
26 (1)	"	10	51	Right, 200; left, 160.	1/8
27 (2)	"	8	85	Upper illumination increased from 4 to 16 c.p. 4 c.p. lamp at top of middle of rear end of discrimination box. Errors in tests 3 and 10.	1/8
28 (3)	"	8	16	Ibid.	1/8
29 (4)	"	10	24	Rear light removed	1/10
30 (5)	1–2 = 36″ – 18″ for 50 flashes	7	14	Ibid. Errors in 3, 6, 7.	1/10
31 (6)	1–2 = 40″ – 20″ for 50 flashes	10	22	Ibid.	1/12
*32 (7)					
33 (8)	"	9	11	Ibid.	1/13
34 (9)	"	9	22	Ibid.	1/14
35 (10)	"	9	10	Ibid.	1/15
36 (11)	"	9	8	Ibid.	1/17
37 (12)	"	10	10	Ibid.	1/17
38 (13)	"	10	13	Ibid.	1/18
39 (14)	"	8	5	Ibid. Physically weak.	1/20
40 (15)	"	9	4	Ibid. " "	1/20

* Tests for specific or relative stimulus difference; see table 17, page 99, and accompanying text. The tests of series 32 (7) for evidence of relativity or specificity were distributed among the tests of subsequent series.

a 4 c.p. lamp was placed at the rear of the reaction chamber. This combination of illuminations made the experiment box quite light. The novelty interfered considerably as is indicated by the rise in the chick's time for choosing. Out of the entire series, however, the chick made eight correct choices.

Although the ultimate choices were not seriously affected by this introduction of novel conditions, the behavior of the chick was considerably modified. In the now relatively light reaction chamber there was considerable pecking and searching for food. Two or three attempts to jump out of the box were made. The error in test 3 apparently resulted from this pecking and meandering which continued longer than in the two preceding tests. Finally, the chick seemed completely to lose its orientation, for it searched the rear portion of the reaction chamber as much as the forward portion and entered the starting chamber once. The entrance into the wrong compartment was very similar to the entrance into the starting chamber. It did not appear as a definite choice and the chick was not shocked. In the beginning of the test, two careful approaches were made to the + compartment and the − compartment was apparently ignored. Then followed this random wandering, jumping, and pecking during which the chick seemed to loose its orientation.

The choices and behavior of chick 27 indicate that it was able to discriminate in this series of January 8th. The error in the last test of the series was apparently due to carelessness. The ten tests were made within forty-five minutes and only two hours earlier a series had been completed. The chick was "full" and probably had no vivid memory of punishment on account of its high percentage of correctness in past records. Carelesssness would be wholly natural at this stage of the work.

Even though it be conceded that the discrimination was satisfactory, there is another point in the behavior which I regard as having greater significance. In the detailed records (unpublished) of behavior in this series, it appears that chick 27 made an unusually large number of approaches to the edge of the electric compartments before venturing in. In addition to this, it "peeked over" towards the exit frequently tossing the head up as though looking at the top of, or over, the door. This suggested that the chick was relying upon the flux of light, for under the cross bar over the forward end of the experiment box, the additional illumi-

nations left a faint shadow which was regularly interrupted by the flashing stimuli. This resulted in a slight but regular alternation of light and shadow on the side of the electric compartments immediately above the exits. The interruption on each side, of course, depends upon the rate of its respective source. This indicates that the interruption of the flux was the basis of the flicker discrimination.

It thus appears that the chick readily discriminates, on some basis, at least a one-two flicker difference. These preliminary results convince me that here is a most promising field of investigation, especially with birds. Interrupted illuminations seem to have high stimulating value, making it relatively easy to direct the attention of the subject to the movement detail. With such stimuli the amount of aimless wandering seems to be considerably less than that which occurs with size and form stimuli.

It is hazardous to compare results obtained in this study from spatial and moving stimuli on account of the improvement in technique which clearly occurred during early stages of the investigation. Since flicker perception represents the last stage of the study it is possible, yet doubtful, that indications of increased responsiveness to moving stimuli are due to improvement in experimental technique. Possibility of individual differences should not be overlooked because objective data on flicker perception have been obtained from a single subject. Moreover, it is not possible to analyze satisfactorily the visual factors that were operative in the intermittent stimuli which were discriminated. On the other hand, subjective judgments support these preliminary data. It seems probable that we shall find the chick, and possibly the birds, more responsive to movement than to spatial factors. At any rate, these results indicate further possibilities of experimentation in animal behavior which ought to receive consideration.

CHAPTER VIII

Problem Learning

1. Analysis of the problem

The problem which the chick is expected to solve in the experiments that have been described in the preceding chapters may be regarded, for present purposes as divided into two separate tasks. The first task, learning the experiment box, is really a maze problem. The experiment box with its entrance box, discrimination chamber, electric compartments, exits, and nest boxes—is only one of various types of maze. The types of maze, commonly regarded as such, provide, more or less frequently, choices between *open* and *blind* passage ways. These open or closed passages are also present in the experiment box, but the two courses are permanent in the maze proper whereas the corresponding courses in the experiment box are interchangeable.

The principle of interchanging the open and closed passages of the experiment box demands the simultaneous display of two different stimuli, one signifying "this way out" and the other "exit closed." With the introduction of these two differentiating stimuli, there appears for the animal the second task of "interpreting the signs." Before the experimenter can study the animal's ability to interpret these signs—the power of distinguishing, for example, a 5 cm. square from a 3 cm. square or a circle from a triangle—it is necessary that the animal should have learned the principle of the experiment box or maze problem. The solution of this maze problem provides opportunity for noting the animal's method of forming habits.

As a matter of economy, the experimenter naturally presents the signs of "exit" and "closed" in appropriate relation to the course which the animal is required to follow in learning the initial maze task. The positive (+) sign meaning "exit" is displayed at the beginning of the training series in significant connection with the course prescribed for the animal to reach the nest box. Similarly, the negative (−) sign meaning "closed" appears contiguously with the forbidden nest box. With the exception of two preliminary or

preference series, such a procedure was followed while the chick's learning was being studied. The two phases of the general discrimination problem, therefore, cannot be sharply separated, but throughout the present chapter they will be regarded as distinct, and referred to as the *primary* and *secondary* tasks in the formation of the discrimination habit.

2. *Individual characteristics*

On December 21, work was started upon a problem in flicker discrimination with five chicks belonging to the fourth group. The chicks were at that time approximately one week old. The present remarks will be confined chiefly to three individuals, chicks 24 ♀, 25 ♀, and 27 ♀. The other two chicks shortly succumbed to the confinement of the laboratory. No. 24 was characterized in my notes as rugged and next in size to No. 25. No. 25, a White Plymouth Rock, remained from the first robust and oversized.[1] No. 27 was somewhat undersized. Chicks 24 and 27 were Barred Plymouth Rocks.

On the first day each of the chicks was allowed to escape ten times at either exit. This was the first preliminary series. The positive stimulus was displayed first at the left, and thereafter alternately at the right and the left. Six tests were made in the morning and four in the afternoon. During the morning tests the exits were wide open. In the seventh test, the doors were nearly closed and thereafter were completely closed. In the eighth, ninth, and tenth tests and in the series following, the door of the exit was opened as soon as the chick had chosen the compartment.

On December 22, the second preliminary series was similarly started. Four tests were given in the morning, three in the afternoon, and the remaining three in the morning of the following day. In these two preliminary series, no preference for either of the stimuli was noticeable. Table 11 summarizes the choices with reference to the stimuli which, in subsequent training, became plus (+) and minus (−) signs. The table indicates that there was no preference for either stimulus.

Certain right or left preferences, on the other hand, are to be found. Table 12 summarizes these tendencies. No. 27 shows a distinct preference for the left side but chicks 24 and 25 manifest no preference.

[1] In comparison with the chicks of the group.

In view of the fact that No. 27, in the secondary task, shows learning superiority over chicks 24 and 25, these initial preference differences are suggestive. Some of the peculiar types of native behavior manifested by these three chicks appear in table 13. Reference to the table indicates a close similarity between the behavior of chicks 24 and 25 which differs some-

TABLE 11

CHICK	STIMULUS CHOSEN	
	+ Stimulus	− Stimulus
15	11	9
23	11	9
24	9	11
25	10	10
27	12	8

what from the behavior of No. 27. The average time of escape for chicks 24 and 25 during these preliminary series is respectively 8.0 and 8.6 seconds; for No. 27, it is 21.7 seconds or two and one half times as great. Further similarities and differences may be noted in the tendencies of chicks 24 and 25 to waver between choosing the right and left sides, and the tendency of No. 27 to stick persistently, after the first two tests, to left choices with only two variations appearing in tests 10 and 13.

TABLE 12

CHICK	RIGHT CHOICES	LEFT CHOICES
15	13	7
23	15	5
24	10	10
25	10	10
27	4	16

On the other hand, table 13 suggests close similarity among all three chicks with reference to the stimuli. The letter following the number of the test indicates the side on which the + stimulus appeared. The columns headed "choices" show which stimulus and which side was chosen in any test by each individual. As three times is the greatest number of successive + or − choices, it is quite evident that neither of

the stimuli was an original factor determining the choosing. Thus, among the individual native tendencies that may have existed with these different chicks as influences in forming the habits demanded by this problem, the tendency of right or left choosing appears to be most pronounced.

TABLE 13

Preliminary Series

TESTS	NO. 24 ♀		NO. 25 ♀		NO. 27 ♀		DATE
	Choices	Time	Choices	Time	Choices	Time	
1 l	+ l	24	+ l	6	− r	24	
2 r	− l	22	− l	25	+ r	61	
3 l	− r	9	+ l	4	+ l	33	12/21
4 r	− l	9	− l	4	− l	12	a.m.
5 l	+ l	5	+ l	5	+ l	9	
6 r	− l	4	+ r	5	− l	5	
7 l	− r	4	− r	5	+ l	10	
8 r	+ r	6	+ r	31	− l	9	12/21
9 l	− r	7	+ l	9	+ l	6	p.m.
10 r	− l	3	+ r	10	+ r	25	
11 r	+ l	6	− l	5	− l	7	
12 l	− r	13	− r	10	+ l	26	12/22
13 r	+ r	6	+ r	9	+ r	33	a.m.
14 l	− r	4	− r	10	+ l	22	
15 r	− l	3	+ r	7	− l	12	12/22
16 l	+ l	7	− r	9	+ l	51	p.m.
17 r	+ r	11	− l	4	− l	11	
18 l	+ l	5	+ l	9	+ l	25	12/23
19 r	+ r	8	− l	11	− l	26	a.m.
20 l	− r	8	− r	7	+ l	27	
Average time		8.0		8.6		21.7	

With the twentieth test the two preliminary series ended and thereafter the training series began. At this point the chicks, instead of being allowed to escape where they chose, were required to escape from the compartment where the + stimulus was displayed. The animals were aided in releasing the tripping device, because they lacked sufficient weight; but the experimenter could not cause a release of the exit door until the chick stood in the proper place, when a pull on the silk line released the tension of the lifting spring so that the

chick's weight released the trip. The chicks readily learned to approach close to the door of the exit which brought them upon the tripping device. As the weight of the growing chicks increased the exit automatically opened when they stepped on the tripping device. The electric shock was not introduced until the fourth training series.

In the first two series of training, the visual stimuli differed with respect only to flicker. This was a period of training during which the chick's task was chiefly to learn the primary problem. Visual discrimination was encouraged at the beginning of the third series by presenting stimuli differing with respect to several factors. This third series may be regarded as transitional between the primary and secondary tasks. It is the last series during which the time record was made from start to exit. In subsequent series the time record represents the number of seconds elapsing between entrance to the discrimination chamber and choice of a compartment. If the choice happened to be wrong (−), therefore, considerable time might subsequently elapse beteeen the choice and the escape, whereas the time elapsing between choice of the + compartment and escape was regularly measurable only in fractions of a second. The maze problem, it was assumed, was sufficiently learned at the end of the third series to permit introduction of the secondary task of discrimination and correct choosing.

For further comparison of the characteristics of the chicks during the preliminary series, table 14 is presented. This table indicates the number of times right or left sides and + or − stimuli were successively chosen throughout the first two preference (preliminary) series. Frequency of change is greater as the number of successive choices of the same side or the same stimulus is smaller. The total number of changes is indicated by the number in the first column which stands on the same line with the last record in any other column. For convenience the total number of changes in choice of sides or stimuli is indicated at the bottom of each column. Persistence in choosing is assumed to be greater as the number of recorded changes is smaller. In other words, the fewer the changes recorded for any individual, the greater is the indication of its persistence in following up a particular line of response.

TABLE 14

Initial Preferences

Computed from records in the two preliminary series

FREQUENCY OF CHANGE	NO. 24 ♀		NO. 25 ♀		NO. 27 ♀	
	Side	Stimulus	Side	Stimulus	Side	Stimulus
0	l 2	+ 1	l 5	+ 1	r 2	− 1
1	r 1	− 3	r 3	− 1	l 7	+ 2
2	l 3	+ 1	l 1	+ 1	r 1	− 1
3	r 3	− 2	r 1	− 1	l 2	+ 1
4	l 2	+ 1	l 1	+ 2	r 1	− 1
5	r 3	− 2	r 5	− 1	l 7	+ 1
6	l 2	+ 1	l 3	+ 3		− 1
7	r 1	− 1	r 1	− 2		+ 2
8	l 1	+ 1		+ 1		− 1
9	r 2	− 2		− 1		+ 3
10		+ 4		+ 1		− 1
11		− 1		− 2		+ 1
12				+ 1		− 1
13				− 2		+ 1
14						− 1
15						+ 1
Total number of changes	9	11	7	13	5	15

TABLE 14A

Initial Preferences

Computed from records in first three training series

FREQUENCY OF CHANGE	NO. 24		NO. 25		NO. 27	
	Side	Stimulus	Side	Stimulus	Side	Stimulus
0	r 2	+ 1	r 2	+ 1	l 1	− 2
1	l 1	− 3	l 1	− 3	r 3	+ 1
2	r 3	+ 1	r 3	+ 1	l 4	− 2
3	l 1	− 3	l 2	− 2	r 1	+ 1
4	r 2	+ 3	r 4	+ 2	l 6	− 1
5	l 2	− 1	l 2	− 6	r 2	+ 5
6	r 2	+ 1	r 2	+ 2	l 1	− 2
7	l 2	− 1	l 1	− 2	r 6	+ 2
8	r 2	+ 2	r 1	+ 1	l 2	− 1
9	l 3	− 1	l 1	− 1	r 1	+ 5
10	r 2	+ 1	r 1	+ 1	l 1	− 1
11	l 1	− 2	l 1	− 1	r 1	+ 7
12	r 1	+ 5	r 4	+ 1	l 1	
13	l 1	− 1	l 1	− 1		
14	r 4	+ 1	r 1	+ 5		
15	l 1	− 1	l 1			
16		+ 2	r 1			
17			l 1			
Total number of changes	15	16	17	14	12	11

Table 14a is similarly presented to show evidence of preferences during the first three training series. Perhaps the outstanding feature of the behavior represented in table 14a is the change in preference of No. 27 from side to stimulus. This change is noticeable at the beginning of the third training series when the two flicker stimuli were made more conspicuously different by the addition of other visual differences. With the introduction of a discriminable visual complex there occurred a noticeable change in the behavior of No. 27, indicated by six side changes and only three stimulus changes, whereas the behavior of No. 24 and No. 25 did not noticeably change. As indicated in tables 14 and 14a, No. 27 made comparatively few changes in choice of sides and many changes in choice of stimuli throughout the two preliminary series and the first two training series. From the beginning of the third training series this relative preference for side suddenly ceased and persistence in choosing the + stimulus became dominant. In the last 13 choices recorded for No. 27 in table 14a, only one stimulus choice is − (wrong).[2]

3. Quantification of the learning process

In learning the primary maze task there are certain details of behavior which are fairly measurable. The possibility of quantitatively measuring these constant evidences of learning was suggested when certain gradual changes were observed in the chick's behavior towards the exit. During the preliminary series, while the exits were open, there is little reason for suspecting that the stimuli were of any significance to the chick. After the exits had been closed in these preliminary series, the stimuli became a factor attracting the chicks to the electric compartments but the exit door was opened as soon as the compartment was entered. The new requirement in the training series was to go into the compartment towards one of the stimuli, to turn *outwards* at the furthermost end of the electric compartment, and to step upon the tripping device close to the unopened exit in a dark wall. The door of the next exit was discernable during preliminary series from the other portions of the wall, but much less clearly than in daylight vision.

[2] Two + choices occurred at the end of the preceding series.

A significant change in this learning process occurred when the chick, moving in the direction of the stimulus, turned aside and approached the exit with that peculiar side-to-side-head-bobbing-and-neck-stretching behavior that is characteristic of a curious old hen. Pushing close to the exit, the chick would squat lower and lower with repeated upward bobs of the head and stretching of the neck as though in anticipation of the upward movement of the exit door. As the door opened, admitting to the relatively dark experiment box a cheerful flood of light, the chick would commonly express its satisfaction by means of the familiar hovering twitter. Where food was a rewarding motive, the hovering twitter was often replaced by a clearly distinguishable feeding twitter, and frequently the expressed satisfaction was a combination of the two types of vocalization.

From the detailed records of behavior in each individual test,[3] table 15 has been computed as a measurement of the learning process in relation to the electric compartments. The table presents quantitatively the changes in the behavior of the chicks with reference to the + responses, the outside corners, the stimuli, and the inside corners. The first column merely represents the series of ten tests to which any of the quantitative measurements belong. The last column indicates the date on which the series was made. The table further presents for comparison the records of chicks 24, 25, and 27. The four columns arranged under each individual chick are arranged to show in any series (1) how many correct (+) choices were made, (2) how many times the outside corners were approached, (3) how many times the stimuli were tried as a place of possible exit, and (4) how many times the inside corners were similarly tried. For my method of collecting these data, the reader is referred to Chapter IV, pages 37 and 38.

1. If the chick profits by preceding experiences in this maze task, tendencies toward certain definite numerical limits should appear in each of the four columns presented in table 15. The number of correct choices, if there be no preference for either stimulus, should start at approximately five. Advance in the series should ultimately bring an increase in this number of correct choices which approaches ten as a limit.

[3] For method of recording this behavior see page 36.

Exclusive of series 3, as reported in table 15, there is very little evidence of learning before series 10. The high record in

TABLE 15

Measurement of Learning in terms of Correct (+) Responses, Trials at Outside Corners, Trials at Stimuli, and Trials at Inside Corners

SERIES	NO. 24 ♀				NO. 25 ♀				DATE
	Correct	Outside	Stimuli	Inside	Correct	Outside	Stimuli	Inside	
1	4	26	23	6	4	37	22	8	12/23–24
2	5	25	20	7	3	18	11	5	12/25
3	8	15	11	6	7	26	12	4	12/27
4	5	17	6	4	5	18	9	1	12/28
5	5	31	10	4	6	22	18	3	12/29
6	3	25	5	1	8	15	15	5	12/29
7	6	29	11	3	5	18	13	1	12/30
8	5	26	5	3	3	19	1	1	12/30
9	6	17	6	5	5	21	6	1	12/31
10	5	14	1	3	8	14	4	2	12/31
11*	6	12	2	3	3	24	0	3	1/1
12	6	22	1	3					
	No. 27. ♀				Average				
1	5	22	21	6	4.3	28.3	22.6	6.66	12/23–24
2	7	25	8	6	5.0	22.6	13.0	6.00	12/25
3	9	20	9	6	8.0	20.3	10.6	5.33	12/27
4	5	19	5	3	5.0	18.0	6.6	2.66	12/28
5	7	20	6	4	6.0	24.3	11.3	3.66	12/29
6	6	19	5	1	5.6	19.6	8.3	2.33	12/29
7	7	16	6	3	6.0	21.0	10.0	2.33	12/30
8	7	18	4	2	5.0	21.0	3.3	2.00	12/30
9	4	20	5	3	5.0	19.3	5.6	3.00	12/31
10	9	11	2	4	7.3	13.0	2.3	3.00	12/31
11*	8	14	3	4	5.6	16.6	1.6	3.33	1/1
12	5	19	2	1	5.5	20.5	1.5	2.00	1/1
13	8	14	3	8					1/1
14	7	16	0	3					1/1
15	9	12	0	3					1/3
16	6	17	2	4					1/3
17	5	20	0	2					1/3
18	8	14	0	0					1/4
19	10	12	0	3					1/4
20	10	11	0	0					1/5
21	7	14	1	1					1/5
22	6	14	0	0					1/6
23	10	11	1	2					1/6
24	8	10	0	0					1/7
25	10	10	0	0					1/7
26	10	10	0	0					1/8

* Brightness reversals at beginning of series 11.

series 3 is probably due to a combination of greater relative brightness with the + stimulus for the purpose of hurrying the discrimination. Although brightness reversal was not

introduced before the beginning of series 11, it is improbable that the brightness factor served as a basis of discrimination in more than two or three series after the third. The brightness difference was rapidly reduced and in view of the brightness threshold as determined by Lashley (reference 21: Chapter 2), this factor would have been nil after series 5. The maximum number of correct choices in a series is first reached by chick 27 in series 19. Additional comment upon the appearance of discrimination evidence will be postponed for discussion in connection with the shock as a motive in the learning.

2. The number of correct choices offers a measurement of progress in forming the discrimination habit or secondary task. In the primary or maze task a more reliable unit of measurement to denote progress is the elimination of useless movements. Change in the number of trials at the outside corners offers one means of determining improvement in the experiment box. To indicate improvement, the number of trials at the outside corners must begin relatively high and decrease with ten as the minimal limit. The larger numbers in the early series may be due either to the chick's failure to step upon the proper portion of the tripping device, even though the approach is the + exit (outside corner), or to choices of the − compartment and consequent trials at the − exit.

Improvement with respect to outside corners is generally noticeable from the first. While each individual has "bad days," the table indicates a general tendency towards decrease. The average for the three chicks suggests that the curve representing the number of outside corner trials would tend to become a fairly straight line gradually descending towards the limit if a sufficiently large number of individuals were tested. This limit is reached by chick 27 for the first time in series 24 and maintained throughout three successive series.

3. Similarly, the number of trials at the stimuli must be relatively large at the beginning. As the chick learns its task, however, the unsuccessful attempts at the stimulus decrease with considerable rapidity. Chick 25 first eliminates all attempts at the stimulus in series 11. Chick 27 next reaches the same stage in series 14. It is interesting to note that perfection in this particular negative task is attained more rapidly than in the positive task of outside corner trials.

4. The remaining factor in this primary learning process is the number of approaches to the inside corner. The minimal limit denoting perfection in this task, like the preceding, is zero. This process of eliminating inside corner trials is also a negative task and perfection, again, is approached relatively early. Several of the first ten series contain only a single inside trial. Absolute perfection, however, is not reached by any chick before series 18.

The effect of the preliminary series is suggested when one compares the records of inside approaches with those of outside and stimuli approaches. The inside trials in series 1 are slightly less than one fourth the outside trials and one third the stimulus approaches. The chicks, it would seem, had acquired in the preliminary series a tendency to go to the outside rather than the inside corners. Turning to the averages, it appears that the outside corners are approached, on the whole, a greater number of times than the stimuli and the inside corners combined. This correctly indicates that the chick, in turning from an outside corner, often went to some other part of the box than my list here indicates. Often the turn was towards the rear of the experiment box followed by a return. Sometimes it was a fairly direct course from one outside corner to the other. Changes from outside corners to other parts followed failure to make an adequate adjustment to the tripping device at the first exit approach and the chicks frequently made several exit attempts before effecting the release of the exit door.

The decline in the number of stimulus approaches is the most abrupt change that appears in any of the four criteria. This is partially due to the fact that the number starts nearly as high as that for outside approaches, but the latter cannot go below ten whereas the stimulus trials have zero for a limit. The high beginning in number of stimulus trials is probably due to the fact that the stimuli are the attracting factors calling the animal to the exit end of the experiment box. Efforts directed toward the stimulus are therefore more to be expected at first than efforts at the inside corners. The most significant feature in these stimulus records, however, is the abrupt and rather permanent decreases that occur.

