

# THE SENSORY CONTROL OF THE MAZE HABIT IN THE WHITE RAT\*

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## INTRODUCTION

Since the work by Small (13) and Watson (15), and particularly since the work by Carr and Watson (4), it has been the favorite hypothesis that the essential sensory control of the maze habit is proprioceptive in kind and that the distinctive proprioceptive stimuli arise when the subject runs a certain distance and makes a certain turn. The proprioception thus aroused is assumed to be the stimulus for the next run and turn, and so on, through the chain of responses making up the maze habit. The subsequent work on the maze by Bogardus and Henke (1), Vincent (14), and Carr (2, 3) served to add new details to the picture, but it did not undermine the central thesis that the essential sensory control of the maze habit is proprioceptive.

The present paper, first reported in 1929 (10, 11), resumes the attack upon the proprioceptive theory which I began in 1918 (7) and 1920 (8). In the latter paper I wrote as follows: "If the conventional account of the reactions in a spatial maze were correct, the rat should be able to learn a temporal maze of almost any complexity. It is said that in the former maze, the kinaesthetic cue from running one segment controls the running of the succeeding segment, so that a chain of proprioceptive activity results. The work on the temporal maze indicates that it is all but impossible to set up a mere temporal sequence of kinaesthetic processes with the rat. . . . It is possible that a rat might learn a space maze requiring simple alternation and then run it in terms of kinaesthesia. The animal however easily masters the ordinary maze where the choices may be in any combination. How can it use the kinaesthesia connected with a left turn at one time to initiate a turn to the right and at another

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\*Received in the Editorial Office, September 27, 1929.

moment to initiate a turn to the left? Our tests have indicated that this cannot be done unless spatially arranged cues are available" (8, pp. 16-17). This problem of the sensory control of behavior I analyzed further in the paper on raccoons in the temporal maze (9).

Two recent papers are of particular importance for our present topic, one by Lashley and Ball (12) and the other by Dennis (5). Dennis found that blind, vibrissaeless rats were unable to perfect a simple maze habit upon a purely proprioceptive basis. The maze was constructed with a wide alley as opposed to the narrow alleys of other mazes. This gave the rat plenty of room in which to avoid the walls and allowed for a correct run in terms of proprioception even though that sense might be slightly inaccurate. Punishment devices were installed in an effort to force the rats to eliminate contacts with the walls and to depend upon proprioceptive stimuli. In certain experiments the walls of the maze were lifted in order to determine whether or not the rat would continue to run the maze pattern when not constrained by the walls. On the basis of these experiments, Dennis writes as follows: "The results of the present experiments indicate that the rat cannot make responses of the degree of accuracy of spatial adjustment required by the maze on the basis of proprioceptive processes. These processes are active, to be sure, as indicated by the occasional perfect runs and by the curved character of the pathways. However, the blind rat must in the very great majority of cases receive a cutaneous stimulation from the walls in order to find the proper openings. To a large extent and perhaps entirely, the seeing rat can dispense with these cutaneous stimuli and utilize vision to supplement the proprioceptive processes. These statements do not necessarily imply that the cutaneous and visual stimuli must serve as differential cues, i.e., that there shall be one kind of contact at one part of the maze and another kind of contact farther on. The cutaneous and visual stimuli may have a *releasing* function only. In such a case, proprioception might indicate that a turn is to be made but that turn would be made only when contact or vision, or both, indicated the presence of an opening through which to turn" (5, pp. 86-87).

Lashley and Ball (12) investigated the problem of sensory control of the maze habit from another angle. They trained white rats to run a simple alternation maze. After this, certain fiber tracts in

the cervical region of the cord were experimentally severed. After the operation the rats were again tested on the maze. No one rat had all of its fiber tracts severed, but all tracts save portions of the ventral funiculus were presumably severed in the group as a whole. The results show that the maze habit can persist practically unimpaired in some animals with each type of lesion. Lashley attacks the chain reflex theory of the maze habit as well as the theory of proprioceptive control. He inclines to the view that the maze habit is controlled by a neural engram, or set.

It is perfectly evident from Lashley and Ball's results that the maze habit may persist after an extensive interference with spinal conduction paths. However, I hesitate to accept the authors' conclusions for several reasons: (1) The maze was a simple alternation *rlrlr* maze which would be easily learned and well retained. Therefore any lack of completeness in the severing of proprioceptive conduction paths might well fail to disturb the response by leaving a sufficient basis for executing this simple habit. (2) We cannot be sure that the proprioceptive impulses are confined to the tracts severed in any one rat. Lashley notes this possibility, but does not regard it as probable. (3) Maze habits are influenced by non-proprioceptive stimuli from the environment of the maze and from the maze itself. These stimuli may have played a sufficient rôle in the present simple habit to have supplied the deficiencies created in the proprioceptive processes.

