THE WHITE RAT AND THE MAZE PROBLEM

IV. THE NUMBER AND DISTRIBUTION OF ERRORS—A COMPARATIVE STUDY

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What is the maze problem? It is the learning of a difficult path, having many blind alleys, under a stimulus so strong and certain that finally, when put into the labyrinth, the animal runs swiftly and surely to the goal without error. It consists of a series of movements which tend toward a definite end and which are so ordered that the position and the direction of the turns seem to be the all important factors The animal's task is to learn this motor co-ordination, ours, if possible, to find out how it does it.

In the learning of the maze we find not a single problem but a complex of many and much light has been thrown upon them through the work of Small, Watson, Richardson, Carr and others. Some of the questions which arise in the course of such investigations are, however, still without satisfactory answers. The preceding numbers of this series have dealt with the problems of sensory control in the maze. This paper attempts to deal, briefly, with some of the more general features of the maze problem in the light of that experimentation. One question which immediately suggested itself concerned the relative value of the different senses when directive in such a problem

THE RELATIVE EFFECTIVENESS OF THE DIFFERENT SENSES AS MODES OF CONTROL

This comparison is not an easy one to make since any one sense factor is never isolated but only emphasized in the sensory complex. The following table (I) shows factual data taken in different ways from the learning scores. If we turn this into terms of per cent, making the lowest and therefore best score always 100, and basing the others on this we get table II. By normal maze is meant the unpainted wooden maze where the

TABLE I

	Time of learning	Average errors first 5 trials	Average errors last 5 trials	Total average errors per animal	Average time first 5 trials	Average time last 5 trials	Surplus time
Normal maze..	12 1 ±3 6 trial	48 7 ±7 7	1 ± 14	66 6±16	16 3±6 7 min.	31± 05 min	93 9±16 5 min.
Olfactory maze, trail in true path	8 1 ±2 4 trial	13 2 ±2 9	.04±.04	20 5±5 6	8 7±3 9 min.	28± 08 min.	64 9±23 6 min.
Composite black-white maze.. ..	14 ±11 trial	17 4 ±4 5	3 ±.4	34 6 ±8 4	7 6±4 min.	4 ± 1 min.	47. ±16 8 min.
Cutaneous maze (sides on) ..	16 5 ±3 7 trial	30 ±12 8	18± 21	51. ±23	1 8±2 7 min	18± 06 min.	15 3 ±6. min.
Cutaneous maze (open) .	16 5 ±6 6 trial	21 ±5 2	09± 11	37 3 ±5 1	1 9 ± 7 min	15± 03 min.	13 9 ±4 3 min.

TABLE II

COMPARISON OF NORMAL, BLACK-WHITE AND OLFACTORY MAZES

Time of learning
Olfactory 100%, Normal 145%, Black-white 175%

Accuracy
Initial—Olfactory 100%, Black-white 130%, Normal 370%
Final— Olfactory 100%, Normal 250%, Black-white 750%
Total— Olfactory 100%, Black-white 175%, Normal 330%

Time
Initial— Black-white 100%, Olfactory 115%, Normal 215%
Final— Olfactory 100%, Normal 110%, Black-white 143%
Surplus—Black-white 100%, Olfactory 138%, Normal 190%

COMPARISON OF OPEN MAZE WITH ENCLOSED NORMAL MAZE OF SAME PATTERN

Time of learning
Open maze 100%, Normal 100%

Accuracy
Initial—Open maze 100%, Normal 150%
Final— Open maze 100%, Normal 225%
Total— Open maze 100%, Normal 140%

Time
Initial—Normal 100%, Open maze 105%
Final— Open maze 100%, Normal 120%
Total— Open maze 100%, Normal 110%

sides to the alleys were high enough to prevent any outlook to the neighboring runways and the light and odor were as evenly distributed as possible. The second maze was of the same plan but the true and the false paths were made to differ decidedly in brightness values. The third maze, again of the same pattern, had an olfactory trail in the true path[1] The figures from the open maze are not compared directly with the others but with the score from the same maze when the restraining walls to the alleys were in place.[2]

We will not stop to comment upon the time of learning, as the chief differences are seen in the accuracy records. The olfactory maze heads the list in this respect both in initial, final and total accuracy within the limits of the experiment. The black-white maze follows second in initial accuracy and in total, because of the initial, but falls far behind in final accuracy.

[1] In these tables the combined black-white figures are used, i.e., two groups of animals of five each where the true path was white and the *cul de sacs* black, and two groups of the same size where the conditions were reversed. The olfactory records are those where the trail was in the true path since this seemed most typical for our purpose. The combined olfactory scores make but little difference in the rating, they simply somewhat lowered the scores in the early trials and raised them in the final. For full details consult the previous papers.

