JOURNAL OF ANIMAL BEHAVIOR

VOL. 5 JANUARY-FEBRUARY, 1915 No. 1

THE WHITE RAT AND THE MAZE PROBLEM

I. THE INTRODUCTION OF A VISUAL CONTROL

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WITH EIGHT FIGURES

Small[1] was the first to emphasize the importance of the kinaesthetic sensations in the life of the rat, while Professor Watson,[2] by eliminating the senses one by one, showed that in learning the maze, at least, senses other than the kinaesthetic and tactual can easily be dispensed with. The natural conclusion was drawn that in such problems these animals use vision, hearing, olfaction, etc., but slightly if at all.

The recognition of the functional value of the kinaesthetic sensations and the dominant part which they play in such a bit of learning as this has been of the greatest possible value. The question is immediately raised, however, of what intrinsic value are eyes, ears, etc., if not for learning. Or, the question might be put in this way: Is this motor co-ordination and the mode of learning entirely different from those other habits which the rat acquires naturally in its usual environment.

Professor Watson himself anticipated further work when he says, "We have supported everywhere the negative conclusions of Small. We, no more than he, offer positive evidence that the kinaesthetic are the only necessary factors in the maze association. Both of us alike used the method of elimination . . We feel that we are now in a position to begin the

[1] SMALL, W. S. Development of the Young White Rat. *Am. Jour. Psychol.*, vol. 11, p. 234. 1899.

[2] WATSON, J. B. Kinaesthetic and Organic Sensations. *Psychol. Rev. Mon. Sup.*, vol. 8, no. 2. 1907.

study of the positive aspects of the problems offered by the behavior of the rat in forming the maze association." [3]

It was this positive aspect of the situation which formed the basis for this study. Our contention was that other senses might enter into the learning of such a problem and modify it. We believed that the true path and the false in the maze might be made to differ so in brightness, in olfactory qualities, in tactual values, etc., as to affect the establishment of the habit. Our object was to find out if the learning process was thus affected and in what particular ways. The first experiments were concerned with an attempt to introduce sight as a control in the formation of this habit. The maze as ordinarily constructed and as used by Professor Watson is all of wood and of one color and is not favorable for the use of vision. The sides of the runways are high enough to prevent any visual help from outside unless from above. It has been shown many times that human subjects under such conditions find it difficult to obtain or to use visual clues. Ours was not the first attempt to introduce visual control in the maze. Others had tried the same thing in different ways but the stimuli which they used were ineffective and the investigators did not carry their experiments far enough to make any final statements. Although so much has been done with rats the proof of their ability to use vision in any exact way was not very conclusive.

PREVIOUS WORK

The previous lines of experimental evidence as to the effectiveness of vision are several. first, the comparison of the time of learning and speed in running of normal rats trained and tested in the dark and light respectively; second, a comparison in the same respects of normal and blind animals.

Professor Watson based his conclusions, as to the uselessness of vision in the maze, upon the fact that normal rats trained in the light could run the maze as quickly in the dark; that normal rats could learn the maze in the dark and acquire as rapid speed as in the light; and that blind rats could learn the maze and run it with a speed equal to that of their normal companions. It has been shown by others that it is scarcely fair, in such a situation, to make speed the sole criterion of the learning process.

[3] Ibid, p. 96.

It must also be remembered that many experimenters who have attacked this problem fail to separate in their detailed results and conclusions the typical learning process, which is shown chiefly in the first few trials, and the perfecting of the automatism, the acquisition of speed, which follows. Possibly Professor Watson's work may bear this criticism.

The third line of evidence comes from attempts to introduce visual clues at critical points in the maze. Small fixed colored posts at such places and also varied the direction of the light which fell upon the maze. He concluded that the use of vision was not shown by any discrimination or recognition.[4] Miss Allen marked the path for another rodent, the guinea pig, with colored cards but her results were negative.[5] Professor Watson, in the case of one rat, used colored lights with no perceptible effect.[6] All of these objects were stationary. It is possible that moving objects might have been better. Rats are hypermetropic and such animals may well fail to respond to near objects in any discriminating way.

The fourth form of attack upon the visual powers of these animals consists in observations of the animals and experiments with them in the dark and in the light respectively and noting the amount of activity and the accuracy of movement. Opinions differ slightly here. Slonaker shows in his studies of the activity of the white rat that its greatest period is during the night, beginning with the first shadows of afternoon. He says that the average distance traveled is five miles per night as against one-tenth of a mile per day and concludes that light normally does have an influence upon the animal's activity.[7] A few of Yerkes' dancers seemed somewhat disturbed by tests in the darkness.[8] Miss Allen found that her guinea pigs made more random movements in the darkness than in the light.[9] So far as I know no one has followed this lead further. It would be an interesting bit of experimental work.

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[4] Op. cit.

[5] ALLEN, JESSIE. Association in the Guinea Pig. *Jour. Comp. Neur. and Psychol.*, vol. 14. 1904.

[6] Op. cit., p. 43.

[7] SLONAKER, J. P. The Normal Activity of the White Rat at Different Ages. *Jour. Comp. Neur. and Psychol.*, vol. 17, p. 342. 1907.

[8] YERKES, R. M. The Dancing Mouse. P. 189. 1907.

[9] Op. cit.