More suggestive, perhaps, than these numbers representing total approaches throughout a series, is a measurement based

TABLE 16

Measurement of Learning in Terms of Correct (+) Responses, First Trials at Outside Corners, First Trials at Stimuli, and First Trials at Inside Corners of Electric Compartments

SERIES	NO. 24 ♀				NO. 25 ♀			
	Correct	Outside	Stimuli	Inside	Correct	Outside	Stimuli	Inside
1	4	2	6	2	4	6	4	0
2	5	4	6	0	3	10	0	0
3	8	5	5	0	7	5	5	0
4	5	9	1	0	5	6	4	0
5	5	8	2	0	6	2	8	0
6	3	7	3	0	8	1	9	0
7	6	4	6	0	5	0	10	0
8	5	8	2	0	3	10	0	0
9	6	8	1	1	5	9	1	0
10	5	7	1	2	8	8	1	1
11	6	9	1	0	3	10	0	0
12	6	10	0	0				
	No. 27. ♀				Average			
1	5	4	5	1	4.3	4.0	5.0	1.0
2	7	10	0	0	5.0	8.0	2.0	0.0
3	9	7	3	0	8.0	5.6	4.3	0.0
4	5	9	1	0	5.0	8.0	2.0	0.0
5	7	9	1	0	6.0	6.3	3.3	0.0
6	6	9	1	0	5.6	5.6	4.3	0.0
7	7	7	3	0	6.0	3.6	6.3	0.0
8	7	9	1	0	5.0	9.0	1.0	0.0
9	4	10	0	0	5.0	9.0	0.6	0.3
10	9	8	1	1	7.3	7.6	1.0	1.3
11	8	10	0	0	5.6	9.6	0.3	0.0
12	5	10	0	0	5.5	10.0	0.0	0.0
13	8	6	0	4				
14	7	9	0	1				
15	9	9	0	1				
16	6	9	0	1				
17	5	8	0	2				
18	8	10	0	0				
19	10	7	0	3				
20	10	10	0	0				
21	7	10	0	0				
22	6	10	0	0				
23	10	8	0	2				
24	10	0	0	0				
25	10	0	0	0				
26	10	0	0	0				

upon *first* approaches to these various departments. In table 16 appear measurements computed upon such a basis.

At the beginning, these *first* approaches suggest, the stimuli

and outside corners are close rivals for the majority of trials. Ignoring certain fluctuations, there is a tendency for the outside corners to gain the supremacy after the first series. At no time are the first choices of inside corners at all prominent. Some of the fluctuations which are noticeable in the table will be discussed in connection with the effects of punishment upon the learning process.

4. Relation of punishment to learning

Reflections by certain observers upon the method of punishment led me casually to note its significance in the learning process. In general, my judgment concerning the method is that it may be made most pernicious in animal training. On the other hand, it is also a valuable supplement. Whether pernicious or meritorious depends upon the intelligence with which it is applied. If the experimenter is careless in its application the results of previous training may be swept away in a flash. If he shows wisdom in its application he can certainly increase the efficiency of his technique.

My lesson on the pernicious possibilities of punishment came early with the first group of chicks. In my eagerness for results I endeavored to hurry the discrimination habit by severe[4] and repeated shocking for wrong choices. The discrimination was easy, as subsequent results proved, but the number and severity of shocks were excessive. The result was inevitable. The most sensitive chicks became so fearful of the electric compartments that they only cowered and chirred in the rear of the discrimination chamber. Thus the subjects which continued to work were only the less sensitive animals. It was not a question of the difficultness of the discrimination problem, therefore, but a lack of intelligence in the application of the electric shock that brought disastrous results.

Subsequent observations have encouraged the belief that the value of the shock cannot be determined in terms of ease

[4] The term "severe" should not be interpreted as "painful." The severest shock that could be administered is little more for the human hand than a tickle. The outstanding feature of the shock as a means of punishment is probably its suddenness and unexpectedness. It is very probable that a chick which chirrs, flees from the shock, and cowers in a far corner is comparable to a chick which behaves similarly when a flying hawk suddenly appears. It is not always pain, no doubt, that calls forth escape behavior.

or difficultness of discrimination, but upon the basis of an optimum dependent upon the sensitiveness of the animal. Experimental data can determine this optimal punishment within the limits of the distribution of sensitiveness in any type of animal. One should expect this optimum to vary not only with the different types of animals, but also with different individuals and at various stages of individual development and progress.

In general, the chick tends to acquire a fairly definite succession of acts in arriving at the appropriate conclusion of the series. In this series there may be a choice which involves entrance, for instance, into the left compartment. If the left compartment happens to be +, the trial at the left exit may culminate the series. If the left compartment, on the contrary, is −, the series of acts must be continued until the right exit is tried. A certain definite "set" in serial acts tends to occur, making certain errors a natural consequence.

In terms of neural organization, an integration occurs of which a portion must be disintegrated and another portion must be retained and further stamped in. That portion of the "set" which corresponds to the error must be eliminated and, if possible, without destroying the appropriate portion of the "set." Thus, the way to eliminate the error portion of the series is to shake up the "set" at the place corresponding to the error, but without shaking up the appropriate portions of the "set." A shock, then, just severe enough to have only an immediate effect is the desirable degree of punishment. Its effect should not spread beyond the error portion of the neural organization, and yet it should be efficient at that particular point. An excessive shock may uproot the entire "set" and destroy all progress that previous training has fostered. The optimal punishment, then, should be just enough to disintegrate the undesired act (or acts) of the series but not enough to extend beyond that one element in the series to other valuable acts.

My method of training chicks of the early groups was merely to adopt what appeared to be a satisfactory shock (tickle) and accept the chance results it brought. With the three chicks discussed in this paper, particular attention was given to the effect of the shock. It appeared that the heavier chicks, 24 and 25, reacted more strenuously than the lightest, No. 27.

The present observations are not presented as in any way contributing to the problem of the relative merits of punishment and reward. They are presented for the sole purpose of showing that the problem can not be disposed of after the dogmatic method of some writers nor on the basis of the superficial study of certain experimenters. The problem is introduced in this connection because of its obvious relation to the learning process.

The shock, in my study, was introduced for the first time at the beginning of series 4. The coil was set at 6 and connected with a Columbia Dry Cell No. 6. The felt pad on the floor of the entrance box was water soaked and the floor of the discrimination chamber was covered with black dry cardboard. Under these conditions, my records for No. 24 in test 4 and for No. 25 in test 5 of this series contain this interpretation: "shock seemed to tickle;" for No. 27 in test 5, where there were three possibilities of shock, "no response."

The coil was now set at 5 and the floor conditions were left unchanged. Under this new arrangement, No. 27 made no perceptible response to the closing of the electric circuit.

In the beginning of series 6, the cardboard on the floor of the discrimination chamber was water soaked. Following this change, No. 27 made no obvious response in test 3; in test 4 it turned back immediately upon the administration of the shock, but there was no violent response. The choices of No. 25 were fortunate and it escaped with very little punishment in this series. No. 24 was shocked every time an approach was made into the wrong exit, the total number of shocks being ten for seven wrong choices.

The behavior of the three chicks clearly indicates that No. 27 was least sensitive to this particular shock. It now remains to note whether or not there is evidence of a correlation between the responses to shocks and the disturbances in the methods of responding to the problem; and furthermore, to determine if possible the relative effects of such disturbances.

Responses to the electric current were so slight that little or no effects in series 4 or 5 may with reason be expected. In test 6, the shock having been increased, possible effects may be noted. The number of correct choices by No. 24 suddenly drops to 3. That this change is due to a "shaking up" is suggested by radically different types of behavior appearing

in each individual test after the third. The individual records in detail cannot well be presented, but reference to them convinces me that these changes in behavior are related to the occurrence of the shock. The "shaking up" in each test where wrong choices occur clearly affects subsequent behavior.

No extraordinary results for No. 24 appear in table 5 prior to series 10 in which the number of stimuli approaches drops off abruptly. In series 9 and 10, as presented in table 6, a change appears with reference to *first* approaches to inside corners. The single *first* inside approach of series 9 occurs in test 9 following a shock for a wrong choice. My notes in this connection read:

> No. 24 is becoming wary of shocks; has not reached stage, however, of No. 27. No. 24 is very sensitive; jumps and screams slightly at each punishment; continues into compartment with sudden haste and jumps when shocked. . . . . No. 24 is beginning to appreciate that shock 'means something;' No. 27, in addition, seems to be coming to an understanding of *what* the shock means.

In connection with test 10, in which an error also occurs, the following observations are reported:

> Approached – compartment very cautiously; entered cautiously after inspecting compartment from two points of view,—one near the partition, the other near the right side of the experiment box; stopped on receiving very brief shock (did not jump or scream); same touch of key was repeated (no jump or scream); turned out from right side; moved deliberately but continuously in a semi-circle and entered – compartment near partition; started toward left front corner (inside), but stopped 6 or 8 cm. from the beginning of the electric wires and retraced the distance entered; turned sharply around end of partition, entered + compartment, and crossed diagonally to + exit.

In series 10, No. 24 made two *first* approaches to the inside corners. One of these responses occurs in test 3 following a shock, the other in test 5 where the inside corner of the compartment was first approached but followed by a retreat, a – choice, and a shock. During the latter half of series 10, it was observed that the chick became "hasty" in making choices.

Turning now to the tabulated records of No. 25, table 5 shows for series 8 a sudden drop in the number of stimulus approaches. Here, it appears, is the point where the severity of the shock succeeded in taking the chick's attention away from the stimulus. The punishment, as that for No. 24 in series 9, tears up a "set" by commanding attention that was

formerly given to other factors. That the effects of the punishment in the training of No. 25 were too far-reaching, is indicated by the number of + responses in series 8 to 11 inclusive. Series 10 is the only one where a high percentage of correctness appears, but my notes suggest that the record is misleading. The notes on this point read: "The high + record is not confirmed by the behavior . . . .; takes either compartment hastily without trying to get a cue." The time record confirms the notes. For the series, the average time for choosing was 3.4 seconds. The maximum time in any one test was 5 seconds.

For chicks 24 and 25, therefore, the behavior indicates that the effects of the shock were too far-reaching. There occurs such a shake-up in the responses that the chicks get even further from the solution of the discrimination problem than they were several series earlier. For No. 27, on the contrary, the shaking-up does not appear to have such negative results.

For No. 27 it is difficult to point to any abrupt changes in the measurements provided by tables 15 and 16. In general there seems to have been a fairly regular development of the discrimination habit. Instead of taking suggestive numbers from the tables, therefore, I shall refer chiefly to my notes and details of behavior.

The first suggestive change in the behavior of No. 27 occurred in series 9. The following note appears in connection with test 8 in which there is an error and approximately three times as much activity recorded as in any other single test of the series:

> Behavior indicates that No. 27 has become upset by punishment; it did not know what to make of the two shocks this time. For some inexplicable reason it seemed to want to go to − exit, but after shock, was wary of both compartments; frequently crowded up close but would not risk stepping in. Seems to be a new stage in learning; recognizes that danger (shock) is connected with these escape compartments. No other chick has reached this stage.

For test 9, the notes read:

> Very careful; behavior bears out above suggestion regarding shock; approached electric compartment very carefully; stopped the instant the shock came, turned out, and went directly to the + exit. Suggests that shock has become a sign that 'this is wrong compartment; other one is right.'

The notes in connection with test 10 are similar:

Again confirms above notes; each movement was "deliberate;" careful looking in direction of stimuli; inspected – compartment thoroughly from two positions close to wires, one being near partition, other near outside of box: + compartment next inspected and entered very short distance; chick stopped and looked carefully again, then continued slowly but steadily to the exit where it escaped. The first evidence that No. 27, or any other chick, considers stimuli in choosing; doubtful if chick understands problem, but it is approaching a solution.

These observations occur at the end of a series in which the chick made the fewest correct choices during its entire period of training.

In series 10, chick 27 made 9 correct choices. An error occurred in test 2. A note in explanation of this error says:

See notes for series 9 (given above); confirms observations there recorded. Concerning the series, the notes read: The same carefulness and deliberation appear throughout this series. The bird has evidently discovered some factor in the last thirteen tests which enables it to respond appropriately.

In connection with series 11, it was observed:

The behavior indicates that it recognizes the stimuli, or some accompaniment, as representing a signal for choosing; the recognition, as such, however, does not imply that the "signs" are fully comprehended; the discrimination habit is started and it must now be "worn in" by repetition. The problem seems to be recognized and the chick is putting forth an effort to solve it. The chick is in a very interesting stage of learning.

An interesting comment comparing the stages of learning attained by chicks 24 and 27 appears in my notes at the close of series 11.

No. 24 seems to have reached a stage attained by No. 27 at the close of series 9. There is now a tendency to turn back after a shock instead of continuing to exit; the shock is beginning to have a definite meaning. The significance of the shock, however, is not so great for No. 24 as it was for No. 27 in the last three tests of series 9. No. 24 does *not always* turn back on receiving the shock. No. 27 has not failed to turn back promptly since test 8, series 9. This is probably due to the fact that the same intensity of shock affects No. 24 more than No. 27. The shock seems to be optimal for No. 27 but too severe for No. 24.

The low number of correct choices by No. 27 in series 12 is probably due to the introduction of new brightness conditions for control purposes. Errors occurred in tests 1 and 7–10. These new features were added only in tests 7–9. It is questionable, also, whether an error should be charged in test 10. After comparing both stimuli, the chick went to the rear right

corner of the discrimination chamber. From this point it advanced to a position close to the − compartment, and in turning, stepped upon the entrance edge of the electric wires, but stepped off immediately and went directly to the + compartment which was promptly chosen. An error recorded for test 6, series 14, is likewise questionable.

The records of No. 27 in series 12–14 were made in a single day (Saturday). The chick was allowed to rest over Sunday. On Monday, series 15–17 were completed. In connection with the 15th series it was noted that "the characteristic behavior of Saturday persisted over Sunday." In series 16 the chick seemed to become careless prior to the last three tests, in which the choices were carefully and correctly made. Preceding shocks for wrong choices, it appeared, had encouraged greater care which, it was hoped, would continue throughout series 17. During the first five tests carefulness did continue and the responses were correct except in test 1. But during the last half of the series, four wrong choices occurred.

In series 17, the chick began for the first time to make the feeding-hovering twitter during the choosing period prior to its entrance into the electric compartment.

5. *Summary*

Natively, No. 27 was found to differ from chicks 24 and 25 in manifesting a persistent side preference and in responding more slowly. Throughout the first three training series, No. 27 maintains an average time for + choices practically equal to that of the other chicks. In series 2 and 3, the − choices of No. 27 are notably low and the average time involved when these errors occur is much higher than that for the other chicks. On the whole, it seems that in No. 27 there was a relatively high persistence combined with a relatively low variability. These characteristics seemed to remain at a fairly constant level throughout the period of experimentation. Alternation between moderate persistence and high variability was characteristic of chicks 24 and 25. The former type of behavior probably predominated in No. 24, the latter in No. 25. Under the conditions of this experiment, No. 27 was the most teachable subject, although in certain phases of the tasks presented it it did not always excel.

The maze habit was found to be measurable with reference to approaches to (1) outside corners, (2) inside corners, and (3) stimuli. Measurability of the discrimination habit was based chiefly upon + and − choices, but certain qualitative criteria were found to be highly suggestive of stages of learning.

The method of punishment for wrong choices was found to be both valuable and pernicious. If intelligently used, it seems, on theoretical grounds at least, to be highly valuable; if carelessly applied, punishment can radically interfere with learning. It is my conclusion, although the present study does not prove it, that the optimal shock is dependent more upon the sensitiveness of the animal than upon the ease or difficultness of discrimination.

For adequate descriptions of animal behavior in problems of discrimination, these results indicate that finer criteria than right and wrong records should be seriously considered. Detailed analysis of the behavior of No. 27 reveals, at least in one place, evidence of discrimination that is not apparent from gross records of right or wrong choices. Furthermore, the common practice of presenting to many or to all subjects precisely identical experimental conditions should be critically considered. Evidently there is an optimal degree of punishment, for example, which varies with individuals. It is desirable at least that mass results be checked with intensive individual observations.

CHAPTER IX

Ideational Behavior

The question whether the chick can react on the general basis of triangularity-circularity, largeness-smallness, or rapidity-slowness was suggested primarily by the different positions regarding ideation taken by Thorndike and Cole. Their divergent conclusions concerning the evidence of ideas furnished by infra-human behavior have stimulated considerable subsequent work. The possibility of my study furnishing data for this problem is suggested in the question: does the chick discriminate on the basis of specific stimuli, or on the basis of relative stimulus difference?

Aside from its ideational bearing, this question has considerable significance also for infra-human threshold experimentation. If it be found possible to train an animal consistently to choose on the basis of relative stimulus difference, it would seem desirable to present, interspersed with the training stimulus setting, other pairs of stimuli differing proportionately by greater and less amounts both above and below the training pair. Such a procedure would tend to distribute the effect of training more evenly through a sequence of daily series. In threshold studies it would make possible a more constant vividness, in the awareness of the subject, of the problem which is presented. In the end, the experimenter could be more certain that the failure of his subject to respond appropriately was due to the threshold limit and not to indifference to the demands of the problem.

Because the material that has been gathered on this question of relativity or specificity of chick reactions is wholly incidental to the primary tasks that have been discussed in the preceding chapters, no attempt will be made to present it in detail. The result of these incidental tests with forms has been presented in Chapter VI. The failure of the chick to respond correctly when the triangle was inverted suggests a negative answer to this question of relative form difference. Negative results are also in evidence when the size of the triangle was changed.

In similar tests on relative size difference, however, the results are more positive. These incidental tests were as easily made with sizes as with forms. After the chick had been trained to react appropriately to the ⊙ 28 + − ⊙ 12+ stimuli, it was confronted, without further training, with two different circles the sizes of which bore the same relation to each other as that of the former pair. This test was made with two different pairs of circles. One pair was larger, the other smaller, than the training pair of circles, but the relative difference was a constant.

The diameters of the circles used in ⊙ 28+ − ⊙ 12+ discrimination are respectively 6 and 4 cm. The standard is thus three halves of the variable. A habit having been established with the 6–4 circles, these stimuli were replaced, during five tests, with 4–3 circles; during five more tests, with 9–6 circles. Nearly all of the chicks mentioned in Chapter V were tested in this manner.

The 9 cm. circles used in the tests with the larger pair of circles was cut from black card board because regulation plates of that size were not available. The circular opening was neatly made by boring with a bit through two thin strips of board placed on each side of the card board. In the dark room human observers could hardly tell that it was a substitute. Since there was no training with this cardboard plate, the substitution could have had no influence.

Not all chicks responded similarly to these novel size relations, but evidently those which were best trained responded most positively to the relative stimulus difference. With all of the subjects tested, the total positive reactions to the larger stimulus considerably exceeded the total choices of the smaller circle. Chick 21 responded without an error to both the 9–6 and 4–3 situations. Several other chicks responded perfectly at least to one of the novel pairs of stimuli. On the whole, the 9–6 test resulted in more correct reactions than the 4–3 test relation.

In brief, these tests with new pairs of circles having approximately proportional size differences indicate that a chick trained to choose a 6 cm. circle and to reject a 4 cm. circle can choose, without further training, the 4 cm. circle when presented

with a 3 cm. circle. Likewise, it can choose a 9 cm. circle circle when presented with a 6 cm. circle. In the one test, what was formerly the sign for rejection is accepted as a positive sign; in the other, what was the positive sign is rejected as the shock sign. Choices, it would thus seem, can be made on the basis of relative stimulus difference.

In the preceding paragraph, it has been said that the chick *can* choose on the basis of relative size difference. In my preliminary account (Chapter II: 2, p. 113), the statement is made that the chick *will* choose on this basis. Obviously, my earlier assertion is too loose, for all chicks did not react unmistakably in this manner. It would seem wholly safe, in view of the number that *did* respond positively, to say that the chick *can* react on the basis of size relationship. Whether it *will* so respond probably depends somewhat upon the degree of previous training.

Coburn's investigation of the crow's reactions to relative stimulus difference is hardly comparable with my work on the chicks. Before the relative difference tests were made, the crows had been trained with 5–2, 9–5, 5–3, 3–2, and 6–3 combinations. On August 25th, the size training ended with the 6–3 combination. On the following day, "relative reactions" to the 3–2 combination were tested with positive results. This was followed by 6–4 training and positive results for the 9–6 "relative reactions." Again the 6–4 training was followed by positive results for the 3–2 "relative reactions."

In comparison with the preliminary training of my chicks, the crows had received a wide variety of experience with different circle combinations before the tests for relative reactions were made. The crows had actually received training with the 3–2 combination which makes me inclined to question the propriety of Coburn's conclusion:

> The results of these experiments indicate fairly clearly the relativity of the crows' reactions. . . . . For example, on August 24th and 25th, when the 3 centimeter circle was presented with the 5 centimeter circle, the crow reacted to the 3 centimeter circle thirty-seven times negatively and three times positively. On August 26, the 3 centimeter circle, displayed with the 2 centimeter circle, was reacted to positively in every case.

Coburn seems to overlook the fact that this same crow had been specifically trained on the 3–2 relation from August 12th to 17th.

Furthermore, Coburn's 9–6 relative reaction tests had been closely approximated in training when the 9–5 combination had been employed. For this reason his additional comment again seems questionable: "The results for crow No. 1 with the 6 centimeter circle when displayed with the 4 centimeter and the 9 centimeter circles, on August 26th and 27th were almost as decisive." While there had been no specific training on the 9–6 combination as such, there had been, aside from its close ap-

TABLE 17

Reactions to Relative Flicker Difference

Chick 27 ♀

DATE	STIMULI	NUMBER OF TESTS	NUMBER CORRECT	CONTROL SERIES 7
1/12	40″ – 20″ (50 flashes)	5	5	
	20 – 10 " "	1	1	1 (faster)
	40 – 20 " "	5	5	
	80 – 40 " "	1	1	1 (slower)
1/13	40 – 20 " "	5	5	
	80 – 40 " "	1	0	2 (slower)
	40 – 20 " "	5	4	
	20 – 10 " "	1	0	2 (faster)
1/14	40 – 20 " "	5	4	
	80 – 40 " "	1	0	3 (slower)
	40 – 20 " "	5	5	
	20 – 10 " "	1	0	3 (faster)
1/15	40 – 20 " "	5	4	
	20 – 10 " "	1	0	4 (faster)
	40 – 20 " "	5	5	
	80 – 40 " "	1	1	4 (slower)
	20 – 10 " "	1	1	5 (faster)
	80 – 40 " "	1	1	5 (slower)

proximation, frequent changes from one relation to another which might have had the effect of a "relative difference preparation." It seems probable that Coburn's conclusions are correct but they are hardly justified on the basis of his experimental method alone.

My results on the reactions of the chick to relative rates of flicker are less positive than the results from the size tests. The method in the flicker study was slightly changed. As table 17 indicates, the chick's training was continued daily while two relativity tests were inserted in each series consisting both of faster and slower rates of flashing. The first day the chick chose the slower rate regularly in all training tests and in both of the relative flicker tests. On the second and third days

it responded negatively in both of the relative stimulus tests. On the fourth day, four of the relative reaction tests were made, of which three were correct. The final result for these special tests was five correct and five wrong reactions. In the faster relative combination, there were only two correct choices; in the slower, there were three positive responses out of five. In each of the first relative flicker tests the responses were correct.

The results of the tests on the relativity of the chick's choices is thus different for each of three kinds of stimuli. With forms, it was so difficult to train subjects that the results are rather meager, but as far as they go they seem to be negative. With sizes the results are fairly positive. With flicker perception, again, the data are too meager to warrant a conclusion on the relativity problem. In general, it seems that with certain stimuli the chick *can* respond on the basis of relative stimulus difference.

CHAPTER X

General Conclusions and Summary

The results of the preceding study can leave no doubt as to the relative importance of size and form in the chick's visual life. It has been found that the number of tests necessary for the formation of a discrimination habit is much greater for forms than for sizes. Moreover, there was little difficulty in finding chicks that could readily discriminate sizes, but subjects that could discriminate forms, even after long training, seemed to be less plentiful. This study has also revealed the fact that even after perfect reactions to the circle-triangle are established, the form element as such plays no part in the discrimination.

The relative discriminative value of size and form was further tested by removing from the visual complex all but one of these factors and comparing the effect of different eliminations upon the chick's choice. The remainder of the complex, exclusive of size and form, was treated as a single factor and is spoken of as "brightness and general illumination." In table 18 the result of this special test is summarized from the records of chicks 15, 16, 17, 18, 19, 20, and 21. The averages of this table indicate that size was first in importance. Correct choices (R) on the basis of size difference alone, series 14, are 86 per cent of the total chances. The complex remainder called "brightness and general illumination" stands next, series 15, with nearly 70 per cent of correct choices. The average record is lowest when form provided the only discriminable basis, series 12, with correct and wrong choices nearly equal. It thus appears that the relative value of special factors in the chick's vision, arranged in the order of their importance, are size, the complex of brightness and general illumination, and form.

No certain comparison between the rôle of flicker and that of size and form can be made on the basis of the present study. However, on the strength of casual observation, it appears

that flicker stimuli have a greater stimulating value for the chick than spatial stimuli. The perception of movement offers a most promising field for subsequent study of vision in animals.