[2] These mazes are all described in previous papers.

The reasons for this have been discussed in another paper. The time records are almost a direct reflection of the accuracy for, although the final scores distinctly favor the olfactory and black-white mazes, the advantage is but slight. The cutaneous open maze is also better than the normal in all of the accuracy counts, and also in final and total time. The small differences in time again are probably more or less an expression of the accuracy with a balance in favor of the open maze.

In these results, then, the olfactory maze leads, the open maze stands next in order while the black-white and the normal mazes approach each other very closely if all of the counts are considered. It will be seen that the big advantages which these sensory mazes offer are found in the early trials, in the setting up of the automatisms, and that the apparent total gain is due, for the most part, to the gain in the early trials. The established habit is practically the same no matter under what sensory conditions it is set up. The distracting effects of some of these sensory situations which affect the final scores are discussed in the previous papers.

Why some experimental workers should choose to neglect the error records is still a mystery to some of us. Certainly the real differences in the bits of learning given above are not shown by the time records. It is more essential in the normal life of a rat that it should be able to thread a beam or a cornice without falling, to jump from one projection to another without missing, to avoid being cornered and to strike its hole exactly when pursued by its enemies than to run a certain number of feet per second. The total distance which has been a measurement warmly advocated has advantages but it does not show really significant variations from the true path, although there is always, we will grant, a relation between the total number and amount of the errors and this total distance. If a rat always took the shortest way home, if it did not have its own peculiar way of getting out from its hole, perhaps this measure would express the facts more truly. The animal runs out into the maze a little way, runs back, runs out a little farther and then back, etc. This is a purely instinctive activity quite on a par with those natural movements in and about a rat's hole that insure it an open way home and such actions may not at all signify that the path as far as traversed is not familiar.

These runs then, which are included in the total distance, are not of the same nature as those other errors which take it entirely off the trail They indicate its method of learning. They are interesting of course, and perhaps valuable for learning but they are not of the same class as the others. In all of this work, since our interest lay in the ability which the animals possessed to follow or to neglect a certain sensory stimulus, the errors consisted in leaving the true path. But it is not alone the number and kind of errors which excite our interest in this problem but also the distribution of the errors within the maze itself.

DISTRIBUTION OF ERRORS

The following tables show the distribution of errors in the different mazes Whether a *cul de sac* will be entered or not depends upon the general direction in which it extends, its relation to the food box and whether it is so placed that the animal enters it headlong, etc., etc For these reasons and for the sake of fairness we have chosen to compare the total scores of alleys 1, 2 and 3 with the corresponding error scores of 5, 6 and 7,[3] in the Hampton Court Maze The normal maze record shows a greater score on every count for the first three than for the last three alleys. The combined black-white maze table reveals the same thing, as does also the cutaneous normal records. In the cutaneous maze, alleys 4 and 5 were very near to the food box, so near that in the open maze the animals sometimes succeeded in jumping across. For this reason these alleys were very attractive and the different results in the open maze may, perhaps, be explained in this way It will be observed, however, that in the last three counts in the open maze also, when the automatism is beginning to be perfected, favor the final alleys The olfactory maze, where the trail is in the true path, gives a record where the conditions are reversed, but when the trail is in the alleys the normal standard is again approached although the degree of difference between the first three and the last three alleys is less. The elimination of the final members of the series first is not only true of the groups as a whole but also of the individual animals The records of 41 rats in the normal, black-white and cutaneous groups were gone over and only five rats found where the relation was re-

[3] The *cul de sacs* are numbered in the order in which they occur in the maze.

versed and two where they were the same. The number might have been easily doubled but it seemed useless to do so.

TABLE III
DISTRIBUTION OF ERRORS, NORMAL MAZE

	Alley 1	Alley 2	Alley 3	Alley 4	Alley 5	Alley 6	Alley 7	Alleys 1, 2, 3	Alleys 5, 6, 7
Total errors...	81	112	146	82	68	121	25	309	214
Trial at which the error was not made three times in succession by any rat.	18	21	26	5	13	16	11	31.6	13—
Average errors per rat after 10th trial	1 1	1 5	2 2	7	1 2	1	.6	1 6	.9
Average error per rat from 20th to 35th trial.	.3	9	1.	.3	.2	1	1	.7	.1

TABLE IV
DISTRIBUTION OF ERRORS, BLACK-WHITE MAZE

	Alley 1	Alley 2	Alley 3	Alley 4	Alley 5	Alley 6	Alley 7	Alleys 1, 2, 3	Alleys 5, 6, 7
Total errors..	31	55	45	43	11	24	5	131	40
Trial at which the error was not made three times in succession by any rat.	16	19	7 5	9	4 5	6	2 5	14 2	4 3
Average errors per rat after the 10th trial.. .	6	1 7	8	6	.1	1	1	1	11
Average errors per rat from 20th to 35th trial.	2	.6	3	.5	1	.05	15	36	.1