The fifth line of proof lies in the comparison of blind and normal animals as to their accuracy of movement. In the experiments reported in Orientation in the Maze where, by means of a removable section, the maze could be lengthened and shortened there was a blind animal which had trouble with turns which the normal rats made correctly. The authors say of some other (normal) animals, " Since two out of the eight animals made eight out of the nine unquestioned immediate orientations we are willing to admit the possibility of the use of distance sense data in their cases." [10] Miss Richardson in some jumping tests with rats, where both direction and distance of the jump were varied independently of each other and also varied from habitually established norms, concluded that the visual stimulus furnished a control as to the direction of the jump but failed to afford any accommodation to changes in distance. Concerning some tests with problem boxes, she says they afforded no conclusive evidence as to the functioning of visual impulses. " The lack of vision, however, was disadvantageous in proportion as the problem demanded finely coordinated and narrowly localized movements." [11]

The sixth method of investigation is more directly concerned with the sense itself. The Watsons concluded from experiments with spectral lights that there is good if not conclusive evidence, since green was not used, that the responses were made to differences in intensity and not quality. Similarly Miss Weidensall showed in a critique of discrimination that in experiments with black and white the white was twice as effective as the black and that in most discrimination experiments with two objects only one of the objects may have any regulative control, the other being neglected.

The use of sight by some animals, as birds and monkeys, is admitted in connection with such problems but we have confined this report to rodents whose vision is of a common type.

The following views are held as to the place of vision in the labyrinth problem: (a) The control is kinaesthetic *par excellence*, coupled probably with tactual and static and possibly with organic sensations; (b) Vision may have a tonic stimulating

[10] CARR, HARVEY, and WATSON, J. B. Orientation in the White Rat. *Jour. Comp. Neur. and Psychol.*, vol. 18, p. 27. 1908.

[11] RICHARDSON, FLORENCE. A Study of the Sensory Control in the Rat. *Psychol. Rev. Mon. Sup.*, vol. 12. 1910.

effect or it may serve merely for general orientation; (c) Vision is not for perceptual purposes—"The rat does not hang his associations upon gross and obvious (visual) objects;" (d) Sight may lessen random movements; (e) It may give general direction if not accurate distance; (f) Vision may even be a hindrance in such problems.

In a previous paper[12] facts have been given which show that the rat's vision is weak. It may be possible that a rat does not discriminate stationary objects and it is probable that brightness is the most effective factor. In this work, however, there was no attempt made to substantiate such opinions or to eval-

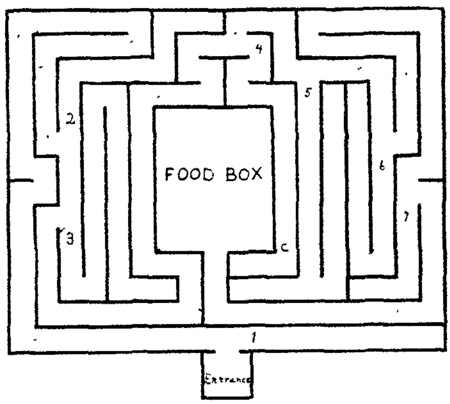

FIG. 1. Plan of maze

uate the visual sense. The only interest lay in the attempt to see whether vision could not be introduced into the labyrinth problem as a control and if this could be done then to determine what was its effect upon the establishment of the automatism.

APPARATUS AND MODE OF EXPERIMENTATION

The maze used was the modified Hampton Court Maze which Professor Watson describes in "Kinaesthetic and Organic Sensations." [13] Indeed it was one of the same mazes which he used in his experiments. The only change in the construction was

[12] VINCENT, S. B. The Mammalian Eye. *Jour. of Animal Behavior*, vol. 2, no. 4, pp. 249-255. 1912.

[13] For detailed description see "Kinaesthetic and Organic Sensations," op. cit., p. 16-18.

the blocking of pathway "C" at the farther end to make it a blind alley instead of a longer way around (Fig. 1). The essential difference, however, was the fact that the true pathways and the blind alleys were made to differ as far as possible in brightness. Black cardboard lined and covered the one and a very white paper lined the other. In the later experiments black and white enamel paint was used on the floor and sides while black cardboard covered the top of the black pathway.

The problem box for the discrimination tests was a pasteboard box 12′ x 12′ x 9′, with round tubes inserted at the floor level in opposite sides. One tube was white, with white oiled paper pasted in the upper third to increase the brightness, the other tube was black. The tubes were not straight but were bent in the middle at right angles to prevent any entering light from the end of the open tube from giving a clue. Only the tube of the brightness for which the animal was being trained remained open at the end. The box was turned in an irregular order to prevent choice by position.

The only stimulus to the activity was the reward of food at the completion of a successful run in the maze or the choice of the right exit in the problem box. Five animals usually constituted a group.

Some records were first made upon the maze as it originally stood with walls and floor of unpainted pine. A group of untrained rats was given 50 trials covering a period of 18 days. These rats were then taken over to the problem box where they were given 50 trials. Then another group of rats which had previously been given 50 trials on the problem box was put in the maze for 50 trials. Ten trials a day were given in the problem box, but on the maze only 3. These records are referred to as the normal records and furnish the standard for comparison.

The maze was then made black and white, the true path black (see dotted line, Fig. 1) and the blind alleys white. Two other groups of rats learned both it and the problem box in alternation as above. This maze is sometimes spoken of as the black maze.

The third change consisted in making the true path white and the *cul de sacs* black and using two new groups of animals in the manner described above. This maze is occasionally referred to as the white maze.