TABLE 18

Relative Values of Visual Factors

CONDITION OF DISCRIMINATION	SERIES	DATE	SUBJECTS																		AVERAGE		
			15			16			17			18			20			21					
			R	W	T	R	W	T	R	W	T	R	W	T	R	W	T	R	W	T	R	W	T
△ 28+ brighter and in lighter compartment than ⊙ 7+	1	Feb. 20	10	0	34	8	2	40	9	1	16	8	2	40	7	3	40	9	1	10	$8\frac{1}{2}$	$1\frac{1}{2}$	30
	2	22	10	0	8	8	2	10	9	1	10	10	0	5	7	3	33	9	1	18	$8\frac{5}{6}$	$1\frac{1}{6}$	14
	3	24	9	1	8	8	2	21	10	0	7	10	0	8	8	2	12	10	0	5	9	1	$10\frac{1}{6}$
	4	26	10	0	3	6	4	35	10	0	6	9	1	4	9	1	10	10	0	3	9	1	$10\frac{1}{6}$
	5	27	8	2	11	7	3	24	9	1	22	7	3	16	9	1	21	6	4	12	$7\frac{2}{3}$	$2\frac{1}{3}$	$17\frac{2}{3}$
	6	28	9	1	7	9	1	7	10	0	6	10	0	4	10	0	7	10	0	3	$9\frac{2}{3}$	$\frac{1}{3}$	$5\frac{2}{3}$
	7	29	9	1	14	9	1	4	10	0	5	9	1	6	10	0	8	10	0	2	$9\frac{1}{2}$	$\frac{1}{2}$	$6\frac{1}{2}$
	8	29	10	0	3	9	1	9				10	0	2							$9\frac{2}{3}$	$\frac{1}{3}$	$4\frac{2}{3}$
	9	Mar. 1	10	0	5	10	0	20				10	0	7							10	0	$10\frac{2}{3}$
	10	1				10	0	12													10	0	12
Form and size	11	1–2	8	2	8	9	1	22	6	4	4	8	2	10	10	0	4	9	1	2	$8\frac{1}{3}$	$1\frac{2}{3}$	$8\frac{2}{3}$
Form.....	12	2	3	3	—	3	3	—	3	3	—	2	4	—	4	2	—	4	2	—	$3\frac{1}{6}$	$2\frac{5}{6}$	—
All factors combined...	13	4	10	0	6	9	1	45	10	0	4	7	3	36	10	0	4	10	0	3	$9\frac{1}{3}$	$\frac{2}{3}$	$16\frac{1}{3}$
Size.....	14	4	9	1	7	9	1	30	10	0	3	8	2	4	9	1	3	7	3	6	$8\frac{2}{3}$	$1\frac{1}{3}$	$8\frac{5}{6}$
Brightness and general illumination.....	15	5	5	5	9	6	4	26	9	1	5	7	3	3	7	3	7	7	3	5	$6\frac{5}{6}$	$3\frac{1}{6}$	$9\frac{2}{3}$

It seems probable that we shall find in birds considerable acuity for moving stimuli.

In studies of the chick's vision, prior to the investigation of spatial perception which has been reported in the preceding

pages, it is quite probable that the reactions observed were made, not to the visual details which the experimenters sought to present to the chick, but to unsuspected visual complexes similar to the "complex remainder" which is here designated as "brightness and general illumination." It is desirable that subsequent studies further analyze our visual complex and determine the visual acuity of the chick with each element as has been done with size and form.

When presented with a standard circle 6 cm. in diameter, it has been found that a variable circle 4.5 cm. in diameter can be discriminated by the chick. If one were to increase the size of the variable by increments no greater than one millimeter, it is probable that the chick would be able to discriminate a larger variable than the 4.5 cm. circle. The threshold of difference with a standard 6 cm. circle, therefore, is certainly one-fourth and perhaps less. In the perception of size the ability of the chick is evidently inferior to that of the crow.

Earlier experiments on the chick's perception of forms have failed to eliminate all discriminable possibilities other than the factor of form. The chick can discriminate between circles and triangles and circles and squares which are equal in area, but, with the conditions as described in this study, none of the subjects were able to discriminate between visual stimuli on the basis of form alone. Reactions to visual stimuli which have been interpreted by observers as indicating form discrimination have probably been made on the basis of unequal stimulation of different parts of the retina. If local inequality of excitations be the basis of these reactions, then the apparent discrimination of form by the chick is, in reality, a keen perception of size differences. In the perception of form, also, the ability of the crow seems to surpass the ability of the chick.

The chick evidently has a keener perception of flicker than of form stimuli. The present experiment indicates that it perceives at least a two to one flicker relation. How much lower the threshold may be, this study has not indicated.

The discrimination method employed in the present investigation furnishes a means of recording the learning process of the chick. An essential part of the discrimination habit is a maze problem. The formation of this maze habit, it was found, can be quantitatively measured in terms of approaches

to outside and inside corners and to stimuli. The most reliable measurement of the discrimination habit itself is the number of correct choices. In addition to these quantitative measurements, certain qualitative criteria were found to be highly suggestive of stages of learning.

The method of punishment was found to be both valuable and pernicious. If intelligently used, it seems to be highly valuable; if carelessly applied, punishment can radically interfere with learning. The maximum value of punishment in chick work evidently depends upon the alertness of the experimenter in selecting an optimal punishment for each subject.

A chick can acquire a perfect circle-triangle or circle-square habit, but control tests indicate that it has no general idea of circularity in contrast with triangularity or squareness. On the other hand, a large-small trained chick can react positively to the larger of two stimuli even though this particular stimuli had been the shock sign of the training combination. Also, the positive stimulus of the training pair, when presented with a larger circle, may call forth negative reactions. Positive results on the question of relativity were not secured from the flicker experiments.

The order of importance of the visual factors which have been studied, it would seem, is size or flicker, the brightness and general illumination complex, and form.

Bibliography

A selected bibliography on the origin and history of the domestic fowl appears on page 5. A complete bibliography of experimental work with the domestic fowl to 1916 appears on page 20.

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Heredity of Wildness and Savageness in Mice

BY

CHARLES A. COBURN

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CONTENTS

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HEREDITY OF WILDNESS AND SAVAGENESS IN MICE

INTRODUCTION

For many years, especially since the appearance of Galton's work on the inheritance of mental abilities (1869), students of heredity have recognized the possibility that mental characteristics are inherited as well as the physical and, perhaps, in a somewhat similar way. The later studies of Galton (1897), and those of Woods (1906), Pearson (1903), Ellis (1904), Bentley (1909), Davenport (1896), Goddard (1911), Conklin (1915), and others tend to substantiate the hypothesis of the inheritance of mental traits.

All of these studies, however, pertain to the heredity of mental or moral characteristics in mankind, and the data from which the studies were made were obtained from various historical and observational sources. In 1910 Professor Robert M. Yerkes began an investigation of the hereditability of savageness, wildness, and timidity in rats (1913). So far as the writer has been able to ascertain this was the first study in mental heredity to be made in a laboratory where the conditions under which the subjects lived could be controlled to some extent. The rats used in this study numbered 300 and consisted of wild rats, tame rats, first generation hybrids obtained from crosses of the wild with the tame rats, and the second generation hybrids procured by crossing the first generation among themselves. The investigation, though incomplete, proved conclusively that these three characteristics, wildness, savageness, and timidity are heritable in rats.

In order to gain more definite information concerning the modes of transmission of such behavior-complexes as the above, the writer, at the suggestion of Professor Yerkes, undertook the investigation described in this paper. Owing to the limited space in the Harvard Psychological Laboratory mice were used instead of rats. The study was begun in December, 1911, and continued without interruption until May, 1914. The

number of mice used was about 1300 and consisted of wild mice, tame mice, and hybrids of the first, second, and third generation.

Professor Yerkes mentioned in the report of his investigation the difficulty he experienced in always being sure he was distinguishing between wildness and timidity in rats. He says: "It is indeed extremely doubtful whether it can with sufficient certainty be distinguished from wildness to render measurements significant." The characteristics of rats are so different from those of mice that it would be all the more difficult to make this distinction in the case of the latter. For this reason timidity was omitted in this study and only the two behavior-complexes, wildness and savageness, were investigated.

MATERIAL AND METHODS

From the beginning of the work in December, 1911, until June 7, 1913, the mice were kept in one of the large, well-ventilated rooms of the Harvard Psychological Laboratory. Upon the latter date the mice were taken to the Franklin Field Station at Franklin, New Hampshire, where the excellent facilities allowed even greater progress during the summer than in the quarters at Harvard although in no way were the methods of the experiment changed. Upon the return from the Franklin Field Station in October, 1913, the study occupied one of the rooms of the newly-completed Harvard Laboratory of Animal Psychology where it remained until the completion in May, 1914. This room was well lighted through the glass ceiling but possessed no direct connection with the outside, hence had to be ventilated by a system of fans. This, however, seemed to have no effect upon the work as the mice throve equally as well here as in the former quarters.

In the beginning the mice were kept in the large cages used by Professor Yerkes in his work with the dancing mice (1907) from the report of which a description may be obtained. Later, when the large number of mice compelled the use of more cages, the type of cage used by Professor William E. Castle and his associates at the Bussey Institute, Forest Hills, Mass., was adopted. A description of this cage, to the knowledge of the writer, has never been printed. It is made entirely of woven wire of one-quarter inch mesh and is, in form, a truncated rec-

tangular parallelepipedon, the truncation beginning at a line in the top 8 cm. from the back side and extending to a line in the front side 8 cm. from the bottom. The bottom of the cage is 30 cm. long by 21 cm. wide; the back, 21 cm. wide by 21 cm. high; the portion of the top parallel with the bottom and the portion of the front parallel with the back are each 8 cm. by 21 cm. The slanting surface comprising the remaining part of the top and front is 26 cm. long by 21 cm. wide. The two remaining sides of the cage are five sided, the measurements of each being 30 cm. by 21 cm. by 8 cm. by 26 cm. by 8 cm. In the slanting surface, 8 cm. from the top and bottom and 5.5 cm. from each side, is the door 10 cm. by 10 cm. The lid is 12 cm. by 12 cm. hinged at the top.

The very convenient watering system in use at the Bussey Institute was also adopted. It consists of a 10 or 12 ounce bottle fitted with a perforated rubber cork through which is passed a small glass tube bent at an angle of about 120 degrees so that when the bottle is placed upon the slanting surface of the cage the tube will extend down through the wire of the fore part of the cage to within easy reaching distance from the floor of the cage. The lower end of this tube is slightly drawn together so the water will not flow of its own accord. The mice soon learn to drink drop by drop from the tube. Thus there is a constant supply of clean water without the evil effects of a wet cage as when the water is placed in a receptacle on the floor or side of the cage. The bottle serves also as a weight on the lid of the cage making it impossible for the mice to escape in this way.

When in use these cages were placed upon wooden shelves which were covered with sufficient sawdust to well cover the bottom of the cage. This sawdust would remain on the shelf when the cage was raised and so could be replaced with fresh sawdust without greatly disturbing the mice.

Shredded tissue paper was used as bedding for the mice and, since it was the purpose of the experiment to minimize as much as possible the effect of the presence of the experimenter while cleaning cages, feeding or testing the mice, there was always sufficient paper in the cage to enable the mice to hide in it if they so wished. Until all the tests were made the mice were seldom handled or otherwise greatly disturbed except when being tested.

It was found that the Bussey Institute cage was very much more adaptable for the breeders than for testing purposes hence when the mice were weaned they were separated according to sex and placed in the larger cages and the subsequent tests made from these. Only occasionally, when the number of mice being tested was too great for the supply of large cages were the smaller cages used in this way.

The food for the mice consisted of cracked corn, oats, sunflower seed, bread moistened with milk, and occasionally a bit of lettuce or other green food. In the beginning some difficulty was experienced in so regulating the food to keep the mice, especially the breeders, in the best condition. The first few months' experience, however, was sufficient to obviate this difficulty.

The method of testing used by Professor Yerkes was followed in this study as closely as was possible. The mice were classified according to the six grades, namely, 0, 1, 2, 3, 4, 5. The grade 0 indicates the absence of all evidences of wildness or savageness, and the grade 5 indicates the presence of all the various signs of wildness or savageness in the greatest number and intensity. After a few mice were tested definite standards which represented the various grades were fixed and there is fairly definite evidence to indicate that these standards were adhered to throughout the investigation. Every few weeks an additional test was made of several mice which had been tested a day or two previous along with so great a number that it would be impossible to remember the grade of any mouse. In making these check tests the mice were taken at random from the different cages and after testing them a comparison would be made of the results of this test and the one immediately preceding. The grading varied occasionally but rarely more than one grade. The results given below were chosen at random and are typical of such tests.

The mice were weaned, given their initial test and numbered when they were about five or six weeks old. The age varied somewhat in order to allow several litters to be grouped and thus facilitate the work. At this age the mice are not full-grown but they have full use of all their organs of sense and are very active.

NUMBER OF MOUSE	DATE	GRADE OF WILDNESS	GRADE OF SAVAGENESS
512 ♀	April 9	5	5
	April 11	5	5
517 ♂	April 9	5	3
	April 11	5	4
990 ♂	January 20	3	3
	January 22	3	4
1002 ♀	January 20	4	4
	January 22	4	4
1008 ♂	January 20	1	1
	January 22	1	0
1040 ♂	January 20	3	2
	January 22	4	2

In order to avoid any effect which a change of surroundings and a possible change of temperature or light may have upon the behavior of the mice, all testing was done in the room occupied by the mice. The cage containing the individuals to be be examined was placed upon the testing table which was located, as a rule, in one corner of the room. Upon the table were also placed paper, pencil, paper punch for marking the mice, and a pair of placental forceps over the jaws of which had been placed soft rubber tubing in order to lessen the pressure and also the chances of injuring the tail of the mouse which required its use in catching. The gloves worn by the experimenter while testing were of kid of medium thickness.

Removing the mouse from the nest was done, when the mouse was hiding in the nest, by gently pushing back with the left hand the shredded tissue paper of the nest until the tail was exposed and then, grasping the tail between the thumb and forefinger, the mouse would be equally as gently pulled from the nest and at the same time placed upon the palm of the hand by turning the palm upward. In this way the mouse could often be removed without greatly disturbing it. When the smaller Bussey Institute cage was used, since the door was so small, often the tail when exposed had to be grasped by the placental forceps and thus the mouse pulled from the nest and placed upon the palm of the hand. When the mouse to be removed was not hiding in the nest the forceps were used to

grasp the tail and hold it only until it could be grasped by the fingers of the left hand whereupon the removal would proceed as usual. It is to be noted that the forceps were used as little as possible since the chance of unconsciously using unnecessary pressure was much greater with the forceps than with the fingers. The mouse was allowed to remain on the palm of the hand for a moment while a definite impression of its behavior was obtained. Then with the tail between the thumb and forefinger of the right hand and the mouse on the palm of the left or being gently held in the left hand the sex would be determined. This done the mouse would be returned to the position on the palm of the right hand and one of the fingers of the left hand or a pencil would be moved fairly rapidly up and down just before the mouse, the experimenter at the same time making a clicking sound with his tongue and teeth. The object of this was to get the behavior of the mouse when excited if such was possible. This completed the testing observations in the case of the initial tests and, the judgment being made, the result was thereupon entered. In the subsequent tests the behavior of the mouse when released was noted before making the judgment. The mouse was then numbered and placed in a cage with others of like sex and, as nearly as possible, like age in order to prevent promiscuous breeding and the killing of the younger mice by the older.

The system of numbering was identical with that in use at the Bussey Institute. It consisted in making certain notches or holes in the ears of the mouse. When viewed from behind the number indicated on the right ear represented the units and that on the left ear the tens of any particular number. Absence of any mark indicated zero. 1, 2, 3, etc. were respectively designated as follows: hole in the upper side of ear, hole in outer side, hole in lower side, notch in upper edge, notch in outer edge, notch in lower edge, notches in upper and outer edges, notches in outer and lower edges, notches in upper and lower edges. Ten was indicated by a hole in the upper side of left ear and nothing in the right ear, 22 by a hole in the outer side of both left and right ears, etc. The wounds thus made were usually observed to be completely healed in a very few days. By such combinations any number up to and including 99 could be indicated. As the different hundreds were desig-

nated on the outside of the cages and a description of each mouse was taken at the time of the first test, no difficulty was ever experienced in determining the identity of any mouse which had escaped from its cage. It may be mentioned that it was necessary to make the rooms occupied by the mice rat proof as well as mouse proof. In the beginning sufficient caution was not taken in this respect the result being that many mice were killed by rats and others lost by escaping from the room after they had by some chance escaped from their cage.

The following is the record of the initial test of one litter. The records of the subsequent tests were kept similarly except the omission of the description of the mice and the number of their parents.

June 18, 1913. F3's from F2 409♀ and F2 440♂. Born April 29, 1913

NUMBER OF MOUSE	DESCRIPTION	WILDNESS	SAVAGENESS
581♀	Chocolate, black eyes	4	3
582♀	Gray	3	3
583♂	Chocolate, red eyes	3	3
584♂	Chocolate, red eyes	4	4
585♀	Chocolate, black eyes	4	5

The types of behavior which were considered the chief indications of wildness in mice and were relied upon as a basis for grading were as follows.

1. Hiding from view in the cage just before the test or immediately after, and attempts to hide from view in the hand during the test. A wild mouse, though it may be feeding in the open in the cage while the experimenter is moving about the room or standing before the cage, will scurry to the back of the cage and hide in the nest at the first move of the experimenter to open the door of the cage. A tame mouse, on the other hand, will continue eating and is easily caught, in fact, it will rarely make any attempt to prevent it. When the wild mouse has been caught it is continually trying to find some crevice between the fingers in which it may hide. If it succeeds in covering its head it will often remain perfectly quiet as long as it is allowed to maintain this position.

2. Running and jumping excitedly about the cage just before being caught and attempts to escape from the hand after being

caught. Often the wildness is sufficiently great that the mouse apparently forgets to hide in the nest at the first move to open the door of the cage, or it may have hidden there but at the first touch of the hand on the outside of the nest it will jump from the nest and begin to run frantically about the cage and finally try to hide in the upper far corner of the cage or it may continue to run about the cage until caught. When one with such wildness is caught it continues to try to escape, jumping about the hand and trying energetically to pull its tail loose. After some time it may become quiet but will immediately resume the attempts to escape at the slightest move of the experimenter, especially if the pressure of the fingers on its tail is somewhat lessened.

3. Squeaking. This was rarely observed except in very young mice or older mice when they were being graded for the first time. However it is included as an indication of wildness since it was never observed in tame mice.

4. Urination and defecation. Both of these are associated with the greater degrees of wildness. They were used in grading only in a general way.

5. Jumping from the hand when released and immediately hiding in the nest or excitedly running about the cage. When a very wild mouse is being put back in the cage it will immediately jump from the hand the instant the pressure on its tail is released. It usually jumps straight ahead no matter whether that is toward the top, side or front of the cage, or directly through the door of the cage toward the experimenter. If it alights in the cage it generally dashes toward the nest and hides. At other times it may run about the cage but sooner or later will seek the nest. A tame mouse will never jump in this way. It will go to the edge of the hand and look down. If the distance is very great it will try the other side and will not of its own accord leave the hand unless it can reach the floor with its fore feet when it hangs over the side of the hand. When it is safely back in the cage it makes no attempt to hide.

Professor Yerkes found that there are two kinds of savageness in rats. These he termed defensive and offensive. Only the former is found in mice. The most savage mouse will never attack the observer nor make the slightest move to do so. It will only bite when it is caught and unable to get loose.

Biting in this case is not, however, always a sign of savageness. Quoting from the writer's notes; "Biting when just caught is not always a sign of savageness for tame individuals will bite if hurt." This is corroborated by Miss Abbie E. C. Lathrop, Granby, Mass., who has had many years' experience in breeding and handling mice. The following statements are taken from one of her letters. "Every one who comes here and tries to handle mice gets bitten even by tame mice, because of grasping the tail too tightly. Some mice are cross even when not hurt, but gentle mice resent pain and bite."

The chief indications of savageness are biting and squeaking. A mouse possessing the greatest degree of savageness may indicate this by biting in either of two ways depending largely, it seems, upon the degree of wildness which accompanies it. Very often a very savage mouse while being pulled from the nest and before the hand has touched its body will swing about and sink its teeth into the glove. This act is the nearest approach to the offensive savageness of the rat. If there is a great degree of wildness present which will cause it to make violent attempts to free itself, everytime that its feet touch a part of the glove in its frightened jumping about the teeth are vigorously used. Often in the instant before the next jump two or three bites will be made in the glove, the mouse trying, as it were, to find some vulnerable spot. If the glove has even a small hole in it in an accessible spot the mouse of this type is very apt to find it and use its teeth with considerable effect.

On the other hand, if there is a much less degree of wildness present the mouse will often seize the glove with its teeth and tenaciously hold on until compelled to let go by the experimenter whereupon it will immediately fasten its teeth in another part of the glove. The mouse with no savageness will make no attempt to bite even when teased unless the tail is held too tightly or it is otherwise hurt. However, many of the non-savage mice made no attempt to bite even when being numbered.

Between these two extremes of savageness there are many types of behavior which were considered as representing different grades of savageness as, for instance, the mouse with a low degree of savageness will, perhaps, use its teeth but once or twice during the test and then only in an indifferent way,

or it may not bite at all until it is teased whereupon it will do so vigorously for an instant or two.

Squeaking is an indication of a fairly high degree of savageness unless the mouse is hurt, in which case it may be observed where there is little or no savageness.

Although the types of behavior mentioned above are the chief indications of wildness and savageness in mice, a great many others which are very significant often appear. The range of individuality of mice, to the experienced observer, is very great. In spite of these many indications and the different degrees of intensity with which they appear in the behavior of mice during a test, very rarely did the writer, after he had had some experience, have difficulty in forming a judgment of the grade of wildness or savageness observed.

A description of the wild and tame mice used in this study is given in table 1.

The observations and tests made on the tame mice from the Bussey Institute and Miss Abbie E. C. Lathrop for some time after they arrived at the laboratory indicated in no case a grade of wildness or savageness above 0. The mice from the Bussey Institute were from a strain which had been in use there for some time for various color and structural studies and were from stock which had originally been obtained from Miss Lathrop. After they had been used in the present study for about a year, it was quite accidently learned that there was some possibility of their possessing some wild blood as mice from this strain had at various times been crossed with wild in the color studies. In order to secure more definite information a mating was made from these mice and the offspring tested. The results are shown in table 2.

The table gives in the upper left hand corner (*a*) the average number of tests; (*b*) the range of tests; (*c*) the average age at the time of the first test; (*d*) the average age for the last test; immediately below, (*e*) the number of mice and sex; to the right of this, (*f*) the average grade attained in the first test for wildness; (*g*) the average of the first and second tests; (*h*) the average of all the tests; (*i*) the average of the third, fourth and fifth tests; (*j*) the average grade attained in the last test. Immediately to the right of these averages is presented the distribution of the mice in the grades 0 to 5. The averages for

the tests for savageness and the distribution of the mice in grades for savageness are presented in like manner.