In the experiments to be described in the present paper I have sought to throw light upon the sensory control of behavior in the maze by controlling the stimuli presented to the animal. All of the mazes were constructed so that the distances between turns were exactly equal and consequently would yield equal proprioceptive stimuli. All turns were right angle turns. As a result, all proprioceptive stimuli from right turns should be alike and all stimuli resulting from left turns should be alike. Furthermore, the pathways were carefully machined in order to eliminate cutaneous differences. The paths were kept clean either by washing or by rubbing with sand- or emery-paper. Stimuli from the environment were controlled: by working in an inside laboratory room, by having the experimenter remain quiet and in a constant position (in some cases screened from the animal), by blinding the rats, and by utilizing

bidimensional, tridimensional, and temporal mazes. There were no drafts, no variations in temperature during a trial, and the only constant noises came from a definite direction.

#### THE DOUBLE ALTERNATION SPATIAL MAZE A

*Apparatus.* Figure 1 presents a ground plan of the double alternation spatial maze used in the present experiment. The maze was of the elevated type. Each unit was  $35\frac{1}{2}$  inches long. Of this distance, 10 inches were cul-de-sac and 24 inches were true pathway. In place of having the rats run along the upper edge of the wooden sections themselves, brass strips  $1\frac{1}{2}$  inches wide and  $\frac{1}{4}$  inch thick were placed on top of the wooden sections. These strips were carefully machined and joined so that no differential cutaneous factors were present. The strips were kept clean (washed daily) and were rubbed with emery-paper to maintain their smoothness. The edges of the strips projected  $\frac{3}{8}$  inch on each side beyond the wood of their supports. It is to be noted that the order of turns in the correct pathway is right, right, left, left, right, right, left (*rrllrrl*). All turns were at right angles. Care was taken to make the maze level so that one section would not slope in one degree and another section, in another. The maze contained no food-box.

The rats were carried one at a time from the living room to the experimental room. One trial daily was given. No food was placed on the maze. When the rat reached the end of the maze, he was lifted to a chair six feet away where he ate his ration of bread and

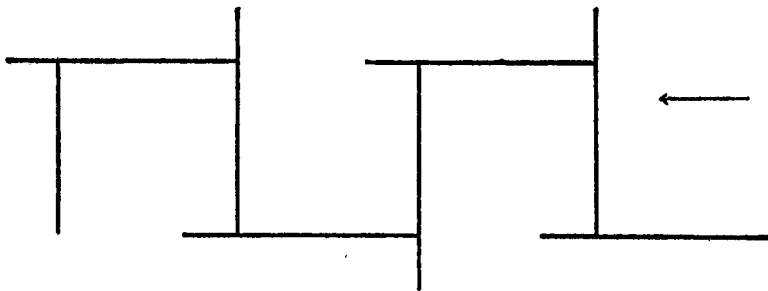


FIGURE 1

GROUND PLAN OF THE DOUBLE ALTERNATION BIDIMENSIONAL SPATIAL MAZE A  
The arrow indicates the direction from which fairly constant sounds were coming. The entrance of the maze is at the top of the figure.

milk. The pathway from the living cage to the maze was always the same, and the cages were never cleaned or otherwise disturbed within the 20 hours immediately preceding any day's experiment. Three perfect runs in succession were set as the standard of mastery.

*Subjects.* Six untrained rats, descendants of Wistar stock, were tested. Three of them were six months old and three were six weeks old at the beginning of the experiment. All were blinded from 4-10 days prior to the experiment, and all had their vibrissae cut close to the head. This vibrissaeless condition was maintained throughout the experiment. Each rat was fed in the experimental room for seven days prior to the beginning of the experiment proper.

*Results.* Table 1 indicates that only three of the animals reached the criterion of three perfect runs in succession. The other three animals were given from 50 to 64 trials, and only one, No. 3, succeeded in making one perfect run within this time. It is possible that all rats would have mastered the problem if the training had been sufficiently extended. This extended training was not given because my chief purpose was to determine whether or not *any rat could learn this maze*. [It is interesting to compare the above results with those which I secured in 1920 (8, pp. 7-8). The double alternation maze used at that time made no effort to control carefully the tactual, proprioceptive, and olfactory factors. The rats were not blinded. In that problem the rats reached a mastery of the maze in from 5-12 trials, 1 trial daily.]

TABLE 1

Rat	Trials before 1st correct run	Trials before 3 correct runs in succession
1	7	24
2	22	31
3	18	(never in 64 trials)
4	43	46
5	(never)	(never in 50 trials)
6	(never)	(never in 50 trials)

It will be interesting to note the nature of the errors that held up the learning of rats 3, 5, and 6 and that intervened between the first perfect run and mastery with rats 1, 2, and 4. Table 2 shows the number of errors made by each rat at each cul-de-sac and also the number of retraces. This latter type of error occurred but

rarely during the period represented in the table. Culs-de-sac 2, 4, and 6 caused the most trouble. Rat 5 also had great trouble with cul-de-sac 1. Rat 6 distributed his errors throughout the maze, although the errors at culs-de-sac 2, 4, and 6 were the most numerous.