In brief the experiments upon which this discussion is based are as follows:

1. Normal maze records—(a) rats trained; (b) rats untrained; (c) discrimination experiment for (a); (d) discrimination experiment for (b).

2. Black-white maze records, true path black—(a) rats trained; (b) rats untrained; (c) discrimination experiment for (a); (d) discrimination experiment for (b).

3. Black-white maze records, true path white—(a) rats trained; (b) rats untrained; (c) discrimination experiment for (a); (d) discrimination experiment for (b).

The reason for the use of the two pieces of apparatus was this: After the first group of animals had learned the black and white maze we wished to see whether it was really brightness to which the animals were reacting. The other experiment —the box with the black and white exits—was devised, therefore, to see whether the brightness experience carried over. Then the suggestion arose that the differences which were seen in the conduct of the rats might not be due to brightness alone but that some of the changed results might be a general effect of training To meet this criticism not only were the experiments doubled by the use of both maze and box, but groups of animals trained upon the box afterward learned the maze and animals trained upon the maze learned the box. In order to make the normal group comparable the training also had to be included in their case although the maze was uniform in brightness.

It may be objected that the contact values of the two media, paper and cardboard, used in the first experiments differed and that the air pressure, sound qualities, etc., were not the same in the two paths. The work will have to face that criticism. The training tests upon the problem box and the succeeding experiments upon it seemed to show, however, that it was really brightness to which the animals were reacting. The six blind animals used upon the black-white maze furnished a further control. If there were other sensory elements fused with vision it does not affect the value of the experiment since this is normally true and since it was the visual element which was the variable one.

The tables submitted show only the time of a total reaction and the errors. Leaving the true path, entering a *cul de sac*, was counted as one error. Returns could not be counted as errors since part of the maze was covered. For the same reason we can say nothing about the total distance traversed. All of the tables upon which this discussion is based would gladly be given but it is impossible within the limits of this paper. The results will be shown by means of graphs upon which the dis-

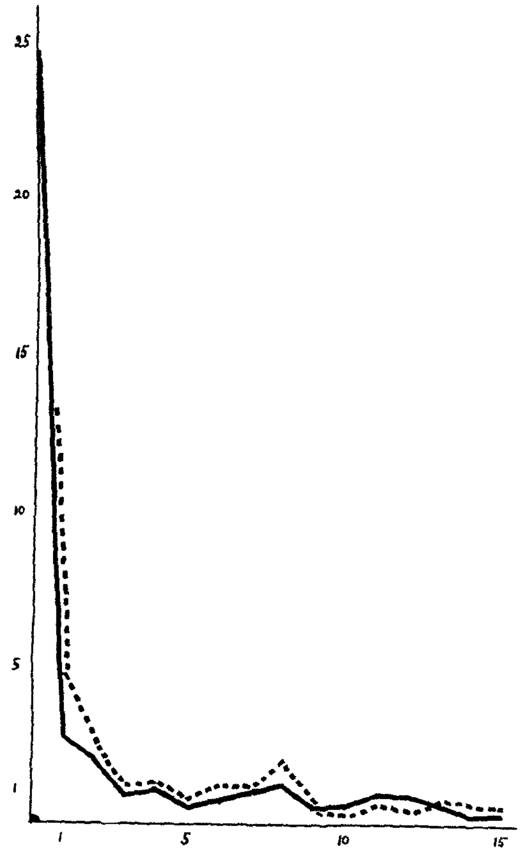

FIG. 2. Learning curves of 10 rats on the normal maze
——— Time, - - - - - - - - Errors

cussion will be based and only such other additional data will be given as is necessary.

Four months' work was put upon this problem in 1907. Nothing more was attempted until it was resumed in 1910. None of the first experimentation is reported here, since it was all repeated in the later series under stricter control and with similar results.

NORMAL MAZE

There is no need in this place of giving a long description of the general behavior or giving the individual details of the experimentation with the groups of rats in the normal maze. The conduct differed in no respect from that noted by so many others. The curve of learning may be seen in Fig. 2. The description of the mode of plotting this curve may be found in my monograph on the tactile hair.[14] The actual time and the number of errors for the first 10 trials are given in Table 1. These records are made from the combined records of two groups of animals, one of which had been previously trained upon a black-white discrimination box. As this training proved to have so little effect upon the subsequent maze record these pages will not be burdened with the numerical results.

TABLE 1

TIME AND ERROR RECORDS, FIRST TEN TRIALS, ON NORMAL AND BLACK-WHITE MAZES

	Time		Errors	
Trial	Normal Maze	Black-white Maze	Normal Maze	Black-white Maze
1	1804 sec	1342 sec	14 9	7 5
2	966	413	11 9	4 3
3	542	254	10 4	3
4	847	211	7.4	3
5	233	98	4 1	1.6
6	193	72	3 5	1
7	63	37	1 6	5
8	49	48	1 4	2
9	37	54	1 5	5
10	33	39	1 1	4

The training upon the box, on the whole, seemed slightly disadvantageous to the group of animals which later learned the original maze. There was not so high a degree of accuracy as evidenced by the number of errors and the average time taken per trial was longer than that of the other group which had had no training. To account for this is not difficult when we consider that the problems are distinctly different. In the one case there is an immediate reaction, in time too brief to be taken, to a situation which offers but two alternatives and in which brightness is the determining factor. In the other case

[14] VINCENT, S. B. The Function of the Vibrissae in the Behavior of the White Rat. *Behavior Mon.*, vol. 1, no 5, p. 15. 1912.

there is a devious way to learn which involves many turns and the possibility of many false turns. The final escape to food takes a time which varies from two hours per trial at the beginning to ten seconds when the problem is learned. The habits set up by the brightness contrast, whether depending upon discrimination or not, clearly cannot be carried over advantageously to a situation where the contrast does not exist. It may easily be conceived also that the motor habits involved in the simpler reactions described above for the problem box which bring the rat immediately to the presence of its food might be disastrous and delay the acquisition of a reaction depending upon the co-ordination of a long series of acts and extending over a considerable period of time.