TABLE 1

Parental Generation

MOUSE	DESCRIPTION	WHERE OBTAINED
1 ♀	Chocolate, tame	Bussey Institute, Forest Hills, Mass.
2 ♂	Chocolate, tame	Bussey Institute, Forest Hills, Mass.
6 ♂	Chocolate, tame	Bussey Institute, Forest Hills, Mass.
7 ♂	Chocolate, tame	Bussey Institute, Forest Hills, Mass.
501 ♀	Chocolate, tame	Miss Abbie E. C. Lathrop, Granby, Mass.
502 ♀	Chocolate, tame	Miss Abbie E. C. Lathrop, Granby, Mass.
503 ♀	Chocolate, tame	Miss Abbie E. C. Lathrop, Granby, Mass.
504 ♂	Chocolate, tame	Miss Abbie E. C. Lathrop, Granby, Mass.
522 ♀	Cream, tame	Miss Abbie E. C. Lathrop, Granby, Mass.
523 ♀	White, tame	Miss Abbie E. C. Lathrop, Granby, Mass.
524 ♀	White, tame	Miss Abbie E. C. Lathrop, Granby, Mass.
525 ♀	Black, tame	Miss Abbie E. C. Lathrop, Granby, Mass.
527 ♀	White, tame	Miss Abbie E. C. Lathrop, Granby, Mass.
528 ♀	White, tame	Miss Abbie E. C. Lathrop, Granby, Mass.
529 ♀	Chocolate, tame	Raised in laboratory, parents, 503 ♀ and 504 ♂
530 ♂	Chocolate, tame	Raised in laboratory, parents, 503 ♀ and 504 ♂
531 ♀	Chocolate, tame	Raised in laboratory, parents, 503 ♀ and 504 ♂
532 ♀	Chocolate, tame	Raised in laboratory, parents, 503 ♀ and 504 ♂
533 ♂	Chocolate, tame	Raised in laboratory, parents, 503 ♀ and 504 ♂
534 ♂	White, tame	Miss Abbie E. C. Lathrop, Granby, Mass.
652 ♀	White, tame	Miss Abbie E. C. Lathrop, Granby, Mass.
3 ♀	Gray, wild	Dwelling-house, Cambridge, Mass.
4 ♀	Gray, wild	Dwelling-house, Cambridge, Mass.
5 ♀	Gray, (Singer) wild	Dwelling-house, Chestnut Hill, Mass.
8 ♂	Gray, wild	Dwelling-house, Cambridge, Mass.
225 ♀	Gray, wild	Emerson Hall, Cambridge, Mass.
346 ♂	Gray, wild	Morgan Memorial, Boston, Mass.
348 ♀	Gray, wild	Morgan Memorial, Boston, Mass.
472 ♂	Gray, wild	Dwelling-house, Brooklyn, New York
474 ♂	Gray, wild	Dwelling-house, Brooklyn, New York.
475 ♀	Gray, (Singer), wild	Dwelling-house, Brooklyn, New York
510 ♂	Gray, wild	Raised in laboratory, parents, 225 ♀ and 350 ♂
511 ♀	Gray, wild	Raised in laboratory, parents, 225 ♀ and 350 ♂
512 ♀	Gray, wild	Raised in laboratory, parents, 225 ♀ and 350 ♂
513 ♀	Gray, wild	Raised in laboratory, parents, 225 ♀ and 350 ♂
514 ♀	Gray, wild	Raised in laboratory, parents, 225 ♀ and 350 ♂
515 ♂	Gray, wild	Raised in laboratory, parents, 225 ♀ and 350 ♂
516 ♀	Gray, wild	Raised in laboratory, parents, 475 ♀ and 474 ♂
517 ♂	Gray, wild	Raised in laboratory, parents, 475 ♀ and 474 ♂
518 ♂	Gray, wild	Raised in laboratory, parents, 475 ♀ and 474 ♂
519 ♀	Gray, wild	Raised in laboratory, parents, 475 ♀ and 474 ♂
520 ♂	Gray, wild	Raised in laboratory, parents, 475 ♀ and 474 ♂
521 ♂	Gray, wild	Raised in laboratory, parents, 475 ♀ and 474 ♂
350 ♂	Gray, wild	Emerson Hall, Cambridge, Mass.

As is readily seen from the table there was undoubtedly some trace of wild blood in these mice, but the amount was so small that all evidence of its presence was effaced by the time the

mice were 110 days old. The wildness and savageness had evidently been counteracted by the taming effect of the daily presence of the experimenter while feeding and cleaning the cages, and the handling during the five tests. The degree of savageness was only about half as great as that of wildness and did not persist as long, since after the second test the grade for savageness was in no case above 0. Another point which should be mentioned here but which is not shown in the table is the difference in the degree of wildness and savageness of the males and females. If the average of all the five tests is used as a criterion, the females were about twice as wild and savage as the males since the average grades for wildness and

TABLE 2

Summary of Results for One Litter of Offspring of Mice from Bussey Institute

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades							Distribution of mice in grades					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 5															
Range of tests, 5	First test	2.6		1	1	2	1		1.8		2	2	1		
Average age in days:															
First test, 46	Average 1 and 2	2.1			4		1		1.1		4		1		
Last test, 110															
	Average all	1.01		4	1				0.44	4	1				
5 mice															
(3 males and 2 females)	Average 3, 4 and 5	0.53	3	2					0.0	5					
	Last test	0.0	5						0.0	5					

savageness, respectively, were 1.8 and 0.6 for the females in contrast with 0.73 and 0.33 for the males.

As a result of this evidence of impurity in the tame mice, 2 males and 10 females were obtained from Miss Lathrop. Before these were used, however, a mating was made from them and the offspring tested as in the previous instance. There was not a mouse in any of these tests which received a grade above 0 in either wildness or savageness. The proof of the purity of the tameness and non-savageness of these young mice (table 1, nos. 529 to 533 inclusive), and their parents was considered so conclusive that there was no hesitation in assuming an equal purity in the remaining 10.

The 11 wild mice which were captured and used for breeding purposes in this study were, with the exception of mouse 472 ♂, full-grown when caught. This mouse was judged from 6 to 8 weeks old. All of these mice were tested several times for wildness and savageness and in each test manifested the highest grades. The last test occurred when the time of captivity varied from 1 to 6 months. Each received a grade of 5 for wildness and savageness except two (nos. 225 ♀ and 474 ♂), which were graded 4 in savageness. Although it was necessary to handle these mice when weaning their young or changing their mates, there was during this handling no observation of any behavior which would tend to indicate that their wildness or savageness had decreased to any appreciable degree even after they had been in captivity from one to two years. However, when not being handled there was a very noticeable difference in the degree of wildness. Instead of scurrying to their nest as they did when the experimenter entered the room during their early captivity, later they would, as a rule, remain in the open and continue eating, but it was never possible to persuade them to come to the front of the cage to secure a bit of food from the experimenter's fingers.

The 12 wild mice, nos. 510 to 521 inclusive, were raised in the laboratory and were tested five or six times in the same manner and at regular intervals as the mice of table 2. A summary of the results of these tests are presented in tables 15 and 16. These mice were chiefly used in matings with the tame mice obtained from Miss Lathrop.

Although no more crosses were made between the mice from the Bussey Institute and the wild individuals after the discovery of the apparent trace of wild blood, the series begun by them was continued and the results will be presented in this study. These results, however, will be summarized in separate tables except in such cases where the information to be noted is equally significant in each series.

To avoid any confusion which might otherwise arise the series from the crosses of Bussey Institute mice with wild mice will be termed Series A, and the first, second, and third hybrid generations of this series will be designated, F_1a, F_2a, and F_3a, respectively. Likewise the series from crossing the tame mice from Miss Lathrop with wild mice will be termed Series B, and the hybrid generations, F_1b, F_2b, and F_3b.

The first generation hybrids in each series were obtained by crossing wild females with tame males and tame females with wild males. The second generations of hybrids were obtained by crossing the first generation hybrids among themselves without selection as to wildness or savageness, except in the cases where selective breeding was tried, the results of which will be presented in separate tables. Likewise by crossing the second generation hybrids among themselves the third generation of hybrids were obtained.

It was aimed to test each individual five times. However, there was a number which because of death or other reason did not receive that number. Those that received but one test have not been considered in the results. On the other hand, for reasons which will be discussed later, some mice received six to eight tests.

Deducting those individuals used in experiments to determine the effect of age on the lowering of grades of wildness and savageness in the successive tests, the average age for the first test was 38.8 days, and for the fifth test, 92.8 days. The average time between the first and second tests was 17 days; between the second and third, 15 days; between the third and fourth and between the fourth and fifth, 11 days each.

EXPERIMENTAL RESULTS

A. General comparison of inheritance in the hybrid generations of both series

In table 3 is presented a general summary of the results for the three generations of both series. A comparison of the averages in each of the generations shows a very great similarity, the difference in any case being so small as to be practically negligible. However, the difference in the grades of wildness and savageness attained in the first and last test is significant. This lowering of the grades is gradual in each generation but is greatest in both wildness and savageness in the F_2's. The model grade, i.e., the grade which is the most frequent, is either 3 or 4 for wildness in each generation, and for savageness ranges from 3 to 5.

In tables 4 and 5 the results of the series are presented separately. The similarities of the averages in the generations so

apparent in table 3 naturally maintain to some extent in the results of each series. There are, however, some differences

TABLE 3

Summary of Results for the Three Generations of Both Series

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 4.46															
Range of tests, 2–5	First test.....	3.95	1	2	2	72	142	75	4.01			3	85	101	103
Average age in days:															
First test 35.27	Average 1 and 2.	3.79		1	5	47	163	78	3.74			9	71	131	83
Last test, 79.36															
	Average all.....	3.49			16	27	135	16	3.13		5	62	126	75	26
294 F_1	* (285)														
Males and females	Average 3, 4 and 5.....	3.25		1	42	128	93	21	2.63	9	33	77	91	55	20
	Last test.....	3.16		17	54	117	71	35	2.45	41	38	55	90	47	23
Average number tests, 4.70															
Range of tests, 2–5	First test.....	3.89	2	2	9	114	181	102	4.09	2	2	16	92	128	170
Average age in days:															
First test 40.99	Average 1 and 2.	3.73		3	9	87	201	110	3.72	1	3	26	74	154	152
Last test, 92.39															
	Average all.....	3.50		7	43	192	159	19	3.26	2	9	95	127	117	45
410 F_2	*(405)														
Males and females	Average 3, 4 and 5.....	3.02	5	25	73	164	114	24	2.63	18	71	97	107	72	40
	Last test.....	2.81	21	32	97	142	89	29	2.13	101	53	67	106	44	39
Average number tests, 4.83	First test.....	3.60		2	7	62	75	18	4.07			7	35	40	82
Range of tests, 2–5															
Average age in days:	Average 1 and 2.	3.80			6	46	92	20	3.80		1	7	36	67	53
First test, 38.09															
Last test, 88.71	Average all.....	3.48			27	64	67	6	3.40		5	25	53	53	28
	*(162)														
164 F_3	Average 3, 4 and 5.....	3.25		7	28	53	61	13	3.13	4	16	31	40	41	30
Males and females															
	Last test.....	2.98	7	19	20	59	41	18	2.91	22	15	23	40	23	41

* The number of mice that received three or more tests.

to be noted in a comparison of the two series. The averages of the first test and of the first and second tests for wildness in the F_1 and also in the F_2 of both series are practically equal,

but the remaining averages in these two generations of Series B are in each case higher than those of Series A. The summary of the tests for savageness in these two generations indicates

TABLE 4

Summary of Results for the Three Generations of Series A

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 4.13															
Range of tests, 2–5	First test	3.98		1	1	21	44	26	3.97	1			23	44	25
Average age in days:															
First test 31.22	Average 1 and 2	3.72			3	18	52	20	3.58			1	26	52	14
Last test, 75.61	Average all	3.31			5	50	36	2	2.96			24	44	21	4
93 F_1a Males and females	(90) Average, 3, 4 and 5	2.92			20	50	17	3	2.38		13	32	33	10	2
	Last test	2.75		5	30	43	13	2	2.04	8	27	20	30	7	1
Average number tests, 4.40															
Range of tests, 2–5	First test	3.90			3	52	80	42	3.94	1		13	39	66	58
Average age in days:															
First test, 41.66	Average 1 and 2	3.72			2	44	90	41	3.46	1	2	15	47	77	35
Last test, 98.72	Average all	3.05			31	96	46	4	2.64	1	17	55	68	32	4
177 F_2a Males and females	(173) Average 3, 4 and 5	2.52	1	19	49	74	27	3	1.97	12	41	51	52	14	3
	Last test	2.39	12	25	57	52	26	5	1.67	52	33	36	36	16	4
Average number tests, 4.88															
Range of tests, 3–5	First test	3.44		2	7	51	46	8	3.84			7	31	28	48
Average age in days:															
First test, 36.76	Average 1 and 2	3.41			5	38	59	12	3.63		1	7	32	44	30
Last test, 93.52	Average all	3.23			24	44	43	3	3.26		5	19	42	32	16
114 F_3a Males and females	(114) Average 3, 4 and 5	3.10		5	26	38	38	7	3.01	4	13	20	35	23	19
	Last test	2.79	6	17	15	41	26	9	2.78	18	9	18	29	14	26

that the mice of Series B attained a higher average grade in the first test and maintained a greater degree throughout all the tests. Likewise the F_3b averaged higher grades in both

wildness and savageness than the F_3a. If the assumption that there was some wild blood in the tame parents of Series

TABLE 5

Summary of Results for the Three Generations of Series B

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 4.62															
Range of tests, 2–5	First test	3.94	1	1	1	51	98	49	4.02	1		3	62	57	78
Average age in days:															
First test, 37.18	Average 1 and 2	3.83		1	2	29	111	58	3.82			8	45	79	69
Last test, 81.09	Average all	3.56			11	77	99	14	3.20		5	38	82	54	22
201 F_1b (195)															
Males and females	Average 3, 4 and 5	3.36		1	22	78	76	18	2.73	9	20	45	58	45	18
	Last test	3.37		12	24	74	58	33	2.63	33	11	35	60	40	22
Average number tests, 4.95															
Range of tests, 2–5	First test	3.89	2	2	6	62	101	60	4.21	1	2	3	53	62	112
Average age in days:															
First test, 40.66	Average 1 and 2	3.75		3	7	43	111	69	3.93		1	11	27	77	117
Last test, 87.15	Average all	3.50		7	12	86	113	15	3.40	1	7	40	59	85	41
233 F_2b (232)															
Males and females	Average 3, 4 and 5	3.32	4	6	24	90	87	21	3.03	6	30	46	55	58	37
	Last test	3.12	9	7	40	90	63	24	2.48	49	20	31	70	28	35
Average number tests, 4.70															
Range of tests, 2–5	First test	3.98				11	29	10	4.60				4	12	34
Average age in days:															
First test, 41.12	Average 1 and 2	4.69			1	8	33	8	4.19				4	23	23
Last test, 77.62	Average all	4.07			3	20	24	3	3.74			6	11	21	12
50 F_3b (48)															
Males and females	Average 3, 4 and 5	3.62		2	2	15	23	6	3.41		3	11	5	18	11
	Last test	3.42	1	2	5	18	15	9	3.20	4	6	5	11	9	15

A is correct, these results are directly opposed to the results Professor Yerkes obtained with the rats.[1]

[1] Robert M. Yerkes, The Heredity of Savageness and Wildness in Rats. The Journal of Animal Behavior, iii, No. 4, page 293.

Of the five averages included in the tables, the average of all the tests and the average of the third, fourth, and fifth tests seem to present the most accurate estimates of the degree of wildness or savageness of the mice, because the number of tests included in these averages tends to counteract the effect of any extreme grade of wildness and savageness or tameness and non-savageness that may have been received in an occasional test due to the influence of some extraordinary conditions upon the mouse or the experimenter or both at the time of the test. Of these two averages, that of the third, fourth and fifth tests is probably the more reliable measurement of the traits in question. This is because there is included in the average of all tests the results of the first two tests which are considered to give an exaggerated estimate of the wildness, and perhaps also savageness, possessed by the mouse on account of the possible effect, in the case of the first test, of the experience of being handled for the first time; and, in the case of the second test, because of any effect which may remain from the more or less painful experience of being numbered immediately after the first test is made. The fact that the lowering of the grades of wildness is greater between the second and third tests than between any other two successive tests seems to support this statement (table 12, page 23).

Using the average of all tests and the average of the third, fourth and fifth tests as criteria, the arrangement of the generations of Series A with respect to grades attained in wildness and savageness is (1) F_3, (2) F_1, (3) F_2, where one represents the highest grade and three the lowest grade. This order of arrangement is maintained when the degree of wildness of the generations of Series B is considered, but the order of this series with respect to savageness is (1) F_3, (2) F_2, (3) F_1.

The modal grade for wildness is either 3 or 4 in all the generations of both series except F_2a where it ranges from 2 to 4. The modal grade for savageness is either 3 or 4 in F_1a and either 4 or 5 in F_3b. In the case of F_3a, F_1b, and F_2b, it ranges from 3 to 5, and in F_2a the range is from 0 to 5.

In tables 6, 7, and 8, the results for the males and females of each generation of Series A are presented separately, and in tables 9, 10, and 11, those of Series B are shown.

The averages for the males and females of F_1a (table 6) indicate but little difference in the grades of wildness and savage-

ness attained by each. The average grades for wildness attained by the males in the first test and in the last test are almost identical with those of the females. But in the case of the averages for wildness in all tests and in third, fourth, and fifth tests, those of the males are a fraction of a grade higher than those of the females. While the averages of the first tests for savageness are somewhat higher for the females than for the males, the average grades attained in the last tests are

TABLE 6

Summary of Results for First Generation Hybrids, F_1, of Series A

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 3.82															
Range of tests, 2–5	First test	4.0		1		10	17	13	3.80	1			13	18	9
Average age in days:															
First test, 31.60	Average 1 and 2	3.74			1	9	21	10	3.45				16	19	6
Last test, 75.63															
	Average all	3.33			4	19	16	2	2.98			10	19	9	3
41 F_1a	(38)														
Males	Average 3, 4 and 5	2.94			12	15	10	1	2.52		5	14	13	6	
	Last test	2.75		3	12	19	6	1	2.14	4	11	6	15	5	
Average number tests, 4.19															
Range of tests, 3–5	First test	3.98			1	11	27	13	4.11				10	26	16
Average age in days:															
First test, 30.92	Average 1 and 2	3.70			2	9	31	10	3.68			1	10	33	8
Last test, 75.59															
	Average all	3.15			1	31	20		2.11			14	25	12	1
52 F_1a															
Females	Average 3, 4 and 5	2.92			8	35	7	2	2.36		8	18	20	4	2
	Last test	2.75		2	18	24	7	1	1.96	4	16	14	15	2	1

just the reverse. The grades representing the averages of all the tests are practically equal, 2.98 for the males and 2.99 for the females. The males in the third, fourth and fifth tests for savageness received, as an average, 0.16 grade higher than the females.

The modal grade for wildness of the males and females of F_1a is either 3 or 4 in each case. The mode for savageness of the males ranges between 2 and 4, and of the females, between 1 and 4.

TABLE 7

Summary of Results for Second Generation Hybrids, F_2, of Series A

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 4.45															
Range of tests, 2–5	First test.....	4.00			1	21	36	24	4.46			1	15	37	29
Average age in days:															
First test, 42.00	Average 1 and 2....	3.67			2	23	40	17	3.44		1	9	22	38	12
Last test, 99.21															
	Average all.....	2.93			22	42	16	2	2.54		11	27	31	12	1
82 F_2a	(79)														
Males	Average 3, 4 and 5 .	2.31		16	22	29	11	1	1.79	9	19	23	25	2	1
	Last test.....	2.10	10	17	22	21	11	1	1.34	35	12	14	15	5	1
Average number tests, 4.36															
Range of tests, 2–5	First test.....	3.82			2	31	44	18	4.07	1		12	24	29	29
Average age in days:															
First test, 41.38	Average 1 and 2.....	3.76				21	50	24	3.63	1	1	6	25	39	23
Last test, 99.27															
	Average all.....	3.17			9	54	30	2	2.83	1	6	28	37	20	3
95 F_2a females	(94)														
	Average 3, 4 and 5 .	2.70	1	3	27	45	16	2	2.19	3	22	28	27	12	2
	Last test.....	2.64	2	8	34	31	15	4	2.00	17	21	22	21	11	3

TABLE 8

Summary of Results for Third Generation Hybrids, F_3, of Series A

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 4.80															
Range of tests, 3–5	First test	3.38		2	5	26	25	4	3.95			4	19	15	24
Average age in days:															
First test, 35.06	Average 1 and 2....	3.30			5	22	28	7	3.66		1	4	13	27	17
Last test, 89.74															
	Average all.....	3.07			16	24	20	2	2.99		4	13	22	17	6
62 F_3a															
Males	Average 3, 4 and 5 .	3.08		3	17	20	17	5	2.69	3	8	14	21	9	7
	Last test.....	2.69	4	9	12	19	13	5	2.48	14	5	11	13	7	12
Average number tests, 4.98															
Range of tests, 3–5	First test.....	3.51			2	25	21	4	3.71			3	12	13	24
Average age in days:															
First test, 38.78	Average 1 and 2....	3.54				16	31	5	3.60			3	19	17	13
Last test, 98.03															
	Average all.....	3.30			8	20	23	1	3.46		1	6	20	15	10
52 F_3a	(50)														
Females	Average 3, 4 and 5 .	3.15		2	9	18	21	2	3.37	1	5	6	14	14	12
	Last test.....	2.92	2	8	3	20	13	4	2.96	4	4	7	16	7	14

The averages for the females of F_2a and F_3a are higher in grade than those of the males in every instance except the averages for the first tests for wildness and savageness in both generations and the average of the first and second tests for savageness in the F_3a. The modal grades in these two generations range as follows: for males in wildness and savageness respectively; F_2a, 2–4 and 0–4; F_3a, 3–4 and 0–5; for the females, F_2a, 2–4 and 2–4; F_3a, 3–4 and 3–5.

TABLE 9

Summary of Results for First Generation Hybrids, F_1, of Series B

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 4.49															
Range of tests, 2–5	First test	3.57	1	1	1	28	50	21	3.96	1		1	33	31	36
Average age in days:															
First test, 36.76	Average 1 and 2	3.56		1	2	18	58	23	3.78			4	24	40	34
Last test, 77.09															
	Average all	3.30			10	44	43	5	3.07		1	28	36	25	12
102 F_1b	(96)														
Males	Average 3, 4 and 5	3.13		1	18	37	33	7	2.53	4	14	27	22	22	7
	Last test	3.04		8	18	47	19	10	2.50	18	7	19	32	16	10
Average number tests, 4.77															
Range of tests, 3–5	First test	4.02				23	48	28	4.10			2	29	26	42
Average age in days:															
First test, 37.43	Average 1 and 2	3.93				11	53	35	3.84			4	21	39	35
Last test, 72.08															
	Average all	3.73			1	33	56	9	3.30		4	10	46	29	10
99 F_1b															
Females	Average 3, 4 and 5	3.59			4	41	43	11	2.91	5	6	18	36	23	11
	Last test	3.71		4	6	27	39	23	2.65	15	4	16	28	24	12

In the three generations of Series B (tables 9, 10 and 11), the females attained higher grades in every instance except the average of the first tests for savageness in F_3b. The modal grades of the averages of this series likewise indicate that the females are generally more wild and savage than the males.

From the results as shown in table 3 it seems fairly clear that the inheritance of wildness and savageness in mice is Mendelian of the "blending" or multiple factor type. The first section of this table shows that the wildness and savageness of the F_1's vary about the intermediate grade 3 with some

TABLE 10

Summary of Results for Second Generation Hybrids, F_2, of Series B

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 4.97															
Range of tests, 3–5	First test	3.86	2	1	3	27	53	29	4.06	1	2	1	27	33	51
Average age in days:															
First test, 41.95	Average 1 and 2	3.61		3	7	22	54	29	3.95		1	8	16	35	55
Last test, 87.64															
	Average all	3.33		6	9	47	48	5	3.24	1	5	25	33	37	14
115 F_2b Males	Average 3, 4 and 5	3.12	3	6	18	43	38	7	2.71	5	19	28	29	23	11
	Last test	2.93	8	6	18	46	27	10	2.00	33	14	17	32	10	9
Average number tests, 4.93															
Range of tests, 2–5	First test	3.93		1	3	35	48	31	4.35			2	26	29	61
Average age in days:															
First test, 39.40	Average 1 and 2	3.90				21	57	40	4.22			3	11	42	62
Last test, 86.67															
	Average all	3.68		1	3	39	65	10	3.70		2	15	26	48	27
118 F_2b	(117)														
Females	Average 3, 4 and 5	3.53	1		6	47	49	14	3.55	1	11	18	26	35	26
	Last test	3.31	1	1	22	44	36	14	2.94	16	6	14	38	18	26

TABLE 11

Summary of Results for Third Generation Hybrids, F_3, of Series B

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 4.65															
Range of tests, 2–5	First test	3.78				7	14	2	4.65				1	6	16
Average age in days:															
First test, 41.13	Average 1 and 2	3.57			1	5	14	3	4.00				3	9	11
Last test, 80.17															
	Average all	3.44			3	12	6	2	3.45			5	6	7	5
23 F_3b	(22)														
Males	Average 3, 4 and 5	3.34		2	2	8	5	5	3.04		3	7	2	4	6
	Last test	3.08	1	1	5	8	4	4	2.65	4	4	4	2	1	8
Average number tests, 4.74															
Range of tests, 2–5	First test	4.14				4	15	8	4.55				3	6	18
Average age in days:															
First test, 41.11	Average 1 and 2	3.77				3	19	5	4.16				1	14	12
Last test, 83.00	Average all	3.82				8	18	1	3.90			1	5	14	7
27 F_3b	(26)														
Females	Average 3, 4 and 5	3.85				7	18	1	3.71			4	3	14	5
	Last test	3.70		1		10	11	5	3.62		2	1	9	8	7

individuals possessing a grade of wildness and savageness or tameness and non-savageness equal to that of the parental generation. The second section of the table indicates that the degree of wildness and savageness of the F_2's varies about the same intermediate grade and that this variability is also in accordance with Mendelian expectation in being greater than that of the F_1's. The number of cases studied, however, is scarcely large enough to give sufficient basis for an estimate of the number of factors involved.