TABLE 2  
NUMBER OF ERRORS MADE IN EACH CUL-DE-SAC AND THE NUMBER OF  
RETRACING ERRORS MADE FOR THE TIME PERIODS INDICATED

Rats	During the 10 trials prior to mastery			During the 10 trials prior to the end of training			Total
	1	2	4	3	5	6	
Retraces	1	0	0	3	0	2	6
Culs-de- sac							
1	0	2	0	2	11	6	21
2	0	5	1	11	3	8	33
3	2	2	1	0	1	6	12
4	4	3	7	11	7	8	40
5	0	0	0	0	2	4	6
6	0	2	2	9	12	8	33
7	0	0	3	0	1	4	8

*Interpretative Comments.* Because of the general construction of this maze, it seems improbable that differential cutaneous cues controlled the completed response in rats 1, 2, and 4. Cutaneous stimuli certainly were present and effective in indicating when a turn could be made. (See Dennis, 5.) It does not seem probable, however, that the carefully joined and polished brass could have offered cutaneous stimuli sufficiently different from point to point to arouse one response at one point and another response at another point.

Auditory and proprioceptive stimuli are the cues that are most obviously suggested as essential for the control of the habit, since olfaction was undoubtedly controlled by washing the brass strips. The work was not carried out in a soundproof room. Slight noises came almost constantly from the adjoining rat room and from the street. Both of these sounds came from the direction indicated by the arrow in Figure 1. If the rats learned, completely or partially, to work in the direction of the sound in order to reach the exit, culs-de-sac 1, 3, 5, and 7 would give less difficulty than 2, 4, and 6. At the entrance to cul-de-sac 1, for example, the rat in turning

toward the source of sound would omit error No. 1. This would be true in a similar manner at culs-de-sac 3, 5, and 7. On the other hand the auditory stimulus would be of no help in solving the problems of culs-de-sac 2, 4, and 6.

If the three rats who learned the maze mastered culs-de-sac 1, 3, 5, and 7 on the basis of *some direction tendency* of the type which we have suggested, the problem of culs-de-sac 2, 4, and 6 would be a problem of simple alternation inasmuch as the correct turns are right, left, right. The problem of simple alternation as such is not difficult for the rat. However, the records of rats 3, 5, and 6 indicate that an *rlr* element in the particular setting of this experiment may be of great difficulty.<sup>1</sup>

Two methods of checking the influence of sound direction were suggested at this stage of the experiment. One called for the introduction of sounds coming from other directions, and the other called for a maze which could not be mastered as a simple alternation plus a simple directional factor. The latter method was selected and will be described in the next section of the paper.

Proprioceptive stimuli as such cannot account for the mastery of the present maze inasmuch as all straight sections were of exactly the same length and inasmuch as one stimulus cannot call forth one response at one time and another response at another time unless it is supplemented by other stimuli or by some retained neural trace. (See footnote 2.) We may illustrate this in terms of Figure 2, I.  $S_E$ , the stimulation at the entrance and along the first runway, causes the response to the right,  $R_R$ . This total response has as sensory consequences  $S_R$ . This stimulation can again cause a turn to the right which is followed by precisely the same sensory stimulation as before, viz.,  $S_R$ .  $S_R$  must now cause a turn to the left,  $R_L$ . The same situation is found with the sensory consequences of turning to the left, after which the series becomes again one of right turns.  $S_R$  or  $S_L$  cannot at one time cause a response to the

<sup>1</sup>Present day writing on maze habits contains many references to direction tendencies. Direction tendencies, to the extent that they exist, are habits of orientation which must be controlled by some sensory or neural factor, or by both. In the present discussion I have assumed, for purposes of illustration, that auditory stimuli may have controlled the orientation.

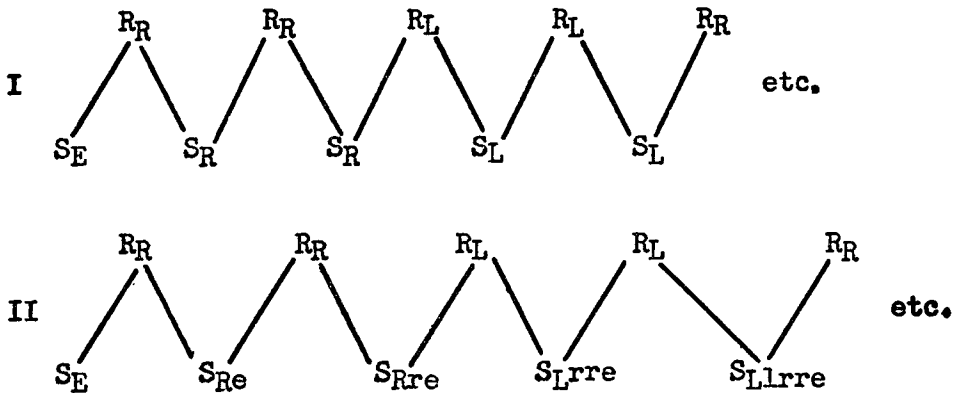


FIGURE 2

A DIAGRAM (I) OF A STIMULUS-RESPONSE MECHANISM IN TERMS OF WHICH DOUBLE ALTERNATION CANNOT BE RUN AND (II) OF A STIMULUS-RESPONSE MECHANISM WITH NEURAL SUPPLEMENT WHICH, IF PRESENT, WOULD MAKE DOUBLE ALTERNATION POSSIBLE

right and at another time a response to the left unless they are supplemented in some way.<sup>2</sup>