As the learning of this maze has been so fully and freely discussed before all mention of it will be neglected here and any facts of interest concerning it will be brought out in the comparison of the two mazes which will follow later.

BLACK AND WHITE MAZE

The outcome of the tests on the black and white maze was noticeably unlike that of the normal maze. The differences were seen in the behavior of the animals and appear in the numerical results and the graphs plotted from them. They were confirmed and checked by the data furnished by the blind animals and by the facts brought out in the box experiments.

Success in such a problem has several measures: (a) the time taken relative to the total distance, i.e., speed; (b) the number and distribution of the errors, i.e., accuracy; (c) the time of learning, i.e., the number of trials in learning; (d) the surplus values of time and errors; (e) the rate of elimination, i.e., distribution of effort; (f) the form of the learning curve—a picture which reveals some of the complex relationships existing among the various factors. In this paper the burden of proof will be put upon accuracy and speed, since it was in these two respects that the greatest divergence was seen. The other criteria, however, will not be entirely neglected.

In the interest of clearness as well as of time and space, the results from the four groups of animals, trained and untrained, for the black and for the white maze, will be combined and presented as a whole. The differences were unessential. Any evidence of training being carried over from the box to the black-white maze was so slight that it may be neglected. This is due, doubtless, to the fact that the two problems were so dissimilar and that the time on the box was so brief. On the contrary, there was decided evidence of the effect of training in animals which went from the black-white maze to the box but that will be mentioned in another connection. The results also, when the true path was white and when it was black, agreed entirely in the essential details and hence they may be massed. The minor differences will be used only by way of explanation or illustration.

SPEED

Speed is time as measured by the distance traversed. In this case it is impossible to state the total distance since the returns, in the part of the maze which was covered cannot be counted. However, some evidence can be offered. One of the first lines of proof is the observed conduct of the animals.

The behavior in the black-white maze was very unlike that in the normal maze. In the beginning trials there was less activity, more sluggishness of movement, fewer errors, yet slow runs. Time and again I find in my notes such expressions as: "Slow start." "A very slow walk around although without error." "Very little rapid running." "Slow movement compared with normal maze." "No running and little sniffing at food-box or anywhere else." "Little running but much actual sitting still." "Few errors but little running." "Do not seem at all frightened or curious." "Do not apparently use covered ways as places of refuge." "Errors do not seem attractive and there is no blind running which would make the animals blunder into errors." There was more hesitation seen in these rats. Even long after the problem was learned they slowed up or wavered in their running when they came to a *cul de sac*. Some typical records, where every move which could be seen was entered with the time which it took, may serve to indicate the lesser activity better than a general description.

First Two Records of Rat "1"

May 10th and 11th.
1st trial:
To first corner and back—10 sec.
About entrance 55 sec.
To first corner 10 sec
Here 2 min 30 sec.
Home—remains 9 min. 30 sec.
First corner 15 sec.

Second corner 30 sec.
Reaches error "2" in 15 sec.*
Reaches error "3" in 5 sec.
Stays here 1 min. 15 sec.
Reaches food box 15 sec.
Reaches error "4" 15 sec
Reaches error "4" 15 sec.
Reaches error "6" 11 sec.
Reaches error "7" 20 sec.
Back to "6" 1 min.
Back to "4" 10 sec.
Back to food box 10 sec.
Returns to "4" 30 sec.
Returns to "6" 20 sec.
On to "7" 1 min. 45 sec.
Back to "6", here 5 min. 15 sec.
Back to "4" 30 sec.
In "4" and out. Sits here 30 sec.
On to "6" 15 sec.
On to "7" 1 min.
Sits at "7" 3 min. 30 sec.
In "7" and out 30 sec.
Sits here 7 min
On to food box 15 sec.
Total time 40 min. 22.6 sec.
Errors 2.

2nd trial, rat "1":
Slow start.
Reaches 2nd corner 5 sec.
Reaches error "2" 10 sec.
In and out error "2" 20 sec.
In and out error "3" 10 sec.
Reaches food box 30 sec.
Reaches error "4" 15 sec.
In and out "4" 30 sec.
Reaches "6" 5 sec. Here 20 sec.
On a short way 30 sec.
Returns to "6". Here 15 sec.
Back to "3" 1 min. 30 sec.
Returns to food box and back to "3" 1 min.
To food box. Here 3 min. 30 sec.
Back to "3". Here 30 sec.
To food box 1 min.
To "4" 15 sec.
Reaches "6" 15 sec. Here 15 sec.
In and out "6" 30 sec.
In alley near 1 min. 45 sec.
Back to "6". Here 45 sec.
Back to "4", to food box, to "3", 30 sec.
Back to "2". Here 1 min.
Back to food box 30 sec. Here 9 min. 30 sec.
On to "4", back to food box 30 sec.
On to "4", back to food box 15 sec.
On to "4", in and out 1 min.
On to "6" 15 sec.
On to "7" 45 sec.
On to food box 15 sec.
Total time 29 min.
Errors 4.