B. Effect of age, frequency and number of tests on the lowering of the grade of wildness and savageness in successive tests

In table 12 are given the average results of the successive tests of all hybrids of the three generations that received the regular tests, and also the amount of difference in the grades of wildness and savageness in the successive tests.

TABLE 12

Summary of Results for Regular Tests of All Hybrid Generations

NUMBER MICE	NUMBER TEST	AVERAGE GRADE FOR		DIFFERENCE IN GRADE	
		Wildness	Savageness	Wildness	Savageness
868	First	3.87	4.06		
850	Second	3.60	3.56	0.27	0.50
850	Third	3.30	3.10	0.30	0.46
797	Fourth	3.11	2.65	0.19	0.45
645	Fifth	2.95	2.21	0.16	0.44

It is readily seen by this table that there is a fairly gradual lessening in the grades of wildness and savageness from the first test to the last. The greatest amount of decrease in the grade of wildness occurs between the second and third tests. With this exception the amount of decrease is greatest between the first and second tests and gradually diminishes with the successive tests.

In the attempt to determine the cause or causes for this lowering of the grades of wildness and savageness with the repetition of the tests, three different methods were used as follows:

1. Individuals were allowed to remain untested, unnumbered, and without being handled, in the cage in which they were

born, (the parents usually being removed), until they had attained the age at which the fifth test would ordinarily be given. Then the five tests were given in the usual way.

This method was used with 9 individuals of F_1a, and with 48 individuals of F_2a. The results are given in tables 13 and

TABLE 13

Summary of Results of Tests of Old Mice of First Generation Hybrids F_1, of Series A

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 4.00															
Range of tests, 4	First test	4.44					5	4	4.44				1	3	5
Average age in days:															
First test, 86.55	Average 1 and 2	4.11					6	3	3.61				3	5	1
Last test, 139.00															
	Average all	3.30				5	4		2.80			2	6	1	
9 (old) F_1a															
Males and	Average 3, 4 and 5	2.61			2	6	1		2.00		1	3	5		
Females	Last test	2.44			5	4			2.00		3	3	3		
Average number tests, 4.00															
Range of tests, 4	First test	4.66					1	2	4.66					1	2
Average age in days:															
First test, 88.33	Average 1 and 2	4.16					2	1	3.83				1	1	1
Last test, 141.00															
	Average all	3.33				2	1		3.00			1	1	1	
3 (old) F_1a															
Males	Average 3, 4 and 5	2.50			1	2			2.16			1	2		
	Last test	2.33			2	1			1.33		2	1			
Average number tests, 4.00															
Range of tests, 4	First test	4.33					4	2	4.33				1	2	3
Average age in days:															
First test, 85.66	Average 1 and 2	4.08					4	2	3.50				2	4	
Last test, 138.00															
	Average all	3.37				3	3		2.70			1	5		
6 (old) F_1a															
Females	Average 3, 4 and 5	2.66			1	4	1		1.92		1	2	3		
	Last test	2.50			3	3			2.33		1	2	3		

14. A comparison of the first part of table 13 with the first part of table 4 shows that while the older mice average higher in wildness and savageness in the first test (4.44 and 4.44, respectively, to 3.98 and 3.97), they grade lower in the fifth test (2.44 and 2.00 to 2.75 and 2.04). When the results of the males and the females are separated the above statement

remains true with the exception of the grade for savageness of the old F_1a females which exceeds that of the F_1a females of ordinary age as shown in table 6. The results of the 48 F_2a's of table 14 when compared with the second part of table 4 and with table 7 indicate that the greater age has caused a

TABLE 14

Summary of Results of Tests of Old Mice of Second Generation Hybrids, F_2, of Series A

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 3.98															
Range of tests, 3–4	First test	3.79		1	7	7	19	14	3.68			4	18	15	11
Average age in days:															
First test, 85.39	Average 1 and 2	3.50			6	11	19	12	3.19			3	23	17	5
Last test, 135.41															
	Average all	2.94		1	10	23	14		2.43		3	21	17	7	
48 (old) F_2a Males and Females	Average 3, 4 and 5	2.38	1	3	17	18	9		1.64	4	16	13	11	4	
	Last test	2.04	3	11	16	17	1		1.35	16	15	4	10	3	
Average number tests, 4.00															
Range of tests, 4	First test	3.65		1	5	3	10	7	3.65			2	12	5	7
Average age in days:															
First test, 85.19	Average 1 and 2	3.17			5	8	9	4	3.01			2	16	6	2
Last test, 134.88															
	Average all	2.62		1	10	10	5		2.18		3	15	7	1	
26 (old) F_2a Males	Average 3, 4 and 5	2.07	1	3	12	6	4		1.34	4	10	7	4	1	
	Last test	1.69	3	9	7	7			1.07	10	10	1	4	1	
Average number tests, 3.95															
Range of tests, 3–4	First test	3.95			2	4	9	7	3.72			2	6	10	4
Average age in days:															
First test, 85.63	Average 1 and 2	3.88			1	3	10	8	3.41			1	7	11	3
Last test, 136.04															
	Average all	3.33				13	9		2.73			6	10	6	
22 (old) F_2a Females	Average 3, 4 and 5	2.76			5	12	5		2.04		6	6	7	3	
	Last test	2.45		2	9	10	1		1.68	6	5	3	6	2	

decrease in the grades of wildness and savageness of all the tests.

2. The number of tests was increased to eight, and the grades of the last three tests noted.

The individuals used in this experiment numbered 17, and were of the F_2a. The results are given in table 15. The

results of the first five tests are essentially the same as those given for the F_2 a's in tables 4 and 7, showing that these 17 individuals were normal. The significance of the table is merely

TABLE 15

Summary of Results for Seventeen Individuals of Second Generation Hybrids, Series A when the number of Tests is increased to Eight

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 8															
Range of tests, 8	First test.....	3.29			3	8	4	2	3.88			1	4	8	4
Average age in days:															
First test, 57.88	Average 1 and 2.....	3.52				8	6	3	3.38			2	6	7	2
Fifth test, 121.82															
Eighth test, 167.82	Average first 5 .	3.06			1	13	3		2.59		3	5	6	2	1
17 F_2a males and females	Average 3, 4, and 5.....	2.74		2	3	10	2		2.00	2	5	1	7	2	
	Fifth test.....	2.82		2	5	5	3	2	2.00	3	3	5	4	1	1
	Average 6, 7, and 8.....	1.64		8	6	2	1		1.30	6	4	3	3	1	
	Eighth test.....	1.47	2	7	3	5			1.00	8	5		4		
Average number tests, 8															
Range of tests, 8	First test.....	3.58			1	3	1	2	4.33				1	4	2
Average age in days:															
First test, 57.54	Average 1 and 2	3.57				3	3	1	3.47			2	2	3	
Fifth test, 121.77															
Eighth test, 167.77	Average first 5	2.19			1	5	1		1.39		2	3	2		
7 F_2a Males	Average 3, 4 and 5.....	2.30		2	2	3			1.30	2	3		2		
	Fifth test.....	1.85		2	4	1			1.14	3	1	2	1		
	Average 6, 7 and 8.....	1.22		6	1				0.40	6		1			
	Eighth test	1.00	2	4		1			0.42	6			1		
Average number tests, 8															
Range of tests, 8	First test.....	3.10			2	5	3		3.70			1	3	4	2
Average age in days:															
First test, 57.92	Average 1 and 2	3.50				5	3	2	3.60				4	4	2
Fifth test, 121.98															
Eighth test, 167.97	Average first 5 .	2.82				8	2		2.60		1	2	4	2	1
10 F_2a females	Average 3, 4 and 5.....	3.06			1	7	2		2.56		2	1	5	2	
	Fifth test.....	3.60			2	4	3	2	2.60		2	3	3	1	1
	Average 6, 7 and 8.....	2.13		2	5	2	1		1.96		4	2	3	1	
	Eighth test.....	2.10		3	3	4			1.40	2	5		3		

to show that the decrease in the grades of wildness and savageness continues with the successive tests when the number of tests is increased to eight.

3. Litters were equally divided and the individuals of one group were tested every day or every two days until the five tests were given, while the individuals of the other group were tested at the usual times.

The division of the mice in this experiment depended entirely upon the order in which the mice were caught for their first test. The first mouse was put in the cage of those to be tested at the usual times and the second was put into the cage of those to be tested daily. Hence, each litter was divided into two practically equal groups which, having the same ancestry, should form a basis for a fairly accurate estimate of the effect of frequency of tests upon the lowering of the grades of wildness and savageness.

The first mice to be used in this experiment were the 12 wild mice raised in the laboratory and later used as wild parental stock (table 1). There were two litters of six mice each. One litter had four males and two females and the other two males and four females. They were therefore not divided according to chance, as has just been mentioned but into two groups of three males and three females each. The results of the group with the usual time intervening between the tests (Group 1) are given in table 16, and those receiving daily tests (Group 2) in table 17. In the case of wildness, when the results of the males and females are considered together as are shown in the first part of the tables, the averages are identical with the exception of that for the fifth test which is 0.34 grade greater for the mice tested daily. The averages of the first test for savageness are also the same for both groups, and the remaining compare very favorably, the difference being in no case greater than 0.25 grade. When the results for the males and females are considered separately the females of Group 2 are seen to grade, as a rule, slightly higher than those of Group 1.

The sixth and seventh tests of the mice of Group 2 were given at the same time the mice of Group 1 were receiving their fourth and fifth tests. Assuming that the three factors, namely, age, presence of the experimenter while feeding and testing, and the handling during the tests, each have a certain effect on the lowering of the grades in successive tests; a comparison of the averages of the fourth and the fifth tests of the mice of Group 1 with the averages of the sixth and seventh tests of those of

Group 2 should give the measure of the effect of the two extra tests, since the ages of both groups are the same and hence, the effect of the presence of the experimenter would likewise be equal. In the case of the males this effect seems to be indicated in both wildness and savageness as the average grades for the

TABLE 16

Summary of Results of Group 1, Parental Generation, Wild, Tested at Usual Times

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 5															
Range of tests, 5	First test.....	5.0						6	4.5				1	1	4
Average age in days:															
First test, 37	Average 1 and 2	5.0						6	4.58					2	4
Fourth test, 70															
Last test, 88	Average all.....	4.83						6	4.23					4	2
6 P (Wild)															
males and	Average 3, 4 and 5...	4.66					1	5	4.0				2	3	1
females	Average 4 and 5	4.58					1	5	3.83				1	4	1
	Last test.....	4.16				1	3	2	3.0			1	4	1	
Average number tests, 5															
Range of tests, 5	First test.....	5.0						3	4.66				1		2
Average age in days:															
First test, 37	Average 1 and 2	5.0						3	4.66					1	2
Fourth test, 70															
Last test, 88	Average all.....	4.86						3	4.2					2	1
3 P (Wild)															
Males	Average 3, 4 and 5..	4.77					1	2	3.88				1	1	1
	Average 4 and 5	4.66						3	3.66				1	2	
	Last test.....	4.33				1	1	1	2.66			1	2		
Average number tests, 5															
Range of tests, 5	First test.....	5.0						3	4.33					1	2
Average age in days:															
First test, 37	Average 1 and 2....	5.0						3	4.5					1	2
Fourth test, 70															
Last test, 88	Average all.....	4.8						3	4.36					2	1
3 P (Wild)															
females	Average 3, 4 and 5..	4.66					1	2	4.11				1	2	
	Average 4 and 5	4.5					1	2	4.0					2	1
	Last test.....	4.0					2	1	3.33				2	1	

sixth and the seventh tests of Group 2 are, respectively, 0.66 and 0.33 of a grade lower than the averages for the fourth and fifth tests of Group 1. In the case of the females, however, this does not maintain inasmuch as the averages for wildness are identical in each group and the average for savageness in the sixth and seventh tests of Group 2 is 0.5 of a grade higher

than that for the fourth and fifth tests of Group 1. The differences in the grades of these wild individuals are so slight and the number of mice so small that these results cannot be con-

TABLE 17

Summary of Results of Group 2, Parental Generation, Wild, Tested Daily

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 7															
Range of tests, 7	First test	5.0						6	4.5				1	1	4
Average age in days:															
First test, 37	Average 2 and 1	5.0						6	4.33				2		4
Fifth test, 41															
Sixth test, 70	Average first 5	4.83					1	5	4.11				2	1	3
Seventh test, 88															
	Average 3, 4 and 5	4.66					1	5	4.2				2	2	2
6 P (Wild)															
males and															
females	Fifth test	4.5				1	1	4	4.0				2	2	2
	Average 6 and 7	4.25					3	3	3.91				2	1	3
Average number tests, 7															
Range of tests, 7	First test	5.0						3	4.0				1	1	1
Average age in days:															
First test, 37	Average 1 and 2	5.0						3	3.66				2		1
Fifth test, 41															
Sixth test, 70	Average first 5	4.66					1	2	3.86				2		1
Seventh test, 88															
	Average 3, 4 and 5	4.44					1	2	4.0				1	1	1
3 P (Wild)															
Males	Fifth test	4.0				1	1	1	4.0				1	1	1
	Average 6 and 7	4.0					2	1	3.33				2		1
Average number tests, 7															
Range of tests, 7	First test	5.0						3	5.0						3
Average age in days:															
First test, 37	Average 1 and 2	5.0						3	5.0						3
Fifth test, 41															
Sixth test, 70	Average first 5	5.0						3	4.53					1	2
Seventh test, 88															
	Average 3, 4 and 5	5.0						3	4.22				1	1	1
3 P (Wild)															
Females	Fifth test	5.0						3	4.0				1	1	1
	Average 6 and 7	4.5					1	2	4.5					1	2

sidered of very great value. The chief significance of tables 16 and 17 is to give an example of the reactions of wild mice to the conditions of the experiment and thus furnish a basis for the more accurate judgment of the hybrids.

Mice from F_1b were next used in this study. 14 individuals comprised Group 1 and 16 Group 2. The results are given in tables 18 and 19. From F_2b four groups were used. The mice forming two of these groups were very much younger than those comprising the other two groups of F_2b and also the two

TABLE 18

Summary of Results of Group 1, First Generation Hybrids, F_1, of Series B, Tested at the Usual Times

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 5															
Range of tests, 5	First test	4.14				2	8	4	4.57				1	4	9
Average age in days:															
First test, 52.00	Average 1 and 2	4.35					7	7	4.53					5	9
Last test, 82.28															
	Average all	4.05				2	10	2	3.94			1	4	6	3
14 F_1b males and females	Average 3, 4 and 5	3.88				4	8	2	3.54		1	1	7	3	2
	Last test	4.07				1	11	2	3.21			2	5	5	2
Average number tests, 5															
Range of tests, 5	First test	4.35				1		2	4.33				1		2
Average age in days:															
First test, 36.00	Average 1 and 2	4.66					1	2	4.66					1	2
Last test, 66															
	Average all	4.26				1	1	1	3.8				1	1	1
3 F_1b Males	Average 3, 4 and 5	4.0				1	1	1	3.22			1	1	1	
	Last test	4.33					2	1	3.0			1	1	1	
Average number tests, 5															
Range of tests, 5	First test	4.09				1	8	2	4.63					4	7
Average age in days:															
First test, 56.36	Average 1 and 2	4.22					6	5	4.50					4	7
Last test, 86.76															
	Average all	4.0				1	9	1	3.98			1	3	5	2
11 F_1b females	Average 3, 4 and 5	3.84				3	7	1	3.63		1		6	2	2
	Last test	4.0				1	9	1	3.27			1	4	4	2

groups of F_1b. There were 37 of these younger mice, 19 in Group 1 and 18 in Group 2. The results are presented in tables 20 and 21. Group 1 of the older mice contained 17 individuals, while 19 mice comprised Group 2. The results of the tests of these are given in tables 22 and 23.

TABLE 19

Summary of Results of Group 2, First Generation Hybrids, F_1, of Series B, Tested Daily

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 5.86															
Range of tests, 4–6	First test	4.62				1	4	11	4.62				1	4	11
Average age in days:															
First test, 54.0	Average 1 and 2	4.22				1	7	8	4.35				1	7	8
Fifth test, 58.93															
Sixth test, 86.21	Average first 5	4.06				1	13	2	3.87				4	10	2
	Average 3, 4 and 5	3.98				3	12	1	3.58				4	10	2
16 F_1b Males and Females	Fifth test (15)	3.42				6	6	3	3.06	1		1	8	4	1
	Sixth test (14)	3.78			1	4	6	3	3.78			1	4	6	3
Average number tests, 5.4															
Range of tests, 4–6	First test	4.8					1	4	4.4					3	2
Average age in days:															
First test, 43.4	Average 1 and 2	4.2					2	3	3.8				1	4	
Fifth test, 48.2															
Sixth test, 76.66	Average first 5	3.8				1	4		3.6				2	3	
5 F_1b Males	Average 3, 4 and 5	3.57				2	3		3.07				2	3	
	Fifth test (4)	3.0				4			2.0	1		1	2		
	Sixth test (3)	4.0				1	1	1	4.0				1	1	1
Average number tests, 6															
Range of tests, 6	First test	4.54				1	3	7	4.72				1	1	9
Average age in days:															
First test, 58.81	Average 1 and 2	4.22				1	5	5	4.59					3	8
Fifth test, 63.81															
Sixth test, 88.81	Average first 5	4.14					9	2	4.07				2	7	2
11 F_1b Females	Average 3, 4 and 5	4.09				1	9	1	3.72				2	7	2
	Fifth test	4.09				2	6	3	3.54				6	4	1
	Sixth test	3.72			1	3	5	2	3.72			1	3	5	2

The sixth test of Group 2 of each set was given at the same time the mice of the corresponding Group 1 received their fifth test. It is to be noted that while the average grade for

the sixth test is greater in each case than that for the fifth test of the same group, (First section of tables 19, 21, and 23), due, without doubt, to the absence of any handling by the experimenter during the 27 or 28 days intervening since the fifth test, yet only in the case of the younger mice of F_2b is the aver-

TABLE 20

Summary of Results of Group 1, Second Generation Hybrids, F_2, of Series B, Tested at Usual Times

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 4.89															
Range of tests, 3–5	First test	4.0	1			2	10	6	3.94	1	1		3	5	9
Average age in days:															
First test, 34.52	Average 1 and 2	3.89		1	1		8	9	4.18		1	2		5	12
Last test, 65.15															
	Average all	3.18		2		7	9	1	3.18	1	1	2	4	11	
19 F_2b Males and Females	Average 3, 4 and 5	2.69	1	1	2	8	6	1	2.49	1	3	3	4	7	1
	Last test	2.42	2	1	4	6	5	1	1.78	6	1		8	3	1
Average number tests, 5															
Range of tests, 5	First test	3.7	1			1	5	2	3.8	1	1			3	4
Average age in days:															
First test, 34.4	Average 1 and 2	3.45		1	1		4	3	3.9		1	1		2	5
Last test, 66.3															
	Average all	2.98		2		4	3		3.12	1	1	1	1	5	
9 F_2b Males	Average 3, 4 and 5	2.66	1	1	1	3	3		2.6	1	2	1	1	4	
	Last test	2.4	2		2	3	2		2.3	3	1		3	2	
Average number tests, 4.77															
Range of tests, 3–5	First test	4.33				1	5	4	4.11				3	2	5
Average age in days:															
First test, 34.64	Average 1 and 2	4.37					4	6	4.5					3	7
Last test, 62.22															
	Average all	3.41				3	6	1	3.25			1	3	6	
10 F_2b Females	Average 3, 4 and 5	2.72			1	5	3	1	2.36		1	2	3	3	1
	Last test	2.44		1	2	3	3	1	1.22	3			5	1	1

age grade for wildness in the sixth test of Group 2 greater than that for wildness in the fifth test of the corresponding Group 1 (table 20). The average grade for savageness for the sixth tests of each Group 2 is greater than that for the fifth test of the corresponding Group 1.

The explanation for the fact that the sixth test for wildness of the older mice in the second groups did not follow that of the younger mice in being higher in grade than the fifth test of the corresponding first groups may be found in the difference observed in the general type of reaction to handling as the

TABLE 21

Summary of Results of Group 2, Second Generation Hybrids, F_2, of Series B, Tested Daily

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 5.94															
Range of tests, 5–6	First test	4.05				5	7	6	4.44				3	4	11
Average age in days:															
First test, 35.11	Average 1 and 2	3.66				5	9	4	4.05				4	6	8
Fifth test, 39.88															
Sixth test, 66.64	Average first 5	3.45			2	9	6	1	3.52		1	1	6	7	3
18 F_2b Males	Average 3, 4 and														
and Females	5	3.31			1	9	8		3.16		1	3	6	4	4
	Fifth test	3.05			3	11	4		2.77	2	2	1	8	3	2
	Sixth test	3.35			1	9	7		3.82		1	1	5	3	7
Average number tests, 5.88															
Range of tests, 5–6	First test	4.11				1	6	2	4.44				2	1	6
Average age in days:															
First test, 35.33	Average 1 and 2	3.33				4	5		3.83				4	1	4
Fifth test, 40.33															
Sixth test, 66.00	Average first 5	3.06			2	6	1		3.2		1	1	3	4	
9 F_2b	Average 3, 4 and														
Males	5	2.88			1	7	1		2.77		1	2	3	3	
	Fifth test	2.77			2	7			2.22	2	1		5	1	
	Sixth test	3.12			1	5	2		3.0		1	1	4	1	1
Average number tests, 6															
Range of tests, 6	First test	4.0				4	1	4	4.48				1	3	5
Average age in days:															
First test, 34.88	Average 1 and 2	4.0				1	4	4	4.27					5	4
Fifth test, 39.44															
Sixth test, 67.22	Average first 5	3.84				3	5	1	3.84				3	3	3
9 F_2b	Average 3, 4 and														
Females	5	3.74				2	7		3.55			1	3	1	4
	Fifth test	3.33			1	4	4		3.33		1	1	3	2	2
	Sixth test	3.55				4	5		4.55				1	2	6

hybrids grew older. There seemed to be a lesser tendency to violent reactions of either wildness or savageness with a somewhat more agressiveness in the latter. With age they became, as it were, more deliberate in their movements.

In order to compare more easily the results included in tables 18 to 23 inclusive, the more important points of these

have been brought together in table 24. The headings at the top show the different hybrid generations and the groups. The headings at the side indicate (*a*) the table in which the complete results of a group may be found, (*b*) the number of mice in each groups, (*c*) the average age in days of the group at the first test, the fifth test, and the difference between these

TABLE 22

Summary of Results of Group 1, Second Generation Hybrids, F_2, of Series B, Tested at Usual Times

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 5															
Range of tests, 5	First test.....	4.0				6	5	6	4.05				6	4	7
Average age in days:															
F rst test, 59.82	Average 1 and 2...	4.14				1	7	9	4.35					8	9
Last test, 91.35															
	Average all.....	3.84				5	10	2	3.49			3	4	7	3
17 F_2b Males	Average 3, 4 and														
and Females	5.....	3.64				8	9		2.92		2	4	7	2	2
	Last test.....	3.64			2	4	9	2	2.58	3	1	3	6	1	3
Average number tests, 5															
Range of tests, 5	First test.....	4.0				3	1	3	4.0				3	1	3
Average age in days:															
First test, 59.57	Average 1 and 2...	4.14				1	4	2	4.42					3	4
Last test, 91.14															
	Average all.....	3.85				2	3	2	3.42				3	4	
7 F_2b	Average 3, 4 and														
Males	5.....	3.66				1	6		2.76		1	2	3	1	
	Last test.....	3.57			1	2	3	1	1.85	2	1	1	2	1	
Average number tests, 5															
Range of tests, 5	First test.....	4.0				3	4	3	4.1				3	3	4
Average age in days:															
First test, 60.0	Average 1 and 2...	4.15					3	7	4.3					5	5
Last test 91.5															
	Average all.....	3.84				3	7		3.6			3	1	3	3
10 F_2b	Average 3, 4 and														
Females	5.....	3.63				7	3		3.13		1	2	4	1	2
	Last test.....	3.7			1	2	6	1	3.1	1		2	4		3

ages, or in other words, the number of days required for the tests in each group, (*d*) the average grade of wildness for the first test, for the fifth test, the difference between the first and fifth, the average of the first and second tests for wildness, the average for wildness as shown by the third, fourth, and fifth tests, and the difference between these two averages. Imme-

diately below this, the results for savageness are treated in a like manner. Following this are given, (*f*) the difference between the number of days required for the tests in Group 1 and in Group 2, (*g*) the difference in decrease in the average grade of wildness of Group 1 and Group 2 as shown by the difference

TABLE 23

Summary of Results of Group 2, Second Generation Hybrids, F_2, of Series B, Tested Daily

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 6															
Range of tests, 6	First test	4.52				1	7	11	4.26			1	3	5	10
Average age in days:															
First test, 59.42	Average 1 and 2	4.18				2	8	9	4.15				3	4	12
Fifth test, 64.42															
Sixth test, 91.0	Average first 5	3.89			2	2	11	4	3.46		2	1	7	4	5
19 F_2b Males	Average 3, 4 and														
and Females	5	3.7			2	6	7	4	2.94	1	1	6	5	2	4
	Fifth test	3.31		1	4	6	4	4	2.68	4		3	6	3	3
	Sixth test	3.63	1			9	3	6	3.47	2		2	4	5	6
Average number tests, 6															
Range of tests, 6	First test	4.7					3	7	4.5				1	3	6
Average age in days:															
First test, 59.3	Average 1 and 2	4.05				1	4	5	4.05				3	1	6
Fifth test, 64.3															
Sixth test, 90.9	Average first 5	3.76			1	2	5	2	3.4		1	1	3	3	2
10 F_2b	Average 3, 4 and														
Males	5	3.53			1	6	2	1	2.93		1	2	5	1	1
	Fifth test	3.3			3	3	2	2	3.1	1		1	4	2	2
	Sixth test	3.6				6	2	2	3.4	1		2	1	3	3
Average number tests, 6															
Range of tests, 6	First test	4.33				1	4	4	4.0			1	2	2	4
Average age in days:															
First test, 59.55	Average 1 and 2	4.27				1	4	4	4.22					3	6
Fifth test, 64.55															
Sixth test, 91.11	Average first 5	4.04			1		6	2	3.46		1		4	1	3
9 F_2b Females	Average 3, 4 and														
	5	3.88			1		5	3	2.96	1		4		1	3
	Fifth test	3.33		1	1	3	2	2	2.22	3		2	2	1	1
	Sixth test	3.66	1			3	1	4	3.55	1			3	2	3

in the average grades of tests one and two and of tests three, four and five, (*h*) the rate of decrease per day as obtained by dividing the fraction of a grade found in (*g*) by the number of days obtained in (*f*). Following this in (*i*) the same values are found for savageness.