If proprioceptive stimuli are to play any essential rôle in the control of the perfected response in this maze, they must theoretically be supplemented either by stimuli from the maze, by stimuli from the environment (for example, by the direction of sound), or by some neural trace of responses previously made during the same trial. This last case is illustrated in Figure 2, II, where the first response is caused by  $S_E$ ; the second, by  $S$  plus the retained effects of the first  $S$ ;

<sup>2</sup>When this argument was presented at the Ninth International Congress of Psychology, some one objected that the arousal of different responses by the same stimulus was a common phenomenon. A flame, for example, presented to a child will at first cause one response and later, another one. Learning consists of a progressive change in behavior aroused by a repetition of a given stimulating condition. Such criticisms, however, miss the point of the present argument. In the double alternation problem there is not, during any one perfect trial, a progressive change of the response with a repetition of the same stimulus. Rather with the repetition of the stimuli there is a *recurrent* pattern of behavior. A given stimulus-complex cannot cause first one response and then another,  $R_R$  and  $R_L$ , and then at a later point in the same trial again cause  $R_R$  and  $R_L$ . Such a phenomenon requires that the stimulus be supplemented in a manner not found in the progressive changes in response which constitute learning in general.



the third, by *S* plus the retained effects of the first two *S*'s; etc. It does not seem probable that this third possibility was influential in the present double alternation maze because this maze was so very much more easily learned than was the double alternation temporal maze (p. 527). The neural accumulation should be no more difficult in the one case than in the other, and yet the explanation of the temporal maze habit requires the postulation of some type of neural accumulation or of some type of symbolic process, or both.

#### THE DOUBLE ALTERNATION SPATIAL MAZE B

*Subjects, Apparatus, and Method.* The six rats, Nos. 1-6 of the first experiment, were used on Maze B, as well as three new untrained rats who were also blind and vibrissaeless. The new rats were between one and two months old when the experiment began. The method of procedure was exactly as described for Maze A.

Maze B was constructed to test the hypothesis that sound direction, or some similar control of a direction tendency, had played an essential rôle in the former experiment. The ground plan of the maze is shown in Figure 3. The portion of the maze on which the rat ran was covered with brass strips as had been the case in the previous experiment.

*Results.* Table 3 shows that this maze was learned by rats 1, 2, 4, 5, 7, and 9. Rat 5 had failed on Maze A. Rats 3 and 6, who

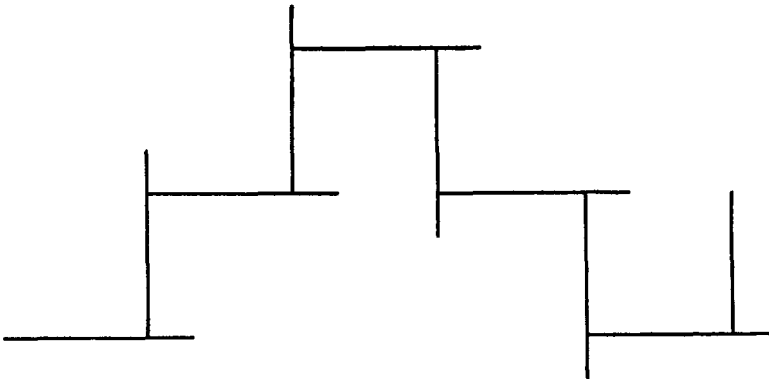


FIGURE 3

#### GROUND PLAN OF THE SPATIAL MAZE B

The entrance of the maze is at the right of the figure.

failed on the previous maze, also failed here. Rat 8, previously untrained, failed also. Fifty-five trials were the most given any subject, and it is quite possible that a much greater period of training would have resulted in the mastery of the problem by all rats.

TABLE 3

Rat	Trials before 1st correct run	Trials before 3 correct runs in succession
1	0	10
2	4	4
3	(never)	(never in 55 trials)
4	10	12
5	4	15
6	(never)	(never in 55 trials)
7	28	31
8	(never)	(never in 51 trials)
9	26	26

Table 4 shows the distribution of errors throughout the maze. Again the rats who mastered the maze had most difficulty with culs-de-sac 2, 4, 6, and 8 that ran at right angles to the general direction from food-box to entrance. Cul-de-sac 1 also presented great difficulty, but No. 6 was the most difficult of all. The fact which stands out clearly is that the maze can be learned by the rat.