* "2", "3", etc., are the numbers of the blind alleys in the Maze. See Fig. 1.

These individual records show the type of behavior described above, which clearly is not like that seen in the normal maze in the first and second trials. There, the rats cover three or four times the distance and make twice the number of errors. Here, the total distance traversed in the true path in trial one was 93 ft., making the rate about 2 ft. per minute. It is true that the rats were not moving all of the time but neither were the rats in the normal maze although they are far more active. The total distance covered in the true path in the second trial

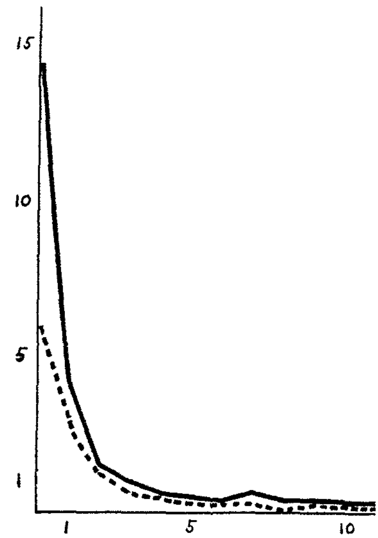

FIG. 3. Learning curves of 20 rats on the black-white maze
———— Time, - - - - - - - - Errors

was 135 ft. The rate, therefore, was but little less than 5 ft. per minute. If the activity had been evenly distributed over the maze, this rat, in its first trial, should have been in the false path 18 minutes and in its second trial 13 minutes.

From the figures of the rats in the normal maze I took those of the rat whose time and error records most nearly approached the average and computed the total distance, etc., for the first and second trials in the same way as above. This rat's time was a little low, so the speed is probably a little high for the first trial. The first trial showed a total distance covered of 313 ft. of which 190 ft. was in the true path and 123 ft. was in the blind alleys. The average speed for the entire distance was a little over 15 ft. per minute. The total distance for the second trial was 184 ft. of which 106 ft. was in the true path and 78 ft. in the *cul de sacs*. The speed then was 27 ft. per minute. Notice the distribution of the activity in this maze and compare it with that of the black-white maze above.

This slowness might be made more evident by another illustration. The average time of the first trial made without error for the rats on the normal maze was 45 sec. The average time of the 20 rats on the black-white maze for the same errorless trip was 122 sec. It took the latter group over four times as

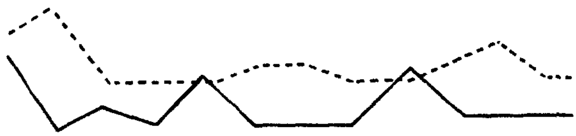

FIG. 4. Time curves for black-white and normal mazes, last 10 trials
——— Normal, - - - - - - - - Black-white

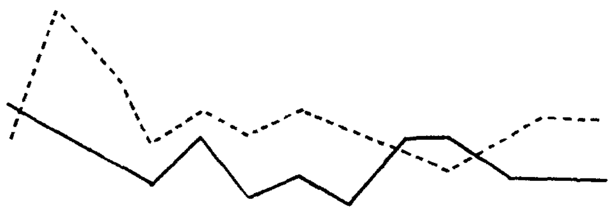

FIG. 5. Error curve for black-white and normal mazes, last 10 trials
——— Normal, - - - - - - - - Black-white

long. Returns were not counted in either case but so far as I can tell they were very few and fairly comparable.

But besides these individual records there are the combined group averages. The numerical data for the first ten trials has already been referred to (Table 1). The curves plotted reveal the same characteristics (Fig. 3). The time curve begins much lower in the black-white maze but that is because of the fewer number of errors which decreases the total distance of the run. These curves do not show the actual number of trials nor the exact average time for any particular trial. The first two-thirds of the distance shows the learning process, the last third an automatism. The ordinary curve where one trial is the unit resembles this in main outlines but the automatic period is greatly extended. Curves plotted with one minute as the unit of time do not reveal really significant fluctuations since the maze can be run in ten seconds. An increase of ten or twenty seconds scarcely shows on the curve, although the rats are taking two or three times longer to run. The end of a graph, in which one trial is the unit, has been magnified and the last ten runs of the fifty are revealed in a more significant fashion (Figs. 4 and 5). The time curve for the normal maze is considerably lower than that for the black-white maze. The records show that the average speed of the last five trials of the rats in the normal maze is ten seconds better than the speed of the rats in the black-white maze for the corresponding trials.

Thus the evidence, from the behavior notes, from typical individuals, from the average speed in the first trials without error, from the actual speed of individual animals in the true path, from the numerical results and plotted curves, confirms the original assertion. Rats in the black-white maze, in experiments continued long past the learning period, maintain a slower speed than rats in the normal maze The significance or cause of this will be discussed later. We will now consider the criterion of accuracy.