TABLE V
DISTRIBUTION OF ERRORS, OLFACTORY MAZE, TRAIL IN TRUE PATH

	Alley 1	Alley 2	Alley 3	Alley 4	Alley 5	Alley 6	Alley 7	Alleys 1, 2, 3	Alleys 5, 6, 7
Total errors	1	14	12	16	14	36	17	27	57
Trial at which the error was not made by any rat three times in succession..	1	11	17	16	10	14	9	9+	11
Average errors per rat after the 10th trial. .	0	0	1.1	9	0	3	.3	4—	3—
Average errors per rat from 20th to 35th trial.	0	0	5	.1	0	0	1	16	03

TABLE VI

DISTRIBUTION OF ERRORS, OLFACTORY MAZE, TRAIL IN THE *Cul de sacs*

	Alley 1	Alley 2	Alley 3	Alley 4	Alley 5	Alley 6	Alley 7	Alleys 1, 2, 3	Alleys 5, 6, 7
Total errors	0	40	59	62	35	73	22	99	130
Trial at which the error was not made by any rat three times in succession	0	7	32	6	5	10	8	13	7+
Average errors per rat after the 10th trial	0	2 1	2 3	5 3	2 3	1 6	3	1 46	1 4
Average error per rat from the 20th to the 35th trial	0	1	1 5	4 6	1 1	1	.1	83	7

TABLE VII

DISTRIBUTION OF ERRORS, CUTANEOUS MAZE—SIDES ENCLOSED

	Alley 1	Alley 2	Alley 3	Alley 4	Alley 5	Alley 6	Alleys 1, 2, 3	Alleys 4, 5, 6
Total errors	53	25	52	60	19	1	130	80
Trial at which the error was not made three times in succession by any rat	26	17	18	23	8	2	20 3	11
Average errors per rat after the 10th trial	2 6	.8	1 6	2 1	5	1	1.6	9
Average errors per rat from the 20th to the 35th trial	.8	0	6	6	0	0	5	2

TABLE VIII

DISTRIBUTION OF ERRORS, CUTANEOUS, OPEN MAZE

	Alley 1	Alley 2	Alley 3	Alley 4	Alley 5	Alley 6	Alleys 1, 2, 3	Alleys 4, 5, 6
Total errors	30	29	48	66	37	4	107	107
Trial at which the error was not made by any rat three times in succession	33	17	17	25	10	2	22 3	12 3
Average errors per rat after the 10th trial	3	2 5	2 3	3 1	2 6	3	2 6	2
Average errors per rat from the 20th to the 35th trial	1 6	1 3	1 3	6	1 1	0	1 4	5+

In a normal maze, when the *cul de sacs* are at all comparable, the number and persistence of the errors of the first part of the series may be explained by the laws of association, i.e., they are made first, made most frequently and therefore persist longer. On the other hand, it may be that the food box as the final and probably the strongest member of the motor series may become more directive and react back into and help to organize the later members of the series most closely connected with it in time much as other memory series—not motor—are known to be organized.

The black-white maze influenced the distribution of errors but as the rat's vision is notoriously poor the influence was chiefly seen in the smaller amount of difference between the records of the first and the last *cul de sacs* as the character of the distribution remained the same.

In the open maze the errors were more evenly distributed for the reasons given above. The animals in the olfactory maze were really learning to follow a trail and incidentally learning a motor series. The incidental errors increased toward the end of the series although the last two counts show a balance in favor of 5, 6 and 7. The experiment when the trail was in the *cul de sacs* gave a situation where the true path resembled that of the normal maze but the *cul de sacs* were made more attractive because of the odor and thus influenced the totals. The last three counts, however, are lower for 5, 6 and 7 in this experiment also.

Sensory clues in these mazes, not only favor accuracy but also affect the distribution of the errors among the members of the series of blind alleys. The influence is seen both in the degree of difference and in the character of the distribution. The distribution could be said to be less mechanical and not quite so predictable as in the normal maze although on the whole the relations were similar in all of the mazes.[4] The final members of the *cul de sacs* were entered less frequently and eliminated first.

[4] Since making these tabulations and comparisons Miss Hubbert's paper has appeared. "Elimination of errors in the maze," *Jour. Animal Behav.*, Vol. 5, No. 1. Her results contradict those reported here, but this work must stand on its own merits. I cannot at this place enter into a discussion of Miss H's. paper. It scarcely seems fair, however, when there are so few *cul de sacs*, to eliminate the first and the last, where the chief differences are seen, from the comparison. There is always overlapping in the middle of any series. If the nature of the maze compelled this elimination then no general conclusions should be drawn.