An examination of the plan of the maze given in Figure 3 will reveal that, if a directional response functioned in the present experiment in the way described above (p. 510), the maze presents a series of double alternation turns interspersed with responses made in accordance with the direction tendency. Thus, if the direction tendency were controlled by sound, the direction of sound would take the animal in the proper direction at the first, third, fifth, seventh, and ninth turns (numbered from the entrance which is at the right of the figure), and the remaining turns would be in the order *rrll*. If we do not consider the possible influence of sound direction, then the correct turns are in the order *rrlrlrlr*, Nos. 2 and 6 being the only cases of double alternation. The maze is chiefly one of simple alternation, and turns 2 and 6 should be the most difficult to learn. Turn No. 2 should not be so difficult as No. 6 if we reason as follows: No. 1 is preceded not only by *S*, certain proprioceptive stimuli, but also by the sensory consequences of hand-

ling the animal in placing it on the maze. This handling factor is sufficient to differentiate between turns 1 and 2 so that they do not really present a problem in double alternation based solely upon proprioceptive differentia. Table 4 shows that cul-de-sac 6 was decidedly the most difficult for rats 1, 2, 4, and 5. It was also difficult for rats 3, 6, and 8, but for rats 7 and 9 the first two culs-de-sac were more difficult.

TABLE 4  
NUMBER OF ERRORS MADE IN EACH CUL-DE-SAC AND THE NUMBER OF RETRACING ERRORS MADE IN THE TIME PERIODS INDICATED

Rat	During 1st 10 trials				Total	During last 10 trials prior to learning			Total	During last 10-trials of training			Total
	1	2	4	5		7	9	Total		3	6	8	
Retraces	0	2	4	0	6	7	4	11	3	1	10	14	
Culs-de sac													
1	0	0	1	5	6	7	7	14	2	4	7	13	
2	1	0	2	5	8	7	4	11	8	13	8	29	
3	0	0	4	0	4	0	0	0	0	1	3	4	
4	2	3	1	3	9	4	0	4	5	5	5	15	
5	1	1	4	0	6	2	0	2	0	0	3	3	
6	6	3	9	6	24	7	2	9	9	12	11	32	
7	1	1	0	1	3	0	0	0	0	0	2	2	
8	6	2	6	0	14	1	1	2	1	3	1	5	
9	1	2	0	0	3	1	0	1	0	0	0	0	

*Conclusion.* The present experiment shows that Maze B can be learned. There is no way to decide on the basis of the present data whether, or to what extent, a direction tendency was present beyond the fact that in general the culs-de-sac which were at right angles to the path from entrance to exit were more difficult than those which led away from the exit.

THE TRIDIMENSIONAL DOUBLE ALTERNATION MAZE

*Introduction.* I started out in the series of investigations reported in the present paper to test the proprioceptive theory of maze control beyond the point at which I had left it in 1920 (8) and, if possible, to discover a maze that would be insoluble for the rat. On the basis of the 1920 work I assumed that rats could not learn the double alternation temporal maze in which they ran *rrllrrll* through a single box in which the path was roughly like a figure 8. The two experi-

ments just reported show conclusively that a double alternation spatial maze in which the true path lies in two dimensions can be mastered. It is difficult to see how this could have been due to differential tactual or olfactory cues. And, as we have seen, the temporal arrangement of proprioceptive stimuli was the same as in the temporal maze. It therefore looked to me as though the essential cues either came from the environment of the maze or from some neural engram or trace left by the stimuli from each unit of the maze. I then asked myself this question: "How can we get a maze which will be a double alternation maze and yet which will possess some of the characteristics of the temporal as well as the spatial maze?" The answer was the tridimensional maze which I have described elsewhere (11) in detail.

Figures 4 and 5 show a simple alternation and a double alternation tridimensional maze, respectively. In these mazes the exits are directly above the entrances. Furthermore, as the rat runs from entrance to exit, he passes through a cross-section rather than through a longitudinal section of the environment. If directional stimuli are to function, they must be to some degree vertical. The tridimensional maze is like the bidimensional maze in that the correct pathway leads constantly into new portions both of the maze and the environment.

The mazes of Figures 4 and 5 were constructed of carefully cut and joined wood which was kept clean and well sandpapered. Each straight section was  $21\frac{1}{2}$  inches long (outside measurement),  $1\frac{1}{2}$  inches wide, and  $1\frac{7}{8}$  inches deep, and each had a slope of 2 inches in each 20 inches. Screens made of wall-board were placed about the maze, and the experimenter watched the animals through peep-holes.

*The Simple Alternation Tridimensional Maze.* The experiments with this maze were conducted solely to determine whether or not a tridimensional maze offered peculiar difficulties for the rat to overcome. Two mazes were used, one with eight units in the order *rlrlrlrl* and one with four units in the order *lrlr*. Rats 1, 2, 4, and 5, who had all been trained on the two spatial mazes previously described, were tested on the eight-unit maze. Rats 9, 10, 11, 13, and 14 were untrained rats having all of their receptors intact. They were tested on the four-unit maze. Before the beginning of the experiment proper, these latter five animals were run daily for five days on an elevated straightaway which was 9 feet long. The wood of which this straightaway was constructed was of the same width and thickness as that used in the tridimensional maze, and it had the same degree of slope as the parts of the latter maze.