ACCURACY

One of the first things to attract the attention of the observer who was watching these experiments day by day was the very few errors which were made No one who had had any experience with other mazes could fail to be impressed by it. A number of animals made their way around several times without error on the second trial. They went slowly, to be sure, but accurately. There were no signs of marked avoidance but neither was there any evidence of direct discrimination. Slow as these animals were they did not enter many *cul de sacs*. If a rat by chance entered one of these blind alleys it did not seem in any hurry to get out but neither did it linger in it. One rather expected that the rats would tend to hide or tarry in the side-paths, especially when the covered ways were the *cul de sacs*.

The accuracy was apparent from the very beginning and was not a virtue of slow growth. Whatever influence was at work it was there from the first. The rats on the normal maze made an average of 14.9 errors the first trial while those on the black-white maze made only half as many, 7.5.

Notice the difference in the initial height of the error curves of the two mazes (Figs. 2 and 3). The error curve of the black-white maze is not like any error curve made for a normal maze and it is a direct expression of the accuracy. The time curve which accompanies it, as has been said, is low because of the fewer errors and not because of more rapid speed.

There is a great decrease in total as well as in beginning errors from the mark set by the normal maze. The latter maze has to its credit an average of 66.6 errors per animal or 1.48 per trial for each rat while the black-white maze gives only 35.6 errors

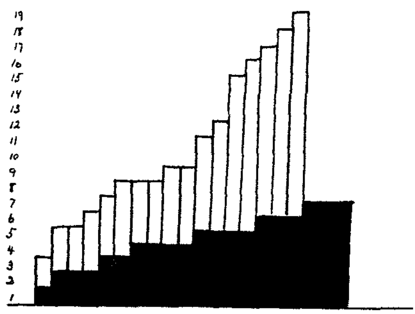

FIG. 6. Graph showing the point at which the animals made their first trial without error. Each vertical bar represents an animal. The black represents those of the black-white maze. This is superimposed upon the white, which represents the animals in the normal maze.

per animal or .8 per trial. The accuracy is nearly twice as great in the black-white maze.

One would naturally expect then, what really is the case, that the error curve for the black-white maze (Fig. 3) would reach its lowest level much sooner than the error curve for the other maze—that the automatism would be more quickly established. The figures show that the rats on the black-white maze made their average first trip without error on the 4.2 trial but the average for this trip on the normal maze was 8.5. If we take the first ten trials and compare them we find that the rats in the black-white maze have an average of 4.2 perfect trips to their credit while the normal maze has only half that number, 2. The graph seen in Fig. 6 is made from the records of 20 animals in the black-white maze and of 17 in the normal maze. It shows the trial at which the zero point was reached and the number making it at each point. It is perhaps more striking than the ordinary error curve.

If the errors are so few in the beginning, if the co-ordination is acquired so quickly, why is it that there is not a greater difference in the total errors? This is a question which requires an answer. The answer is that the final accuracy is less. See the curves, Figs. 2, 3 and 5. The normal error curve is regularly at the end of 50 trials below the black-white. What the causes are which produce this greater final variability is a question for our future inquiry. The three main points to be emphasized here are the few beginning errors, the rapid drop to the zero point and the persistence of errors to the very end.

SURPLUS TIME AND RATE OF ELIMINATION OF TIME AND ERRORS

Professor Carr argues at length for the value of the rate of elimination of surplus time and errors as one of the elemental components of the learning curve which varies independently from the other components.[15] The curves which show elimination in the experiments here reported are seen in Fig. 7. The rate of elimination is very similar in the two mazes There are, however, some points of contrast.

The time curve for the normal groups exhibits a fairly steady rate of decline to the 24th trial. Here the final limit is reached, .4%. The time curve for the black-white group reaches its final limit of 1.8% on the 9th trial It then follows the same course as the curve for the normal maze but with greater variability. The curve for the black-white maze reaches its level much sooner but cannot maintain it with the same constancy; neither can it reach, in the limits of the experiment, the same low level which the normal curve so easily reaches and maintains.

The error curve of the black-white maze indicates a much quicker rate of elimination than that of the normal maze. There is a steady drop till the 6th trial. From this point on there is only 6% of the errors left to eliminate. It will be remembered that the black-white maze had fewer errors to eliminate at the

[15] HICKS, VINNIE, and CARR, H. A. Human Reactions in the Maze. *Jour. of Animal Behavior*, vol. 2, no. 2, p. 98. 1912.

beginning. From the 6th trial on, however, the rate of elimination is below that of the normal maze. For the twenty succeeding trials the average is slightly above 6% and is only 1% less than this at the end.

The errors are eliminated more slowly in the normal maze. This curve does not reach the 6% level until the eleventh trial.