The decrease in both wildness and savageness for hybrids F_1b (tables 18 and 19) compares very favorably with the older mice of F_2b (tables 22 and 23), except that the latter show a

TABLE 24

General Summary of Tables 18, 19, 20, 21, 22, and 23

	1 HYBRIDS F_1b		2 HYBRIDS F_2b		3 HYBRIDS F_2b	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
Table	18	19	20	21	22	23
Number of mice	14	16	19	18	17	19
Average age in days:						
Fifth test	82.28	58.93	65.15	39.88	91.35	64.42
First test	52.00	54.00	34.52	35.11	59.82	59.42
Difference	30.28	4.93	30.63	4.77	31.53	5.0
Wildness, average grade:						
First test	4.14	4.62	4.0	4.05	4.0	4.52
Fifth test	4.07	3.42	2.42	3.05	3.64	3.31
Difference	0.07	1.20	1.58	1.0	0.36	1.21
Tests 1 and 2	4.35	4.22	3.89	3.66	4.14	4.18
Tests 3, 4 and 5	3.88	3.93	2.69	3.31	3.64	3.7
Difference	0.47	0.29	1.20	0.35	0.50	0.48
Savageness, average grade:						
First test	4.57	4.62	3.94	4.44	4.05	4.26
Fifth test	3.21	3.06	1.78	2.77	2.58	2.68
Difference	1.36	1.56	2.16	1.67	1.47	1.58
Tests 1 and 2	4.53	4.35	4.18	4.05	4.35	4.15
Tests 3, 4 and 5	3.54	3.53	2.49	3.16	2.92	2.94
Difference	0.99	0.82	1.69	0.89	1.43	1.21
Difference in number days required for tests in Group 1 and Group 2		25.35		25.86		26.53
Difference in decrease in average grade of Group 1 and Group 2, as shown by tests 1 and 2, and 3, 4, and 5:						
Wildness		0.18		0.85		0.02
Rate of decrease per day		0.0071		0.0328		0.00075
Savageness		0.17		0.80		0.22
Rate of decrease per day		0.0067		0.0309		0.00829

slightly greater decrease than the former. Between these two, however, and the younger mice of F_2b (tables 20 and 21) there is a striking difference. Considering the difference between the first and last tests for wildness and savageness in

each of the three sets of groups (numbered for sake of convenience, 1, 2, and 3), it is to be noted that this difference in Group 2 of the first and third set is greater than the difference in the corresponding Group 1, while in the second set the reverse is true. In other words, with the older mice, whether they are from F_1b or F_2b, the decrease in grade of wildness and savageness is greater when the mice are tested every day than when they are tested at intervals of six or eight days, but with the younger mice the daily testing shows the lesser decrease.

When, however, the decreases are considered from the differences of the averages of tests one and of tests three, four and five, the results are uniform in all three sets of groups, that is, the results in the first and third set are reversed and in each set the tests given at intervals of 6 or 8 days show a greater decrease in the grades of wildness and savageness than in the case of the daily testing. It is the opinion of the writer that the difference between the average of the first and second tests and the third, fourth and fifth tests forms the more accurate basis for the judgment of the rate of lowering of the grades of wildness and savageness, since the effect of an error in testing is thus minimized.

Assuming that a test has an equal effect in lowering the grade of wildness or savageness of the mice in Group 1 and Group 2, from the results in table 24 it is possible to obtain an approximate estimate of the effect of age plus the effect of the presence of the experimenter in the room while feeding, cleaning cages and testing other mice. For instance, in the case of Group 1, F_1b, 0.47 grade represents the lessening of wildness due to the effect of five testings, plus 30.28 days of age and the presence of the experimenter during that time. From Group 2, F_1b, it is observed that 0.29 grade represents the lessening of wildness due to the effect of five testings, plus 4.93 days of age and the effect of the presence of the experimenter. Subtracting the results of Group 2 from those of Group 1, there is a remainder of 0.18 grade which represents the lessening of the wildness due to the effects of 25.35 days of age and the presence of the experimenter during that time. In the same way the lessening in savageness for the same reasons is found to be 0.85 grade. By dividing the amount of decrease by the number of days are obtained the rates of decrease per day which in

this case are 0.0071 grade for wildness and 0.0067 grade for savageness. These represent the grade-lowering effect of age and the presence of the experimenter exerted each day on the mice of F_1b when they receive their first test at the average age of 53 days. Likewise the rates per day for wildness and savageness of the younger mice of Fb are, respectively, 0.0328 grade and 0.0309 grade, and for the older mice of F_2b, 0.00075 grade and 0.00829 grade. It would thus seem that age and the presence of the experimenter have an effect in lessening the grade of wildness and savageness of the mice inversely in proportion to the age of the mouse, providing the first test is given when the mice are between 33 and 60 days old. The rates according to sex are as follows:

	WILDNESS RATE OF DECREASE PER DAY	SAVAGENESS RATE OF DECREASE PER DAY
F_1b		
Males	0.00833	0.0281
Females	0.00976	0.0000
F_2b (Young)		
Males	0.0126	0.00892
Females	0.0603	0.0616
F_2b (Old)		
Males	0.00225	0.0203
Females	0.0049	−0.00339

From these results it is seen that the females had a higher rate of decrease per day for both wildness and savageness except in savageness of the F_1b and the F_2b (Old), in which cases it was zero for the former and a negative quantity (0.00339) for the latter.

C. Results from crossing wild females with tame males in comparison with the results from crosses of tame females with wild males

The hybrids used by Professor Yerkes in his study were all obtained by crossing tame female rats with wild male rats. It was to neutralize the effect due to the possibility of the parent of one sex exerting a stronger hereditary and environmental influence on the offspring than the parent of the opposite sex that the first generation hybrids of both series of this study were obtained about equally from wild females crossed with tame

males and from tame females crossed with wild males. For the same reason both parents were allowed to remain, with few exceptions, in the cage with the young until they were weaned. It is proposed, in this section of the paper, to present for closer consideration groups of hybrid individuals of the

TABLE 25

Summary of Results of First Generation Hybrids, F_1, of Series A, from Matings of Parental Generation, Tame Female with Wild Male

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	2	4	5
Average number tests, 4.06															
Range of tests, 3–5	First test	4.02				11	22	12	4.04				11	21	13
Average age in days:															
First test, 43.14	Average 1 and 2	3.61			2	11	23	9	3.55				18	18	9
Last test, 63.0															
	Average all	3.15			4	29	12		2.79			15	20	8	2
45 F_1a Males	Average 3, 4 and														
and Females	5	2.70			17	24	3	1	2.06			9	19	15	2
	Last test	2.44		3	21	19	2		1.75	4	17	10	14		
Average number tests, 4.17															
Range of tests, 3–5	First test	3.88				6	7	4	4.0				5	7	5
Average age in days:															
First test, 32.11	Average 1 and 2	3.47				8	6	3	3.61				8	4	5
Last test, 56.2															
	Average all	2.87			3	13	1		2.80			5	7	3	2
17 F_1a	Average 3, 4 and														
Males	5	2.32			10	7			2.05			4	6	6	1
	Last test	2.29		2	8	7			1.2	2	8	3	4		
Average number tests 4.0															
Range of tests, 3–5	First test	4.10				5	15	8	4.07				6	14	8
Average age in days:															
First test, 49.85	Average 1 and 2	3.69			2	3	17	6	3.51				10	14	4
Last test, 67.25															
	Average all	3.33			1	16	11		2.79			10	13	5	
28 F_1a	Average 3, 4 and														
Females	5	2.96			7	17	3	1	2.07			5	13	9	1
	Last test	2.53		1	13	12	2		1.25	2	9	7	10		

first, second and third generations obtained from a cross of wild females with tame males and other groups obtained from a cross of tame females with wild males. In most cases the individuals of the F_2 were offspring of the F_1 mice represented in the tables, likewise most of the F_3 mice were obtained from matings of the F_2.

The results of tests of the group of first generation hybrids of Series A from matings of tame females with wild males are presented in table 25, and from matings of wild females with tame males in table 26, while those of Series B are to be found in tables 27 and 28, respectively. In the same order the results from the second generation hybrids are given in tables 29,

TABLE 26

Summary of Results of First Generation Hybrids, F_1, of Series A, from Matings of Parental Generation, Wild Female with Tame Male

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 4.52															
Range of tests, 4–5	First test	4.0		1	1	10	23	15	4.0	1			11	23	15
Average age in days:															
First test, 35.84	Average 1 and 2	3.91			1	6	29	14	3.63				9	36	5
Last test, 62.38															
	Average all	3.36			1	21	26	2	2.96			10	26	13	1
50 F_1a Males	Average 3, 4 and														
and Females	5	2.93			4	29	15	2	2.42		4	15	21	8	2
	Last test	3.02		1	12	24	11	2	2.07	4	11	11	17	6	1
Average number tests, 4.52															
Range of tests, 4–5	First test	4.08		1		4	9	9	3.65	1			8	10	4
Average age in days:															
First test, 31.53	Average 1 and 2	4.04			1	2	17	3	3.34				7	15	1
Last test, 62.16															
	Average all	3.48				7	14	2	2.81		6	12	5		
23 F_1a Males	Average 3, 4 and														
	5	3.03			3	9	10	1	2.39		1	9	8	5	
	Last test	3.17			4	12	6	1	2.25	2	5	5	7	4	
Average number tests, 4.51															
Range of tests, 4–5	First test	3.92			1	6	14	6	4.29				3	13	11
Average age in days:															
First test, 34.44	Average 1 and 2	3.79				4	12	11	3.87				2	21	4
Last test, 62.57															
	Average all	3.27			1	14	12		3.08			4	14	8	1
27 F_1a Females	Average 3, 4 and														
	5	2.85			1	20	5	1	2.45		3	6	13	3	2
	Last test	2.88		1	8	12	5	1	1.92	2	6	6	10	2	1

30, 31, and 32; and those from the third generation hybrids in tables 33, 34, 35, and 36.

The differences in the results of the tests of these mice are so slight that no attempt will be made to discuss each table separately. The essential points from all the tables have been brought together and are presented in table 37. In the first

column of this table will be found the average grade for all the tests and the average grade for the third, fourth, and fifth tests for wildness and savageness of the first, second, and third generation hybrids of Series A from the matings of tame females with wild males. In the second column are given the

TABLE 27

Summary of Results of First Generation Hybrids, F_1, of Series B, from Matings of Parental Generation, Tame Female with Wild Male

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 5															
Range of tests, 5	First test	4.43				3	11	16	4.2				9	5	16
Average age in days:															
First test, 36.26	Average 1 and 2	4.13				3	10	17	4.01				5	12	13
Last test, 73.26															
	Average all	3.54			2	10	17	1	2.8		1	7	13	9	
30 F_1b Males	Average 3, 4 and														
and Females	5	3.14			7	12	11		2.21	3	6	8	8	5	
	Last test	3.0		3	4	15	6	2	1.96	8	4	4	10	3	1
Average number tests, 5															
Range of tests, 5	First test	4.33				2	4		3.66				4		2
Average age in days:															
First test, 37	Average 1 and 2	3.91				2	3	1	3.58				3	1	2
Last test, 73.0															
	Average all	3.13			2	3	1		2.33		1	3		2	
6 F_1b Males	Average 3, 4 and														
	5	2.61			3	2	1		1.50	2	1	1	2		
	Last test	3.0			2	2	2		1.66	2	1	1	1	1	
Average number tests, 5															
Range of tests, 5	First test	4.86				1	7	16	4.72				5	5	14
Average age in days:															
First test, 39.36	Average 1 and 2	4.18				1	7	16	4.12				2	11	11
Last test 80.0															
	Average all	3.64				7	16	1	3.08			4	13	7	
24 F_1a females	Average 3, 4 and														
	5	3.25			4	10	10		2.38	1	5	7	6	5	
	Last test	3.27		3	2	13	4	2	2.22	6	3	3	9	2	1

sexes which attained the higher average grade in these tests. In the third and fourth columns are presented the like values for Series B of the same matings, while in the fifth and sixth, and the seventh and eighth columns are given these values for Series A and Series B, respectively, from matings of wild females with tame males.

From this table it is readily seen that the mice of Series A, tame female by wild male, became generally less wild and less savage in succeeding generations according to the averages of all the tests and the averages of the third, fourth, and fifth tests, the only exception being the average of all the tests for savageness of the F_2 hybrids, which grade is greater than the

TABLE 28

Summary of Results of First Generation Hybrids, F_1, of Series B, from Matings of Parental Generation, Wild Female with Tame Male

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 4.65															
Range of tests, 4–5	First test	3.76		1		10	8	7	4.07			1	7	7	11
Average age in days:															
First test, 39.76	Average 1 and 2	3.61		1	1	6	11	7	3.94			1	4	11	10
Last test, 104.52															
	Average all	3.35			5	9	9	3	3.25			7	6	10	3
26 F_1b Males	Average 3, 4 and														
and Females	5	3.16		1	6	10	6	3	2.73	1	3	6	6	8	2
	Last test	3.22		2	4	10	6	4	2.47	5	1	6	9	4	1
Average number tests, 4.53															
Range of tests, 4–5	First test	3.71		1		7	4	5	3.88			1	6	4	6
Average age in days:															
First test, 37.70	Average 1 and 2	3.14		1	1	6	4	5	3.73			1	4	7	5
Last test, 101.88															
	Average all	2.93			5	5	5	2	2.93			7	4	4	2
17 F_1b	Average 3, 4 and														
Males	5	2.74		1	6	6	3	1	2.3	1	3	5	3	4	1
	Last test	2.76		2	3	9	3		1.44	5	1	4	6	1	
Average number tests, 4.88															
Range of tests, 4–5	First test	3.88				3	4	2	4.44				1	3	5
Average age in days:															
First test, 32.77	Average 1 and 2	4.44					7	2	4.33					4	5
Last test, 107.48															
	Average all	4.09				4	4	1	3.81				2	6	1
9 F_1b Females	Average 3, 4 and														
	5	3.84				4	3	2	3.46			1	3	4	1
	Last test	4.11			1	1	3	4	3.62			2	3	3	1

like average of the F_1 or the F_3. The females of this series were, as a rule, more savage than the males, and were also more wild in the first and second generations, the males grading higher in wildness in the third generation.

The results of the crosses of Series B, tame female by wild male, are directly opposed to those of Series A, the mice in this

case attaining, without exception, increasingly higher average grades of wildness and savageness in the successive generations. In this series, again, the females grade higher in wildness and savageness in the first two generations while the males of the third generation were both more wild and more savage than the females.

TABLE 29

Summary of Results of Second Generation Hybrids, F_2, of Series A, from Matings of Parental Generation, Tame Female with Wild Male

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 4.39															
Range of tests, 3–5	First test	3.51		1	3	16	16	5	4.12			1	6	21	13
Average age in days:															
First test, 47.78	Average 1 and 2	3.35			2	17	19	3	3.47		1	5	8	20	7
Last test, 115.22															
	Average all	2.92			11	22	7	1	3.21		4	15	13	8	1
41 F_2a Males	Average 3, 5 and														
and Females	5	2.57		6	16	14	4	1	1.96	5	10	10	13	3	
	Last test	2.48	2	6	15	8	8	2	1.38	10	7	9	10	4	1
Average number tests, 4.35															
Range of tests, 4–5	First test	3.35		1	2	8	7	2	4.2				2	12	6
Average age in days:															
First test, 50.30	Average 1 and 2	3.17			1	11	8		3.4			4	5	8	3
Last test, 107.25															
	Average all	2.73			8	9	3		2.39		3	8	6	3	
20 F_2a Males	Average 3, 4 and														
	5	2.36		2	9	5	4		1.53	4	5	3	8		
	Last test	2.2	2	3	9	1	5		1.14	6	5	3	5	1	
Average number tests, 4.42															
Range of tests, 3–5	First test	3.66			1	8	9	3	4.04			1	4	9	7
Average age in days:															
First test, 45.38	Average 1 and 2	3.52			1	6	11	3	3.54		1	1	3	12	4
Last test, 120.45															
	Average all	3.10			3	13	4	1	3.97		1	7	7	5	1
21 F_2a Females	Average 3, 4 and														
	5	2.76		4	7	9		1	2.37	1	5	7	5	3	
	Last test	2.76		3	6	7	3	2	2.45	4	2	6	5	3	1

The results of both Series A and Series B of the hybrids, wild female by tame male, seem to show, as a rule, that the grades attained in wildness and savageness in the first generation are lowered in the second generation and then, in the third, raised to somewhat near that attained in the first. The exceptions to this rule are the averages for all the tests for

wildness in Series A, which show a decrease in wildness in the successive generations, and the averages of the third, fourth and fifth tests for savageness in Series B, which indicate a slight increase in savageness in each succeeding generation.

The grades in wildness and savageness attained by the females of Series B are generally in excess of those attained by

TABLE 30

Summary of Results of Second Generation Hybrids, F_2, of Series A, from Matings of Parental Generation, Wild Female with Tame Male

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 4.10															
Range of tests, 3–5	First test.....	3.96				8	24	7	3.97	1			5	16	17
Average age in days:															
First test, 38.07	Average 1 and 2..	3.84				7	22	10	3.52	1		2	6	20	10
Last test, 104.2															
	Average all.....	3.1			5	22	11	1	2.76	1	3	8	14	12	1
39 F_2a Males	Average 3, 4 and														
and Females	5.....	2.4		5	14	14	5	1	2.04	2	8	12	12	4	1
	Last test.....	2.43	2	6	11	14	5	1	0.86	7	10	9	9	3	1
Average number tests, 4.30															
Range of tests, 4–5	First test.....	4.0				3	7	3	4.23				2	6	5
Average age in days:															
First test, 31.53	Average 1 and 2..	3.8				3	7	3	3.76			1	3	4	5
Last test, 97.0															
	Average all.....	2.92			3	5	4	1	2.83		1	2	4	5	1
13 F_2a	Average 3, 4 and														
Males	5.....	2.16		4	3	2	3	1	2.03	1	2	3	5	1	1
	Last test.....	2.46	2	2	2	3	3	1	1.25	2	2	3	5		1
Average number tests, 4.															
Range of tests, 3–5	First test.....	3.96				5	17	4	3.84	1			3	10	12
Average age in days:															
First test, 41.34	Average 1 and 2..	3.86				4	15	7	3.4	1		1	3	16	5
Last test, 100.68															
	Average all.....	3.2			2	17	7		2.73	1	2	6	10	7	
26 F_2a	Average 3, 4 and														
Females	5.....	2.53		1	11	12	2		2.05	1	6	9	7	3	
	Last test.....	2.42		4	9	11	2		0.72	5	8	6	4	3	

the males. In Series A, however, the males graded higher in wildness in the first generation and higher in savageness in the third generation. In the case of the averages for savageness of F_1, Series A, tame female by wild male, and of F_2, Series B, tame female by wild male, and also in the case of the averages for wildness of F_3, Series B, wild female by tame male, the males

attained the higher grades, according to the averages of all the grades, and the females, when the averages of the last three tests are considered, however, the females are assumed to be the more savage or wild, as the case may be, since the height of the grades of the females, though not so great in the first two tests as that of the males, was more nearly maintained throughout the five tests.

TABLE 31

Summary of Results of Second Generation Hybrids, F_2, of Series B, from Matings of Parental Generation, Tame Female with Wild Male

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 4.97															
Range of tests, 4–5	First test	4.21				16	20	30	4.63		1		3	14	48
Average age in days:															
First test, 38.01	Average 1 and 2	3.99			1	10	27	28	4.42			1	1	21	43
Last test, 85.82															
	Average all	3.72		2	1	16	39	8	3.90		2	2	11	32	19
66 F_2b Males	Average 3, 4 and														
and Females	5	3.54	2	1	4	13	38	8	3.55	1	3	7	14	24	17
	Last test	3.31	2	2	8	26	17	11	2.96	8	2	6	28	11	11
Average number tests, 5															
Range of tests, 5	First test	4.2				8	10	12	4.63		1		1	5	23
Average age in days:															
First test, 38.36	Average 1 and 2	3.86			1	7	11	11	4.43			1	1	7	21
Last test, 88.36															
	Average all	3.64		1	1	9	13	6	3.79		1	1	7	12	9
30 F_2b	Average 3, 4 and														
Males	5	3.48	1	1	2	7	16	3	3.36		2	6	8	8	6
	Last test	3.33	1	1	3	13	6	6	2.7	6	1	2	13	5	4
Average number tests, 4.91															
Range of tests, 4–5	First test	4.22				8	10	18	4.63				2	9	25
Average age in days:															
First test, 37.72	Average 1 and 2	4.09				3	16	17	4.98					14	22
Last test, 83.58															
	Average all	3.79		1		7	26	2	3.99		1	1	4	20	10
36 F_2b	Average 3, 4 and														
Females	5	3.59	1		2	6	22	5	3.69	1	1	1	6	16	11
	Last test	3.30	1	1	5	13	11	5	3.2	2	1	4	16	6	7

D. General summary of individual inheritance and the results of selective breeding in the hybrid generations of both series

In this section of the study the attempt is made to indicate the differences in the inheritance of individual mice rather than

that of groups of mice as in the preceding sections. The results of the inheritance of the offspring from selected matings are included in the results of the general matings in order to give better opportunity for comparison than could otherwise be obtained.