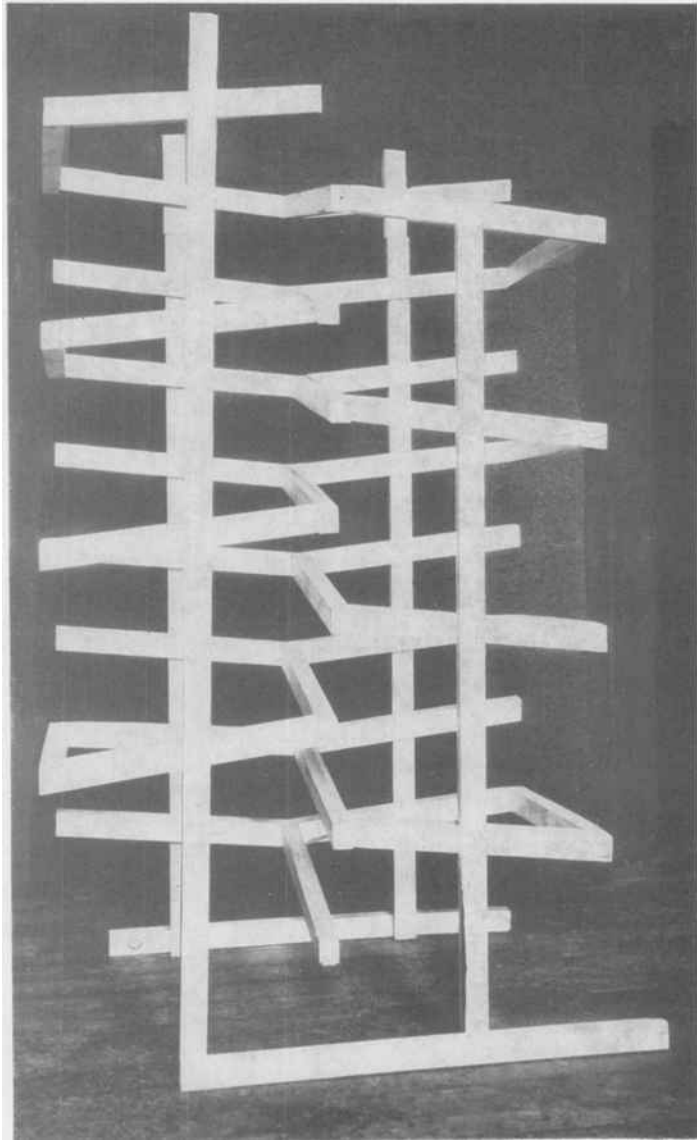


FIGURE 4  
A SIMPLE ALTERNATION TRIDIMENSIONAL MAZE

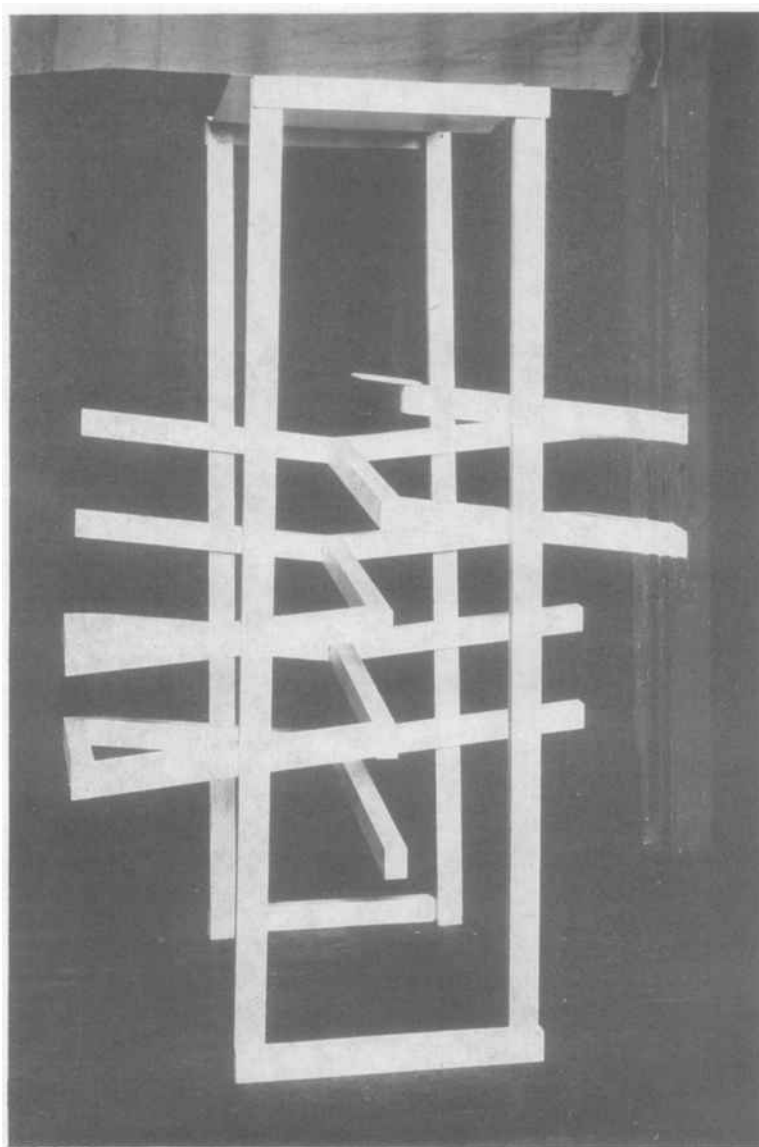


FIGURE 5  
A DOUBLE ALTERNATION TRIDIMENSIONAL MAZE

Table 5 shows the number of trials which elapsed prior to the first perfect run and also prior to three perfect runs in succession. The results indicate that these simple mazes are readily mastered by the rat.