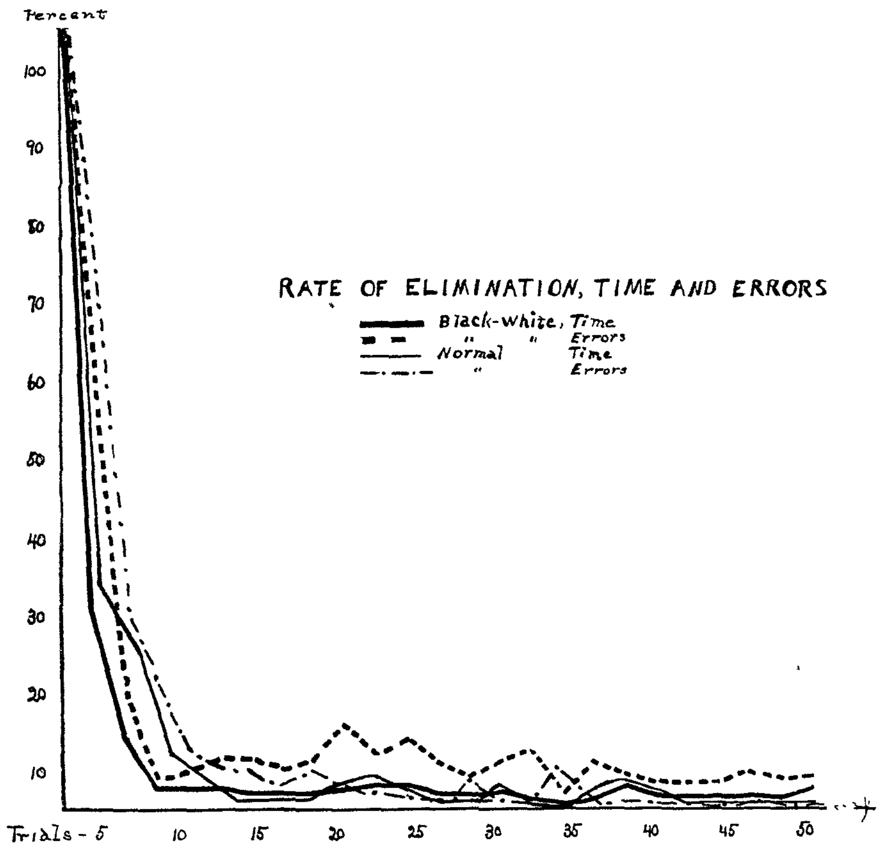

FIG. 7. Curves showing the rate of time and error elimination in the black-white and the normal mazes

From here on, however, there is a regular decline until, in the eighteenth trial, there is only 1% left to be eliminated. The curve wavers above and below 1% but this is practically the final level. The black-white maze has five times as much left to eliminate at the end as the normal maze.

BRIGHTNESS

But it may be argued that although the reactions of the rats in the black-white maze differ from those made in the normal maze in respect to speed and accuracy, the contributing cause may not have been the brightness of the runways. In reply it can only be said that no other difference can be seen in the experimental conditions The maze was the same in every experiment and it stood in the same place. The animals were from the same breeding cages, were given the same care and were used by the same person throughout. Tests to prove that it was the brightness factor, however, were introduced.

The blind animals furnished the best means of control. These animals were of the same original stock as the others and during the entire period of experimentation were kept in the cage with the others. They ran the maze daily with the other rats. They were put through the box problem but could not learn this as the rats with vision did. When taken over to the maze they behaved just as the blind rats in the normal maze behave. The learning curve for these rats has been plotted and may be seen in Fig. 8. Compare this curve with that made for the rats in the normal maze, Fig. 2, and see how nearly identical they are. Neither resembles at all the curve for the black-white maze, Fig. 3. These blind rats were in good physical condition, active and strong, and the only observable difference from their companions was in their lack of vision. Is not the conclusion fair that the contrast in behavior and the different numerical results of the two groups of animals used in this part of the experiment were due to the visual situation in the maze ?

The second control was the use of the problem box. Rats taken from the box over to the normal maze showed no favorable effect of general training. The training if anything resulted unfavorably. The reasons have already been given. Rats trained on the box when taken to the black-white maze exhibited no unfavorable effects of training but gave some slight indications that the brightness experience had been an aid. The slightness of this effect was probably due to the differences in the essential nature of the two problems and the briefness of the time in which the animals were in the box.

From the black-white maze to the box, however, the effect was different. The experience certainly did carry over. The number of trials in learning was one-third less and the total number of errors was reduced in the same proportion. The brightness situation must have been responsible for these contrasting results. The lengthened period of training on the maze before attempting the problem box may account for its greater effectiveness in this case.

Although the conduct described above was influenced by

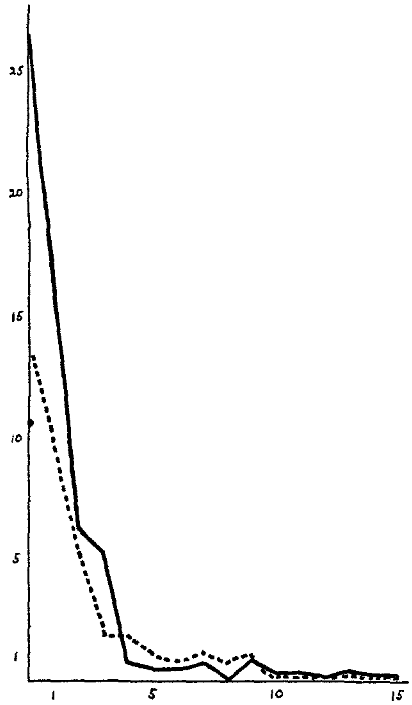

FIG. 8. Curves of the blind rats in the black-white maze
———— Time, - - - - - - - - Errors

brightness, may there not have been a preference, either instinctive or acquired, for black or for white ? It must be remembered that the animals in the experiments described may have been reacting to one color only regardless of any changes in the maze.

We do not think the reactions were due to preference. If they had been, there would have been greater differences between the results of the experiments where the true path was white and those where it was black. The following figures, taken from many others, show the similarity of the conduct in the two cases.