TABLE 32

Summary of Results of Second Generation Hybrids, F_2, of Series B, from Matings of Parental Generation, Wild Female with Tame Male

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 5															
Range of tests, 5	First test.....	3.28	1	2	2	5	14	1	3.36	1		2	7	6	9
Average age in days:															
First test, 39.96	Average 1 and 2..	3.4		1	1	7	11	5	3.84		1		7	6	11
Last test, 80.23															
	Average all.....	2.92		2	4	12	7		3.2	1	1	5	7	8	3
25 F_2b Males	Average 3,														
and Females	4 and 5.....	2.6	1	1	9	10	3	1	2.77	2	3	5	6	6	3
	Last test.....	2.28	2	3	10	6	4		2.04	6	2	4	9	3	1
Average number tests, 5															
Range of tests, 5	First test.....	3.3	1	1	1	1	8	1	3.84	1		1	2	3	6
Average age in days:															
First test, 38.61	Average 1 and 2..	3.21		1	1	2	7	2	3.8		1		5	1	6
Last test, 77.15															
	Average all.....	2.66		2	2	7	2		2.95	1	1	3	2	6	
13 F_2b	Average 3,														
Males	4 and 5.....	2.3	1	1	5	5	1		2.38	2	2	3	2	4	
	Last test.....	1.76	2	3	4	4			1.46	5	2	1	5		
Average number tests, 5															
Range of tests, 5	First test.....	3.25		1	1	4	6		3.66			1	5	3	3
Average age in days:															
First test, 41.41	Average 1 and 2..	3.62				5	4	3	3.87				2	5	5
Last test, 87.91															
	Average all.....	3.2			2	5	5		3.46			2	5	2	3
12 F_2b	Average 3, 4														
Females	and 5.....	2.91			4	5	2	1	3.19		1	2	4	2	3
	Last test.....	2.83			6	2	4		2.66	1		3	4	3	1

To show to best advantage the individual inheritance, the results of the averages of the third, fourth, and fifth tests have been arbitrarily chosen as the criteria and the six grades, 0 to 5, have been divided into two equal parts. All mice which received as an average of their third, fourth and fifth tests, grades not exceeding 2.4 are considered tame and non-savage. Those whose averages of these tests were equal to or between

2.5 and 5, are considered wild and savage. It is thus seen by this arrangement that four distinct groups are possible, i.e., a mouse would be found in one of the four classes, viz: wild and savage (w-s), wild and non-savage (w-n), tame and savage (t-s), tame and non-savage (t-n). Since the averages of the tests of the wild parental stock were greater than 2.5 grade

TABLE 33

Summary of Results of Third Generation Hybrids, F_3, of Series A, from Matings of Parental Generation, Tame Female with Wild Male

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 5															
Range of tests, 5	First test.....	3.83				1	5		3.83				3	1	2
Average age in days:															
First test, 38.0	Average 1 and 2..	3.16			1	2	3		3.41				3	2	1
Last test, 112.0															
	Average all.....	2.6			3	3			2.4			4	1	1	
6 F_3a Males	Average 3, 4														
and Females	and 5.....	2.22		1	2	3			1.72		3	2	1		
	Last test.....	1.83	1	1	2	2			1.66	1	2	2		1	
Average number tests, 5															
Range of tests, 5	First test.....	3.66				1	2		3.66				2		1
Average age in days:															
First test, 38	Average 1 and 2 .	2.83			1	1	1		3.16				2	1	
Last test, 97															
	Average all	2.66			2	1			2.26			2	1		
3 F_3a	Average 3, 4														
Males	and 5	2.55			1	2			1.66		1	2			
	Last test.....	2.0		1	1	1			2.0	1		1		1	
Average number tests, 5															
Range of tests, 5	First test.....	4.0					3		4.0				1	1	1
Average age in days:															
First test 38	Average 1 and 2..	3.5				1	2		3.66				1	1	1
Last test, 127															
	Average a l.....	2.53			1	2			2.53			2		1	
3 F_3a	Average 3, 4														
Females	and 5	1.88		1	1	1			1.77		2	1			
	Last test	1.66	1		1	1			1.33		2	1			

they are classed as wild and savage, and similarly the tame parental stock are tame and non-savage inasmuch as their averages never exceeded 2.4 grade.

From the matings of the parental stock and of the first and second hybrid generations in the general and selected breeding eleven different sets are to be found. These include all the

different matings used in this study. In addition to the symbols they are designated in the tables by the Roman numerals which precede them in the following list.

I. Female wild and savage × male wild and savage (♀ w-s × ♂ w-s)
II. Female wild and savage × male wild and non-savage (♀ w-s × ♂ w-n)
III. Female wild and non-savage × male wild and savage (♀ w-n × ♂ w-s)

TABLE 34

Summary of Results of Third Generation Hybrids, F_3, of Series A, from Matings of Parental Generation, Wild Female with Tame Male

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 4.21															
Range of tests, 3–5	First test	3.5		2		4	5	3	3.92				5	5	4
Average age in days:															
First test, 41.64	Average 1 and 2	3.25			2	5	5	2	3.6			1	4	5	4
Last test, 103.22															
	Average all	2.89			7	4	3		3.05		1	2	5	4	2
14 F_3a Males	Average 3, 4														
and Females	and 5	2.58		1	6	2	5		2.54	1	1	3	5	2	2
	Last test	2.64		3	3	4	4		2.66	2		2	5	1	4
Average number tests, 3.75															
Range of tests, 3–5	First test	3.0		2		3	2	1	4.12				3	3	3
Average age in days:															
First test, 35.12	Average 1 and 2	2.81			2	3	2	1	3.75			1	1	3	3
Last test, 98.66															
	Average all	2.56			4	4			3.26		1		2	3	2
8 F_3a	Average 3,														
Males	4 and 5	2.28			5	1	2		2.71	1		1	3	1	2
	Last test	2.62		1		3	2	2	2.33	1		1	3		3
Average number tests, 4.83															
Range of tests, 4–5	First test	4.16				1	3	2	3.66				3	2	1
Average age in days:															
First test, 48.66	Average 1 and 2	3.83				2	3	1	3.41				3	2	1
Last test, 105.5															
	Average all	3.24			3		3		2.82			2	3	1	
6 F_3a	Average 3,														
Females	4 and 5	2.82		1	1	1	3		2.41		1	2	2	1	
	Last test	2.66		2		2	2		2.83	1		1	2	1	1

IV. Female wild and savage × male tame and non-savage (♀ w-s × ♂ t-n)
V. Female tame and non-savage × male wild and savage (♀ t-n × ♂ w-s)
VI. Female wild and non-savage × male wild and non-savage (♀ w-n × ♂ w-n)
VII. Female wild and non-savage × male tame and non-savage (♀ w-n × ♂ t-n)
VIII. Female tame and non-savage × male wild and non-savage (♀ t-n × ♂ w-n)
IX. Female tame and non-savage × male tame and non-savage (♀ t-n × ♂ t-n)
X. Female tame and non-savage × male tame and savage (♀ t-n × ♂ t-s)
XI. Female wild and savage × male tame and savage (♀ w-s × ♂ t-s)

A general summary of the results of the three hybrid generations, according to the above arrangements, is presented in table 38. The first column of this table, beginning at the top, gives the following values for Series A of the first hybrid generation: (a) number of litters, (b) total number of mice, (c) number of mice which were wild and savage, (d) number which were

TABLE 35

Summary of Results of Third Generation Hybrids, F_3, of Series B, from Matings of Parental Generation, Tame Female with Wild Male

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 4.62															
Range of tests, 4–5	First test.....	4.0				1	9	1	5.0						11
Average age in days:															
First test, 44.09	Average 1 and 2..	3.77				2	6	3	4.5					4	7
Last test, 87.12															
	Average all.....	3.9				5	4	2	4.37				1	5	5
11 F_3b Males	Average 3,														
and Females	4 and 5	4.0				2	6	3	4.27				1	6	4
	Last test.....	3.72			1	3	5	2	4.5				1	4	6
Average number tests, 4.8															
Range of tests, 4–5	First test.....	4.0				1	4		5.0						5
Average age in days:															
First test, 44.6	Average 1 and 2..	3.8				1	2	2	4.6					2	3
Last test, 86.25															
	Average all.....	4.08				2	1	2	4.62					2	3
5 F_3b	Average 3,														
Males	4 and 5.....	4.2				1	1	3	4.64					2	3
	Last test.....	3.8			1	1	1	2	4.75					1	4
Average number tests, 4.5															
Range of tests, 4–5	First test.....	4.0					5	1	5.0						6
Average age in days:															
First test, 43.66	Average 1 and 2 .	3.75				1	4	1	4.41					2	4
Last test, 88.0															
	Average all.....	3.74				3	3		4.14				1	3	2
6 F_3b	Average 3,														
Females	4 and 5.....	3.73				1	5		3.93				1	4	1
	Last test.....	3.66				2	4		4.25				1	3	2

wild and non-savage, (e) number which were tame and savage, (f) number which were tame and non-savage. Immediately below this are the number for the males which in turn are followed by the numbers for the females. Following these values are the numbers of mice of this series which, according to the foregoing classification were, respectively, wild, tame, savage.

and non-savage. The number of mice which were considered wild is found by adding the number of wild and savage and the number of wild and non-savage found in the first division of the table. Likewise the total number of tame mice is the sum of the tame-savage and the tame-non-savage. The

TABLE 36

Summary of Results of Third Generation Hybrids, F_3, of Series B, from Matings of Parental Generation, Wild Female with Tame Male

		WILDNESS							SAVAGENESS						
			Distribution of mice in grades:							Distribution of mice in grades:					
		Av.	0	1	2	3	4	5	Av.	0	1	2	3	4	5
Average number tests, 4.64															
Range of tests, 3–5	First test.....	3.64				7	5	2	4.5				2	3	9
Average age in days:															
First test, 42.35	Average 1 and 2..	3.59			1	4	6	3	4.25				2	5	7
Last test, 82.63															
	Average all.....	3.46			2	5	7		3.43			3	3	6	2
14 F_3b Males	Average 3, 4 and														
and Females	5.....	3.36		1	2	4	5	2	2.81		3	3	2	4	2
	Last test.....	3.14	1		3	5	2	3	2.63	2	3	3	2	1	3
Average number tests, 4.54															
Range of tests, 3–5	First test.....	3.63				6	3	2	4.54				1	3	7
Average age in days:															
First test, 42.09	Average 1 and 2..	3.95			1	3	6	1	4.19				2	4	5
Last test, 76.0															
	Average all.....	3.52			2	5	4		3.32			3	2	5	1
11 F_3b	Average 3, 4 and														
Males	5.....	3.2		1	2	3	3	2	2.62		3	2	2	2	2
	Last test.....	2.9	1		3	4	1	2	2.63	2	2	3	1		3
Average number tests, 5															
Range of tests, 5	First test.....	3.66				1	2		4.33				1		2
Average age in days:															
First test, 34.	Average 1 and 2..	4.33				1		2	4.5					1	2
Last test, 100.33															
	Average all.....	3.26					3		3.8				1	1	1
3 F_3b	Average 3, 4 and														
Females	5.....	3.88				1	2		3.23			1		2	
	Last test.....	4.0				1	1	1	3.66		1		1	1	

sum of the wild-savage and the tame-savage equals the total number which were savage, while the sum of the wild and non-savage mice and the tame and non-savage gives the number which were non-savage. In the second column are given the percentages which indicate what part of the total number of mice are the various numbers. The third and fourth column

give these values for Series B of the F_1 hybrids. Then follow in order similar values for Series A and B of the F_2 and F_3.

The chief value of this table is to show the similarity in the results of the three generations. With the exception of the results of the males and females (first section, table 38) and of the males of F_2a, the percentages for the four classes in each division of the table range from highest to lowest in the following order: wild-savage, wild-non-savage, tame-non-savage,

TABLE 37

General Summary of Tables 25 to 36 Inclusive

	TAME FEMALE × WILD MALE				WILD FEMALE × TAME MALE			
	Series A		Series B		Series A		Series B	
	Averages	Sex testing highest	Averages	Sex testing highest	Averages	Sex testing highest	Averages	Sex testing highest
Hybrids F_1								
Wildness								
All tests	3.15	Female	3.54	Female	3.36	Male	3.35	Female
Tests, 3, 4, 5	2.7	Female	3.14	Female	2.93	Male	3.16	Female
Savageness								
All tests	2.79	Male	2.8	Female	2.96	Female	3.25	Female
Tests, 3, 4, 5	2.06	Female	2.21	Female	2.42	Female	2.73	Female
Hybrids F_2								
Wildness								
All tests	2.92	Female	3.72	Female	3.10	Female	2.92	Female
Tests, 3, 4, 5	2.57	Female	3.54	Female	2.40	Female	2.60	Female
Savageness								
All tests	3.21	Female	3.9	Female	2.76	Male	3.2	Female
Tests, 3, 4, 5	1.96	Female	3.55	Female	2.04	Female	2.77	Female
Hybrids F_3								
Wildness								
All tests	2.6	Male	3.9	Male	2.89	Female	3.46	Male
Tests, 3, 4, 5	2.22	Male	4.0	Male	2.58	Female	3.36	Female
Savageness								
All tests	2.4	Female	4.37	Male	3.05	Male	3.43	Female
Tests, 3, 4, 5	1.72	Female	4.27	Male	2.54	Male	2.81	Female

tame-savage. The order for the males and females of F_2a is tame-non-savage, wild-savage, wild-non-savage, tame-savage. This change from the order of the remaining hybrids is caused by the great number of tame-non-savage males which is almost twice as great as the combined number of wild-savage and wild-non-savage. The percentage of tame-savage remains the smallest among the males but the numbers of wild-savage and wild-non-savage are the same, each being 24. It is to be noted that the percent of wild-savage females in each group

is much in excess of that of the males, especially in the case of the F_3b where they are, respectively, 0.469 and 0.224.

In table 39 appear the results of the F_1 hybrids divided according to the matings of the parental stock, i.e., wild female and tame male, or tame female and wild male. With the exception of the results from the matings of tame female with wild male in Series A, the percentages follow the order noted in the

TABLE 38

General Summary of the Individual Inheritances of the Three Hybrid Generations

		F_1 hybrids				F_2 hybrids				F_3 hybrids			
		Series A		Series B		Series A		Series B		Series A		Series B	
		Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Litters		17		50		44		52		25		13	
Mice total		99		216		212		269		114		49	
Males and Females	w-s	45	0.454	139	0.643	70	0.33	169	0.628	64	0.561	34	0.693
	w-n	32	0.323	54	0.25	56	0.264	62	0.23	19	0.165	11	0.224
	t-s	5	0.051	3	0.013	14	0.066	7	0.022	13	0.113	1	0.02
	t-n	17	0.171	20	0.092	72	0.339	31	0.115	18	0.157	3	0.061
Males	w-s	16	0.161	51	0.236	24	0.113	71	0.264	30	0.263	11	0.224
	w-n	11	0.111	25	0.115	24	0.113	33	0.122	13	0.113	7	0.142
	t-s	4	0.04	2	0.009	6	0.028	4	0.014	7	0.061	1	0.02
	t-n	9	0.09	18	0.083	46	0.216	26	0.097	12	0.105	3	0.061
Females	w-s	29	0.292	88	0.407	46	0.216	98	0.364	34	0.298	23	0.469
	w-n	21	0.212	29	0.134	32	0.15	29	0.107	6	0.052	4	0.081
	t-s	1	0.01	1	0.004	8	0.037	3	0.011	6	0.052		
	t-n	8	0.08	2	0.009	26	0.122	5	0.018	6	0.052		
Males and females	Wild	77	0.777	193	0.893	126	0.594	231	0.858	83	0.726	45	0.917
	Tame	22	0.222	23	0.105	86	0.405	38	0.137	31	0.270	4	0.081
	Sav.	50	0.505	142	0.656	84	0.396	176	0.65	77	0.674	35	0.713
	Non-sav.	49	0.494	74	0.342	128	0.603	93	0.345	37	0.322	14	0.285

F_1 generation in table 38, namely, wild-savage, wild-non-savage, tame-non-savage, tame-savage. In the case of this exception the non-savageness of the tame female seems to have exerted a greater influence over the offspring than usual, especially with the females. The wild-non-savage class is the greater among the females and the tame-non-savage among the males. In the combined results of the males and females the wild-non-savage mice are in greater numbers, the wild-savage

and tame-non-savage are equal and the tame-savage are, as usual, the least in numbers. This apparent influence of the tame female over the offspring is not shown in the like mating in Series B, since only 0.08 of the total number of mice (sum of t-s and t-n) are found in the tame classes and 0.328 (sum of w-n and t-n) are in the non-savage classes. These percentages

TABLE 39

Summary of Matings of Parental Generation and Results of Individual Inheritance of F_1 Hybrids, Series A and B

		P MATING							
		Series A				Series B			
		IV ♀ W-S × ♂ T-N		V ♀ T-N × ♂ W-S		IV ♀ W-S × ♂ T-N		V ♀ T-N × ♂ W-S	
		Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Litters		9		8		13		37	
Mice total		54		45		55		161	
Males and females	w-s	32	0.592	13	0.288	33	0.60	106	0.658
	w-n	17	0.314	15	0.333	12	0.218	42	0.26
	t-s	1	0.018	4	0.088	1	0.018	2	0.012
	t-n	4	0.074	13	0.288	9	0.163	11	0.068
Males	w-s	12	0.222	4	0.088	11	0.20	40	0.249
	w-n	8	0.148	3	0.066	5	0.091	20	0.124
	t-s	1	0.018	3	0.066	1	0.018	1	0.006
	t-n	2	0.037	7	0.155	9	0.163	9	0.056
Females	w-s	20	0.37	9	0.20	22	0.48	66	0.409
	w-n	9	0.166	12	0.266	7	0.127	22	0.136
	t-s			1	0.022			1	0.006
	t-n	2	0.037	6	0.133			2	0.012
Males and females	Wild	49	0.906	28	0.621	45	0.818	148	0.918
	Tame	5	0.259	17	0.376	10	0.181	13	0.08
	Sav.	33	0.777	17	0.376	34	0.618	108	0.67
	Non-sav.	21	0.388	28	0.621	21	0.381	53	0.328

are in each case higher in the opposite mating (wild female with tame male).

The results of the matings of the mice of Series A, F_1, are presented in table 40, and those of Series B in table 41. The division of the number of mice of any generation into various groups according to the grades of wildness and savageness of

their parents lessens the value of each group, as far as mere numbers are concerned, in proportion as the numbers comprising each group are lessened. In this case, however, the loss seems to be more than counteracted by the value of the demonstrated tendency that a difference in the grade of wildness and savageness of the hybrid parents seems to make some, though

TABLE 40

Summary of Matings of F_1 Hybrids, Series A, and Results of Individual Inheritances of F_2 Hybrids, Series A

		F_1 MATINGS													
		I ♀ W-S × ♂ W-S		II ♀ W-S × ♂ W-N		III ♀ W-N × ♂ W-S		IV ♀ W-S × ♂ T-N		VI ♀ W-N × ♂ W-N		VII ♀ W-N × ♂ T-N		XI ♀ W-S × ♂ T-S	
		Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Litters....		7		8		7		7		8		4		3	
Mice total		35		39		39		30		33		23		13	
Males and females..	w-s	17	0.485	6	0.153	13	0.333	8	0.266	13	0.393	8	0.347	5	0.383
	w-n	4	0.114	18	0.461	7	0.179	7	0.233	9	0.272	6	0.26	6	0.461
	t-s	3	0.085			4	0.102	5	0.166	1	0.03				
	t-n	11	0.314	15	0.383	15	0.383	10	0.333	10	0.303	9	0.391	2	0.153
Males....	w-s	8	0.228	1	0.025	2	0.051	3	0.10	7	0.212	3	0.13		
	w-n	3	0.085	7	0.179	2	0.051	4	0.133	4	0.121	3	0.13	1	0.076
	t-s	1	0.028			2	0.051	3	0.10						
	t-n	5	0.143	9	0.23	10	0.256	7	0.233	8	0.242	5	0.217	2	0.153
Females..	w-s	9	0.257	5	0.128	11	0.282	5	0.166	6	0.181	5	0.217	5	0.383
	w-n	1	0.028	11	0.282	5	0.128	3	0.10	4	0.121	3	0.13	5	0.383
	t-s	2	0.057			2	0.051	2	0.066	2	0.06				
	t-n	6	0.171	6	0.153	5	0.128	3	0.10	2	0.06	4	0.173		
Males and females..	Wild	21	0.599	24	0.614	20	0.512	15	0.499	22	0.665	14	0.607	11	0.844
	Tame	14	0.399	15	0.383	19	0.485	15	0.499	11	0.333	9	0.391	2	0.153
	Sav.	20	0.57	6	0.153	17	0.435	13	0.432	14	0.423	8	0.347	5	0.383
	Non-sav.	15	0.428	33	0.844	22	0.562	17	0.566	19	0.575	15	0.651	8	0.614

not a striking difference, in the grade of wildness and savageness of the offspring. If the results given in table 40 are considered, it would seem fairly reasonable to expect more of the mice from Mating I. (♀ W-S X ♂ W-S) to be wild and savage than tame and non-savage since the parents both graded wild and savage. This seems to be the case, at least to some extent, since the percentage of wild mice and the percentage of

savage mice are in excess, although in this particular instance one third of the offspring were considered tame and non-savage.

In Mating II (♀ W-S X ♂ W-N) and Mating III (♀ W-N X ♂ W-S) wherein one parent in each mating was non-savage the majority of the offspring, according to the above statement, should be wild since each parent was wild, while the number

TABLE 41

Summary of Matings of F_1 Hybrids, Series B, and Results of Individual Inheritances of F_2 Hybrids, Series B

		F_1 MATINGS											
		I ♀ W-S × ♂ W-S		II ♀ W-S × ♂ W-N		IV ♀ W-S × ♂ T-N		VI ♀ W-N × ♂ W-N		VII ♀ W-N × ♂ T-N		VIII ♀ T-N × ♂ W-N	
		Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Litters		28		7		1		5		10		1	
Mice total		147		34		7		22		53		6	
Males and females	w-s	110	0.748	17	0.50	4	0.571	8	0.363	25	0.471	5	0.833
	w-n	21	0.142	5	0.147	2	0.285	11	0.50	22	0.415	1	0.166
	t-s	4	0.027	3	0.088								
	t-n	12	0.081	9	0.264	1	0.142	3	0.136	6	0.113		
Males	w-s	44	0.299	6	0.176	2	0.285	4	0.181	13	0.245	2	0.333
	w-n	13	0.088	1	0.029	2	0.285	6	0.272	10	0.188	1	0.166
	t-s	2	0.013	2	0.058								
	t-n	9	0.06	8	0.235	1	0.142	3	0.136	5	0.094		
Females	w-s	66	0.449	11	0.323	2	0.285	4	0.181	12	0.226	3	0.50
	w-n	8	0.054	4	0.117			5	0.227	12	0.226		
	t-s	2	0.013	1	0.029								
	t-n	3	0.02	1	0.029					1	0.018		
Males Males and females	Wild	131	0.89	22	0.647	6	0.856	19	0.863	47	0.886	6	0.999
	Tame	16	0.108	12	0.325	1	0.142	3	0.136	6	0.113		
	Sav.	114	0.775	20	0.588	4	0.571	8	0.363	25	0.471	5	0.833
	Non-sav.	33	0.223	14	0.411	3	0.427	14	0.636	28	0.528	1	0.166

of savage and non-savage should be about equally divided. From the last section of table 40 it is seen that the number of wild does exceed the number of tame but in the case of Mating II by only one mouse. The savage and non-savage are fairly well divided (17 and 22 respectively) in Mating III but in Mating II the non-savage are over five times as numerous as the savage.

TABLE 42

Summary of Matings of F_2 Hybrids, Series A, and Results of Individual Inheritances of F_3 Hybrids, Series A

		F_2 MATINGS																			
		I ♀ W-S × ♂ W-S		II ♀ W-S × ♂ W-N		III ♀ W-N × ♂ W-S		IV ♀ W-S × ♂ T-N		V ♀ T-N × ♂ W-S		VI ♀ W-N × ♂ W-N		VII ♀ W-N × ♂ T-N		VIII ♀ T-N × ♂ W-N		IX ♀ T-N × ♂ T-N		X ♀ T-N × ♂ T-S	
		Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Litters		1		1		1		8		1		1		1		2		7		2	
Mice total		3		5		4		46		3		3		4		11		28		7	
Males and females	w-s	2	0.666	5	1.0	4	1.0	20	0.434	1	0.333			1	0.25	7	0.636	20	0.714	4	0.57
	w-n							13	0.282			2	0.666	1	0.25	2	0.181	1	0.035		
	t-s							3	0.065	2	0.666					1	0.09	4	0.142	3	0.428
	t-n	1	0.333					10	0.217			1	0.333	2	0.50	1	0.09	3	0.107		
Males	w-s	1	0.333	4	0.80	1	0.25	11	0.239							2	0.181	8	0.285	3	0.428
	w-n							9	0.195			2	0.666			2	0.181				
	t-s									2	0.666							3	0.107	2	0.285
	t-n	1	0.333					7	0.152					1	0.25			3	0.107		
Females	w-s	1	0.333	1	0.20	3	0.75	9	0.195	1	0.333			1	0.25	5	0.454	12	0.428	1	0.142
	w-n							4	0.096					1	0.25			1	0.035		
	t-s							3	0.065							1	0.09	1	0.035	1	0.142
	t-n							3	0.065			1	0.333	1	0.25	1	0.09				
Males and females	Wild	2	0.666	5	1.00	4	1.00	33	0.716	1	0.333	2	0.666	2	0.50	9	0.817	21	0.749	4	0.57
	Tame	1	0.333					13	0.282	2	0.666	1	0.333	1	0.25	2	0.18	7	0.249	3	0.428
	Sav.	2	0.666	5	1.00	4	1.00	23	0.499	3	0.999			1	0.25	8	0.726	24	0.856	7	0.998
	Non-sav.	1	0.333					23	0.499			3	0.999	3	.75	3	0.271	4	0.142		

In Mating IV (♀ W-S X ♂ T-N) in which case the male parent is tame and non-savage the percentages for wildness and tameness are identical, while those for savageness and non-savageness are 0.432 and 0.566 respectively. This seems to indicate that the hereditary influence of the parents was about equally divided between wildness and tameness and between savageness and non-savageness.