TABLE 5

Rat	Trials prior to 1st perfect run	Trials prior to 3 correct runs in succession
Eight-unit maze		
1	14	25
2	9	18
4	12	12
5	5	5
Four-unit maze		
9	21	21
10	6	6
11	6	23
13	10	19
14	6	14

No error record for the individual trials was taken with the eight-unit maze. Such records were taken, however, on the four-unit maze, and the following comments can be made. Rats 10, 11, and 14 had their learning delayed chiefly by retracing errors. Rats 9 and 13 had the greatest difficulty with the third cul-de-sac. For example, No. 9 responded *lrrr* in place of *lrlr* on each of the 12 days prior to mastery, except that one day he responded *rrrr*. It would be interesting to test a large number of animals on the four-unit simple alternation tridimensional maze in order to determine whether or not there is a well-defined probability that learning would be retarded by the difficulty of the third cul-de-sac. It is to be noted that an error in this cul-de-sac involves a turn (to the right) which is identical with the turn (also to the right) leading to the exit in the next unit. This general problem will be discussed more in detail in the experiments now to be described which were made with the double alternation tridimensional maze.

*The Double Alternation Tridimensional Maze.* Having satisfactorily ascertained the fact that the white rat can learn a simple alternation tridimensional maze without difficulty, work was begun upon tridimensional mazes of four units whose turns were in the order *lrrr*, in the one case, and *rrll*, in the other case. We will consider first the experiments with the latter maze.

*Experiments with the rrl maze*

*Method and apparatus.* The present maze was an exact duplicate of that shown in Figure 5 except that the turns were reversed; the true path, beginning at the bottom, led upward with a series of turns at the points of choice in the order *rrll* (not *llrr* as shown in the figure). In order to exclude distractions from the environment as far as possible, the maze was surrounded by four walls, each about 14 inches from the maze. The rats were brought one at a time from the living cages and given one trial per day. A small pellet of milk-soaked bread was placed on the small platform at the exit of the maze. As soon as the rat nibbled at this food he was removed from the maze and placed on a chair where he ate the remainder of his day's rations. The experimenter observed the rat while on the maze through a series of peep-holes in one of the surrounding walls. This could be done with no noise whatsoever and without in any way disturbing the rat. Again, as I have described earlier in the paper, care was taken to keep the pathway from the cage to the maze constant and to exclude any factor which might disturb the animals. The maze was illuminated from above by an electric lamp suspended directly over the center of the apparatus. A large sheet of white paper, tacked to the upright supports of the maze, diffused the light uniformly so that there were no shadows on the apparatus. The maze pathway was kept clean and well sandpapered. For five days prior to the beginning of work on this maze the rats were trained on the inclined straightaway described on page 516.

*Subjects.* Twenty-three rats were used. The receptors of all of these animals were in normal condition until certain animals were blinded late in the experiment. All animals were untrained and were from 6-10 weeks of age at the beginning of the work. The rats were all in excellent physical condition throughout the experiment. They were allowed to eat for 5 minutes each day at the close of experimentation.

*Results.* Table 6 shows the number of trials which elapsed prior to the first perfect run and also the number of trials prior to three perfect runs in succession. Only six rats made one perfect run, and only two rats, Nos. 13 and 22, mastered the problem with three perfect runs in succession. Seventeen rats never made a perfect run.

No control tests were made with rat 13. Rat 22, however, was tested as follows: After 10 perfect runs in succession, the light above the apparatus was turned off for one trial. In this condition the



TABLE 6

Rat	Trials prior to the 1st perfect run	Trials prior to 3 correct runs in succession
1 } 2 } 3 } 4 } 5 }	(never in 82 trials)	(never in 82 trials)
6 } 7 }	57	(never in 82 trials)
9 } 10 }	(never in 82 trials)	(never in 82 trials)
11	46	(never in 86 trials)
12	(never in 86 trials)	(never in 86 trials)
13	66	79
14 } 15 } 16 }	(never in 86 trials)	(never in 86 trials)
17 } 18 }	77	(never in 98 trials)
19 } 20 }	(never in 86 trials)	(never in 86 trials)
21	82	(never in 118 trials)
22	49	52
23 } 24 }	(never in 86 trials)	(never in 86 trials)

maze was in semi-darkness. The responses were in the order *rlll*, one error. With the light on again the responses were correct. On three later trials the light was turned off, but in each case there was no disturbance of the behavior. This rat was then blinded, by removing its eyes, and was tested 24 hours later. Thirty-two trials were given, two per day, after the blinding. Of these trials Nos. 2, 5, 7, 9, 22, and 31 were correct. On all but three of the remaining trials the rat ran *rlll*, thus making one error. This rat was able to run the maze correctly without the use of vision, but for some reason it lost that ability. I am unable to account for this loss of ability, inasmuch as all factors which might affect the performance remained constant so far as I could determine. We shall have occasion in the later sections of this paper to note the same type of loss of ability after blinding.