	Black	White
Speed in first 5 trials	8 1 ± 4 min.	7 1 ± 3 min.
Final speed	36 ± .1 min.	.44 ± .14 min.
Surplus time	46.4 ± 17 6 min.	47 6 ± .16 min.
Errors in first 5 trials	18 4 ± 4.4	16.5 ± 4 6
Total errors	30 ± 6 4	39 2 ± 10 5

There are variations, as will be seen in the above table, but the balance is now on one side, now on the other side of the scale.

If there were a preference for either black or white the observed behavior would have shown it. There would have been a lingering in one path rather than the other, a choosing or avoidance of the covered way, more errors in the one case than the other. There was no observable conduct which would indicate such a preference either for black or for white. There must be some other explanation than that of preference.

It is quite possible, even when it is granted that these results are not due to an instinctive preference, that there may have been a difference in the relative stimulative effectiveness of the black and the white paths. Since the effects of training were the same for both black and white the two groups may be compared directly irrespective of the minor grouping for training. The results are very similar. The differences are slight indeed in comparison with the larger differences which were seen between the black-white and the normal mazes and may be due to chance.

The white true path seems to give a better initial direction for the first trials. The animals constituting this group stayed in the true path more consistently than those of the group where the true path was black. But the black *cul de sacs* proved more attractive in the end, for while following the white path more total and more average errors were made than while following the black. A greater number of trials was also necessary in learning. The white path gave the lowest initial time and the the lowest final time although the total time of the two mazes was about equal. Thus while the white path probably gave a better beginning both in speed and accuracy and the speed as a whole was better, the record for total and final accuracy was less than that of the maze when the true path was black.

CONCLUSIONS

The conclusion seems justified that such a contrast in brightness between two roads is exceedingly effective with these animals as they learn the maze. It gives increased accuracy, as is shown both in initial and total decrease of errors, and in a decrease of total time. So far it seems advantageous, yet there was a final inaccuracy greater than normal and a lesser final speed.

There were no outward signs of discrimination such as marked avoidance, quick reaction, noticeable change of behavior with change of stimulus. There was no lingering in one path or another which might indicate an instinctive preference. There was only a slower, perhaps a more cautious, activity in which random movements were inhibited in both initial and early trials prior to any effects of learning.

If the difference is not due to discrimination, and we have no evidence from the behavior or the nature of the curve as ordinarily interpreted that it is, what has caused the different character of the learning ? All who have worked with animals know that a stimulus may be effective although not discriminated. In such a case as this, where two widely differing degrees of brightness were used, one may have been more directive, more potent, more attractive than the other. Professor Carr suggests the phrase " dominance of a stimulus." This would tend to attract the animal's attention either to the white or to the black pathway.

It was said above that the different behavior was seen " prior to any effect of learning." It must be remembered, however, that such a problem is solved not by one act but by a series of acts and hence there may be learning within the trial itself. If the second trial is influenced by the first, if learning has begun, where did it begin ? Learning the maze is not at all like a single act, jumping a certain distance, for example. In a problem of this kind, which takes so long a time, it clearly may begin in the first attempt As the animals enter this maze they are in the true path be it black or white. The first error, to the right, is barred almost immediately, probably by kinaesthesis. It is seldom made again except in times of great confusion. The true path includes first, a run to the left half way across the maze, then a turn, and then a clear run across one side. In this side there is the possibility of an error, but not one into which the animal runs headlong. Hence from the very first there is a safe experience of a definite sensory sort which extends over a considerable period of time. Because it is the first experience, because it proves safe, because the animal, on the whole, is more in this path than the other, because his returns are made on this path, these may be some of the reasons why this path proved more potent, more dominant, more directive than the other and indicate one way in which learning may possibly begin.

The term learning needs more careful definition Certainly there was little evidence of discriminative learning here. If there was any, it must have occurred chiefly within the first trial. This possibility may be referred to in a later paper. The curve showing the rate of elimination of time and errors furnishes a slight indication of learning to use vision in the interval between the fifth and the tenth trials, Fig. 7.

If the mere strength of the visual stimulus was the effective cause of the reinforcement or modification of the usual controls, then we shall have to conclude that the white path was, on the whole, the more dominant one. The entire matter then would hang upon the supposition that the brightness factor in a certain path had the power to hold or compel the attention of the animal

The time taken per trial depends of course upon the speed and the accuracy. The more errors an animal makes, the more blind alleys he explores, the longer the time per trial. Thus the fewer errors would largely account for the lessened initial time. The contrast between black and white, as will be remembered, was as strong as could be produced. The final inaccuracies might have been due to this contrast effect which persisted to the end and attracted the attention of the rats when they were momentarily distracted and thus led them into errors. The stimulating power of this contrast was no doubt responsible for the late development of the kinaesthetic control. But the slow change, when it did come, from reliance upon vision to the automatism of kinaesthesis left vision free to be caught, to be attracted by these contrasts, and led the animals into errors.

The decrease of final speed might have been due to the greater number of errors, yet this is probably not sufficient to account for the result since the speed was less in cases where there were no errors. The slower speed was caused, perhaps, by a natural hesitation because of the attractiveness of the errors and this was made possible by the slighter kinaesthetic automatism.

Our final conclusion is then that if animals are given two contrasting paths side by side, differing in brightness, the one path may prove more dominant and favor accuracy and because of accuracy a shorter time in the early trials. After the problem is learned, in the slow turning over to kinaesthesis, when attention is freed, these sensory factors may still retain their potency in times of momentary distraction. The result is a less perfect automatism and a slower speed.