TABLE 43

Summary of Matings of F_2 Hybrids, Series B, and Results of Individual Inheritances of F_3 Hybrids, Series B

		F_2 MATINGS					
		I ♀ W-S × ♂ W-S		II ♀ W-S × ♂ W-N		IX ♀ T-N × ♂ T-N	
		Number	Per cent	Number	Per cent	Number	Per cent
Litters		10		1		2	
Mice total		41		2		6	
Males and females	w-s	27	0.658	2	1.00	5	0.833
	w-n	10	0.243			1	0.166
	t-s	1	0.034				
	t-n	3	0.073				
Males	w-s	9	0.219			2	0.333
	w-n	7	0.17				
	t-s	1	0.024				
	t-n	3	0.073				
Females	w-s	18	0.439	2	1.00	3	0.50
	w-n	3	0.073			1	0.166
	t-s						
	t-n						
Males and females	Wild	37	0.901	2	1.00	6	0.999
	Tame	4	0.097				
	Sav.	28	0.682	2	1.00	5	0.833
	Non-sav.	13	0.316			1	0.166

In Mating VI (♀ W-N X ♂ W-N) the wildness percentage is 0.665 and the non-savage 0.575 in comparison with 0.333 for tameness and 0.432 for savageness. The effect of the grading in the parents seems to be here also quite apparent.

The percentage for non-savageness in Mating VII (♀ W-N X ♂ T-N) is 0.651 in comparison with 0.347 for savageness. While this seems to show the effect of the non-savageness of the parents, there was no equalization of wildness and tameness as the percentages for these are 0.607 and 0.391 respectively.

In the results of the tests of the 13 mice from Mating XI (♀ W-S X ♂ T-S) there is a contradiction of the results in the preceding matings because, though both parents were savage, 8 of the offspring were non-savage and 5 savage.

From the last division of table 41 similar results to those just noted in the preceding table may be seen to exist fairly regularly throughout the matings from which came the F_2b hybrids. The exceptions in this table are found in Matings IV, VII, and VIII. In Mating IV (♀ W-S X ♂ T-N) the savage and non-savage offspring are rather evenly proportioned but the wild exceed the tame by 6 to 1. In Mating VII (♀ W-N X ♂ T-N) the non-savage are slightly more numerous than the savage but, as in Mating IV, the wild are almost 8 times greater in numbers than the tame. Likewise the 6 mice from Mating VIII (♀ T-N X ♂ W-N) show practically opposite results of inheritance since all 6 were in the wild class and the proportion of non-savage to savage was 1 to 5.

In tables 42 and 43 the summaries of the tests of the F_3a and F_3b hybrids are presented. Evidence that the grade of wildness and savageness existent in the parent tends to produce a similar grade in the offspring is to be found in the results of Mating I of both tables, in the results for wildness and tameness in Mating II of each table, and in Mating III of table 42, in the results for savageness and non-savageness in Mating IV, and also in the complete results of Mating VI and VII of this same table.

The exceptions in the case of Mating IX (♀ T-N X ♂ T-N) of both series and of Mating X (♀ T-N X ♂ T-S) of Series A (table 42) are interesting inasmuch as the number of wild in the offspring is in excess of the number of tame although both parents were in each case classed as tame. The number of savage individuals exceeds that of the non-savage in Mating IX although both parents were non-savage. This is likewise true in Mating VIII (♀ T-N X ♂ W-N).

Mating I and Mating II are the only ones which appear throughout both series of the two hybrid generations. The results of these matings are presented in table 44 in order to enable a more comprehensive comparison. The blending heritable tendency that has been mentioned above may be more clearly noted in this table. It is rather well defined

TABLE 44

Summary of Mating I (♀ W-S X ♂ W-S) and Mating II (♀ W-S X ♂ W-N) of Both Series of F_1 and F_2 Hybrids and Their Results in the F_2 and F_3 Hybrids of Both Series

		MATING I (♀ W-S × ♂ W-S)								MATING II (♀ W-S × ♂ W-N)							
		F_2 Hybrids				F_3 Hybrids				F_2 Hybrids				F_3 Hybrids			
		Series A		Series B		Series A		Series B		Series A		Series B		Series A		Series B	
		Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Litters		7		28		1		10		8		7		1		1	
Mice total		35		147		3		41		39		34		5		2	
Males and females	w-s	17	0.485	110	0.748	2	0.666	27	0.658	6	0.153	17	0.50	5	1.00	2	1.0
	w-n	4	0.114	21	0.142			10	0.243	18	0.461	5	0.147				
	t-s	3	0.085	4	0.027			1	0.024			3	0.088				
	t-n	11	0.314	12	0.081	1	0.333	3	0.073	15	0.383	9	0.264				
Males	w-s	8	0.228	44	0.299	1	0.333	9	0.219	1	0.025	6	0.176	4	0.80		
	w-n	3	0.085	13	0.088			7	0.17	7	0.179	1	0.029				
	t-s	1	0.028	2	0.013			1	0.024			2	0.058				
	t-n	5	0.143	9	0.06	1	0.333	3	0.073	9	0.23	8	0.235				
Females	w-s	9	0.257	66	0.449	1	0.333	18	0.439	5	0.128	11	0.323	1	0.20	2	1.00
	w-n	1	0.028	8	0.054			3	0.073	11	0.282	4	0.117				
	t-s	2	0.057	2	0.013							1	0.029				
	t-n	6	0.171	3	0.02					6	0.153	1	0.029				
Males and females	Wild	21	0.599	131	0.89	2	0.666	37	0.901	24	0.614	22	0.647	5	1.00	2	1.00
	Tame	14	0.399	16	0.108	1	0.333	4	0.097	15	0.383	12	0.352				
	Sav.	20	0.57	114	0.775	2	0.666	28	0.683	6	0.153	20	0.588	5	1.00	2	1.00
	Non-sav.	15	0.428	33	0.223	1	0.333	13	0.316	33	0.844	14	0.411				

throughout the Series of Mating I but is noted only in the inheritance of wildness and tameness in Mating II, the proportion of savage and non-savage varying greatly in each case.

On the following pages there are presented three representative genealogical charts which give the number of litters from each mating, the classification of the mice and the numbers of the individual breeders.

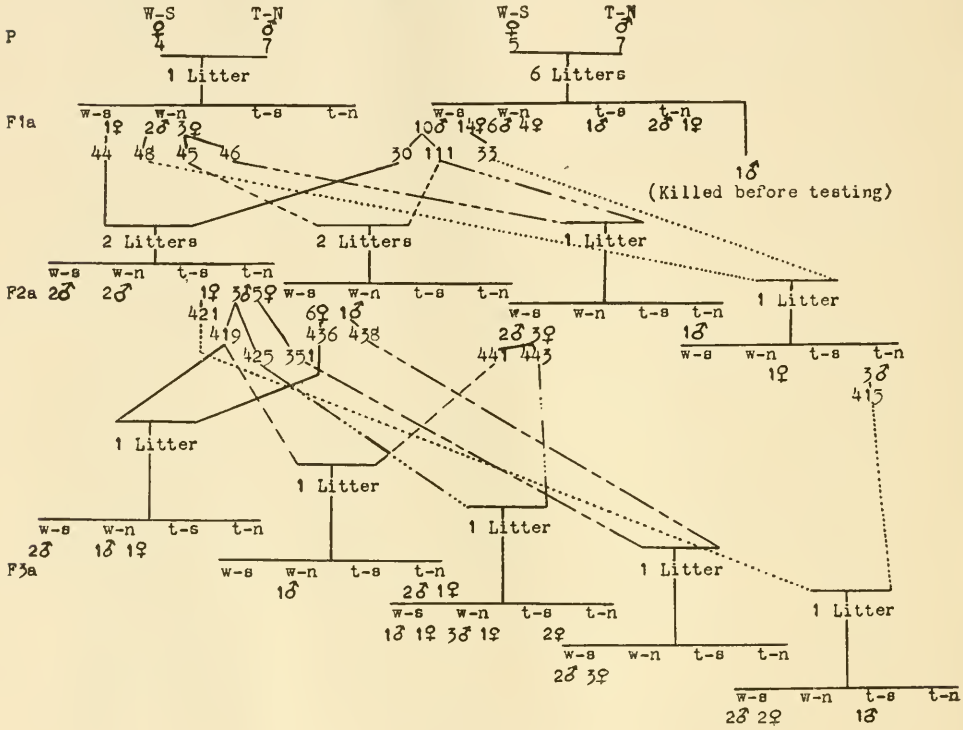
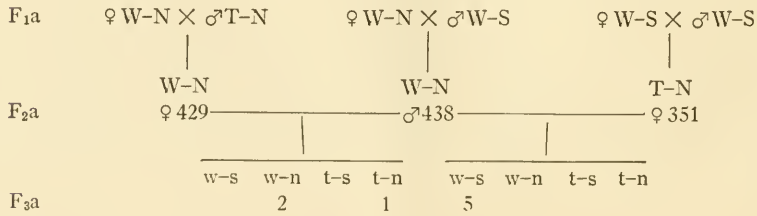


CHART 1.

A closer study of these charts reveals instances of inheritance which suggest the possibility of some slight segregation of the behavior-complexes under consideration. An example of this may be found in charts 1 and 2, graphically illustrated as follows:



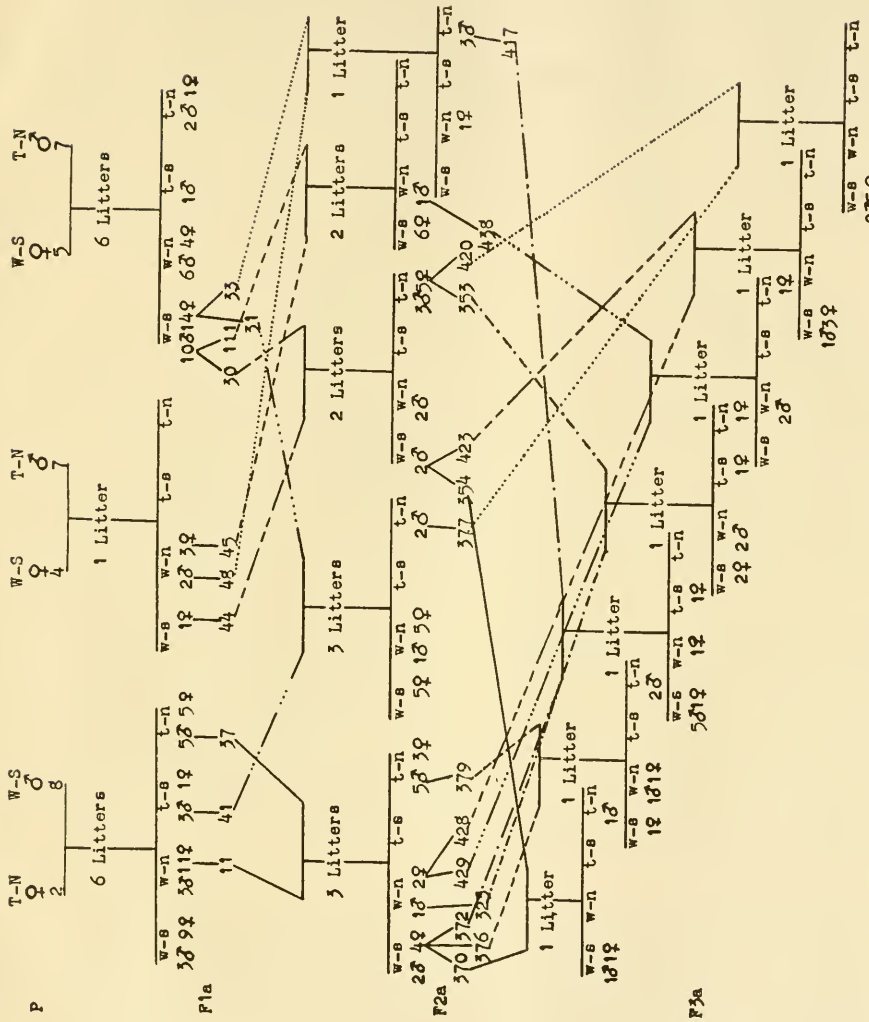

P
F1a
F2a
F3a
T-N
W-S
6 Litters
1 Litter
2 Litters
3 Litters
w-s
w-n
t-s
t-n

CHART 2.

As is seen here ♀ 429 came from a ♀ W-N X ♂ T-N mating, ♂ 438 from a ♀ W-N X ♂ W-S mating, and ♀ 351 from a ♀ W-S X ♂ W-S mating. From the mating of ♀ 429 (W-N) with ♂ 438 (W-N) there were 2 w-n and 1 t-n mice, while from the mating of ♀ 351 (T-N) with ♂ 438 (W-N) all the five mice were w-s. From the blending type of inheritance alone we would be led to expect a higher grading from the former

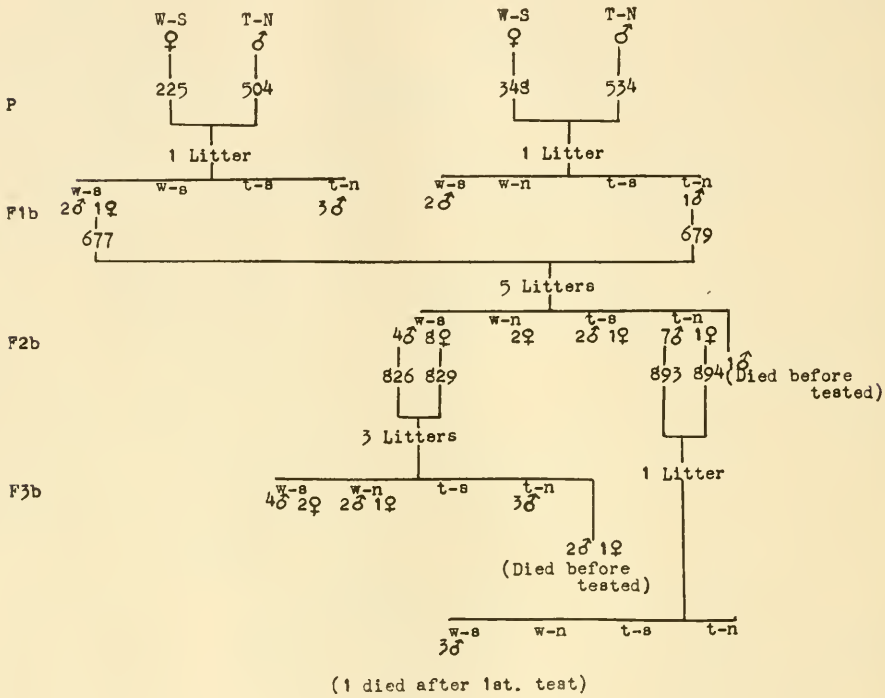


CHART 3.

mating than from the latter since both parents of the former were W-N, while the female in the latter was a T-N. To find a possible explanation we must go back to the preceding generation. Here we find in the case of the former mating an ancestry consisting of two female W-N, one male T-N and the other W-S, while in the case of the latter mating one female of the preceding generation was a W-N and the other female and the two males were each W-S. Other cases are to be found

where wildness seems to behave in a similar manner, as for instance, in chart 2 (F_2a, ♀ 420 with ♂ 377) and in chart 3 (F_2b, ♀ 894 with ♂ 893).

While the segregation of the various determining factors of savageness or wildness and their behavior as a recessive or, as it seems in some instances, a dominant, apparently explains the inheritance in these various crosses, the number of matings giving such results is comparatively few, hence, a statement more definite than a mere suggestion of a possibility must necessarily be left until a further study in this particular field has been made.

OBSERVATIONS ON "SINGING" IN MICE[2]

In the literature of animal behavior appear several references to the production by mice of sounds of musical quality.

The "singing" of mice is described variously by different writers. Lee (1878) states that it consists of a series of chirps at the rate of three or four per second. At the beginning of the series, the chirps are low but gradually they become louder. The "song" of one mouse this author likens to the sweet and varied warbling of a canary. Every note was "clear and distinct."

In referring to the same phenomenon, the naturalist Brehm (1896), attributes the following descriptions to various observers. One informant states that the "song" is an irregular mixture of chirps and trills with here and there a snarling, smacking sound followed by a low murmur. Another describes it as a twitter which is a mixture of long drawn squeaking and piping sounds which may be heard at a distance of twenty paces.

One observer noted the phenomenon only in the case of a female mouse while giving birth to young, while another observer states that only the male "sings."

The majority of those who have heard "singing" in mice have assumed that it is due to a diseased condition of the lungs or of the vocal organs, but conditions so diverse as pregnancy and parasites in the liver have also been suggested as causes.

[2] Revised note which appeared under heading of Singing Mice, *Journal of Animal Behavior*, 1912, ii, No. 5, pp. 363–366.

The writer desires to add, to the observations already reported, an additional record of "singing" mice. About the first of December, 1911, while working one evening in his study, he heard a series of sounds which seemed to come from above the ceiling. At the time, they were thought to resemble the soft chirping of a bird.

Shortly afterward, some wild mice were needed for breeding experiments and, by means of a trap, two mice, a male and a female, were captured in the room.

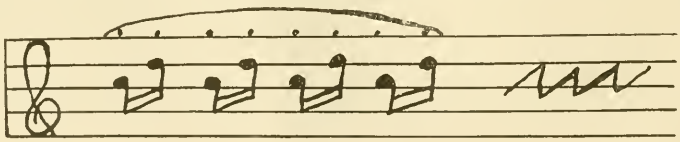
These animals, while being taken to the Harvard Psychological Laboratory, produced sounds like those previously heard in the room and they continued to do so at intervals after being placed in a laboratory cage. A few days after their capture, the male escaped. Inasmuch as the writer had not separated the two mice, placed each in a separate cage in a different part of the room, it is not possible to state whether the sounds were produced by both the mice or only by the female which remained and continued to "sing."

The female was mated with a tame mouse and produced, during the period of observation, five litters, thirty-three individuals. None of these offspring produced unusual sounds, nor did "singing" appear in the second or the third generations obtained from these hybrids.

The "singing" individual, so far as could be ascertained, was a common house mouse (Mus musculus). She was somewhat larger than the ordinary wild female, but no other external peculiarities were noted. She was extremely active and savage and her mate always bore the marks of her teeth. An attempt to mate her with a second tame male resulted in the death of the latter.

No definite time for "singing" was noted, except three or four days before and for six or seven days after the birth of a litter. It was observed, also, that the individual "sang" sometimes when frightened.

The sound is best described as a rapid whole-toned trill involving the tones C and D as is indicated below.



The quality of the tone resembled somewhat that of a fife or flute, but each tone ended with a slight throaty click. The tones were uttered at the rate of four or five per second in groups of varying size. Sometimes a group occupied one second, sometimes as long as ten seconds. As a rule, the tones of a group were not clear and distinct but, instead, were uttered so rapidly as to seem connected. The throaty click was more noticeable in the case of the last tone of a group. Often the "singing" would be continued for a period of ten or fifteen minutes with rests between groups.

The sound could readily be heard at a distance of fifteen or twenty feet, but it was difficult to localize it. The individual "sang" little during June, 1912, and it was not heard after July 1st, 1912. She died in August, apparently of old age.

During May, 1912, "singing" was again heard in the room in which the "singing" mice had earlier been captured, but efforts to capture the "singer" failed.

In January, 1913, a "singing" mouse was captured in the home of an Italian family in Brooklyn, New York. It was brought to the Laboratory and appears in the study described in this paper as female no. 475. There was captured with it a male, mouse no. 474, which, however, did not "sing." These two mice were mated and produced six of the wild individuals which were raised and tested and later used as breeders in Series B of the study in wildness and savageness inheritance. This "singer" was mated with a tame male, and again with a F_2 hybrid male but no "singer" appeared in these two litters, nor among the first, second, or third generation hybrids from the six wild offspring mated with tame individuals.

Later another "singer" was found on a farm in Michigan. It was sent to the Laboratory and proved to be a female also. No attempt was made at breeding this individual since it arrived just before the end of the study and there would not have been sufficient time for any observations to be made on the offspring.

The "singing" of these last two individuals was very much like that of the first, except that the mouse from Michigan did not "sing" as long at any time nor as frequently as did the other two.

The writer received several letters from different persons in various parts of the United States giving their observations

on this "singing" phenomenon in mice. In each case the observations had been merely casual and the reports gave no new information on the subject.

The results of this investigation, though by no means complete, indicate fairly definitely that this "singing" characteristic in mice is not heritable. From the fact that no males were captured that were definitely known to possess the characteristic, and the phenomenon in two of the three individuals observed was more often noted just before and after the birth of young, it seems quite possible that it is a characteristic peculiar to females and, perchance, due to a diseased condition or otherwise structural defect of the vocal organs, caused or, at least, accentuated by the birth of young.

SUMMARY AND CONCLUSIONS

1. When the grades of wildness and savageness attained by mice of each hybrid generation are considered collectively, the lowering of the average grades of wildness and savageness in the successive tests is gradual in each generation but is greatest in both wildness and savageness in the second hybrid generation. The greatest amount of difference in the grade of wildness for any two consecutive tests occurs between the second and third.

2. The mice of Series B, as a whole, graded higher than those of Series A in both wildness and savageness. This result does not indicate the presence of wild blood in the tame parents of the hybrids of Series A, and hence is directly opposed to the results Professor Yerkes obtained with the rats.

3. Savageness is more usually associated with wildness than with tameness.

4. The females, as a rule, attained higher grades in wildness and savageness than the males.

5. From the results of the tests of the first and second hybrid generations of Series A, it was found that, generally speaking, the older the mice the lesser the average grades in wildness and savageness attained by them in the five tests.

6. The decrease in the grades of wildness and savageness continues with the successive tests when the number of tests is increased to eight.

7. Age, frequency of tests, number of tests, and the presence of the experimenter in the room, each has a certain effect

in the lowering of the grade of wildness and savageness in the hybrids.

8. The hybrids of Series A from the matings of parental generation tame female with wild male became generally less wild and less savage in the succeeding generations, while the hybrids of Series B of this mating attained an increasingly higher average grade of wildness and savageness in the successive generations. The females of both series from this mating were more wild and savage in the first and second generations and the females of Series A more savage in the third generation than the males, the males of both series being more wild than the females in the third generation, while the males of Series B were also more savage than the females in this generation.

9. The average grades attained in wildness and savageness in the first generation hybrids of both series, from matings of parental generation wild female with tame male, were, as a rule, lowered in the second generation and then, in the third generation, raised almost to the height of the grades obtained in the first. The grades received by the females of both series from this mating are in excess of those obtained by the males except in the case of the males of Series A, which graded higher in wildness in the first generation and higher in savageness in the third generation than the females of Series A.

10. Under the conditions existing in this study it is very doubtful whether there was much, if any, difference in the inheritance of wildness and savageness by the hybrids due to the fact that one type of parental mating was wild female and tame male and the other, tame female and wild male.

11. When the individual mice are separated into the four classes; wild-savage, wild-non-savage, tame-savage, tame-non-savage, according to the average of the third, fourth and fifth tests for wildness or savageness being equal to or above 2.5 grade or below this, the wild and savage class, as a rule, represented the greatest number of mice, the wild and non-savage class the next highest, the tame and non-savage the next, and the tame and savage class the least number. The one exception to this is in the second generation hybrids of Series A, for which the order was as follows: (1) tame-non-savage, (2) wild-savage, (3) wild-non-savage, (4) tame-savage, where 1 represents the greatest number of mice and 4 the lowest.

12. The number of wild and savage females in each hybrid generation is always greater than the number of wild and savage males.

13. In the experiments in selective breeding it was generally to be noted that there was a tendency for the degree of wildness or savageness possessed by the parents to be reproduced in the offspring, that is, if both parents were wild, (the average of their third, fourth and fifth tests for wildness being equal to or exceeding 2.5 grade), in the majority of cases it would be found that the number of wild offspring was greater than that of tame, or if the parents were tame the greater number of offspring would be tame. The occasional isolated case in which this tendency did not maintain and where the results seem to indicate some particular combination of hereditary units is very interesting. It confirms the conviction of the writer that much more work is needed in this field before the precise manner of the inheritance of wildness and savageness in mice can be definitely stated. However, from this study it seems that the two behavior-complexes in question are the result of several different inheritance factors which follow the Mendelian rules.

14. Three female wild mice were found which possessed the "singing" property. No male was obtained which had this characteristic. This "singing" did not appear in any of the offspring to the third generation. It is evidently not inheritable, and quite possibly is a characteristic peculiar to females. The phenomenon seems to be associated in some way with the birth of young, and probably is caused by some structural defect or a diseased condition of the vocal organs.

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