Certain peculiarities of the learning process deserve attention. There were practically no retracing errors after the 10th trial, and there was practically no reduction in the time records after this

trial. The quickest run secured required 10 seconds. The average trial after the 10th was run in about 15 seconds. Oddly enough, the perfect runs, when they occurred, showed no time reduction over the average run. This is partly, although not entirely, to be explained on the basis of hesitations which occurred in the perfect runs. The error which retarded the mastery of the maze for rats 13 and 22 was at the second cul-de-sac. The remaining 21 animals were unable to master this cul-de-sac. *As early as the 5th trial and not later than the 15th trial all of the animals had mastered the maze except for the error at the second cul-de-sac.* This error resulted in the series of responses *rlll* in place of the correct series *rrll*. Occasionally after the 15th trial other errors would be made. An animal might run *llll*, *rlrl*, *lrll*, or *rlrl*, or he might retrace; no animal, however, ever ran all four units to the right, *rrrr*. This may have been chance, but I doubt it. As has been said, the typical error was at the second cul-de-sac, making the series of responses *rlll*. How typical the error was and how insistent, a few figures will show. From trials 8-86, inclusive, rat 1 made this error and only this error in all but 9 trials. Rat 6 did likewise in all but 7 cases in trials 6-82, inclusive. The most irregular record was made by rat 11. In trials 5-86, inclusive, 30 trials were in the order *rlll* and 19 were in the order *llll*. Practically never was more than one error made. Nos. 13 and 22, the animals who finally mastered the maze, never made more than one error per trial after the 7th and 8th trials, respectively. After the 7th trial, rat 13 made 40 trials of which two were *llll* and 38 were *rlll*. During the 32 trials remaining before this rat mastered the responses *rrll*, it ran *llll* for 21 trials. After the eighth trial rat 22 ran *rlll* 31 times and *llll* 10 times out of the total of 44 trials before mastery. We may generalize these findings with reference to progress of the learning as follows: Some rats after the 5th trial, and all rats after the 15th trial, entered upon a plateau both in time and in errors. The plateau of time persisted for all animals. The plateau of errors, amounting to one error with but few exceptions, was overcome only by rats 13 and 22.

So far as I know this is the first time that a long and serious plateau has been found in a curve for maze learning. It does not seem necessary to reproduce the actual curve here. With errors represented on the ordinate and trials on the abscissa, the curve begins high and drops by the 15th trial to one unit on the ordinate.

The curve is then maintained at this height with but slight and rare variations until, in the case of two animals, the error is eliminated. If the difficulty of a particular response is measured in terms of the length of time required to master it, then the correct turn at cul-de-sac 2 is the most difficult element in the present maze, and the plateau in the error curve is due to the difficulty in mastering this cul-de-sac.

*Interpretative comment.* Interpretative comments upon the general aspects of this experiment will be deferred until we have presented the next two experiments.

It remains to point out a possible reason for the great difficulty of the second cul-de-sac. The final turn in the maze leading to food was to the left. The turn before the last was also to the left. It would therefore appear that this left turn tended to be temporally anticipated so that it occurred in the second and even in the first unit of the maze leading to responses *rIII* and *IIII*, respectively. The phenomenon is similar to that ordinarily discussed under the title "retroactive influence of feeding." I would rather regard the occurrence as an earlier and earlier appearance in the total behavior of that *type* of response which leads immediately to food and the exit. (An example of a similar phenomenon was noted above, p. 519, in connection with the simple alternation maze.)

#### *Experiments with the llrr maze*

*Method and apparatus.* Figure 5 shows the *llrr* maze. It was exactly like the *rIII* maze except for the direction of turns. It was made of the same kind and dimension of wood and by the same cabinet maker. The maze was surrounded by screens and was illuminated in the same manner as the previous apparatus. The method was exactly the same. I wish especially to emphasize these points of identity because of the difference in results for the two experiments.

*Subjects.* Eleven normal rats from our laboratory stock were used as subjects. They were untrained and were from 6-7 weeks old when the tests began. The food consisted of bread and milk, and, as before, the rats were allowed to feed five minutes after each day's trial.

*Results.* Table 7 shows the number of trials which elapsed prior to the first perfect run and also the number of trials prior to three perfect trials in succession. As indicated in the table, 10 of the

11 animals mastered the maze. Five of them learned in less than 30 trials. Three possible explanations for the remarkable difference between this and the previous experiment occur to me: (1) a difference in the abilities of the rats used; (2) a difference in hunger drive; and (3) some factor in the experimental conditions which made one maze easier than the other. I have no data to render the situation clearer than it is. I know of no reason why an *llrr* maze should be easier than an *rrll* maze. I am inclined to believe that the explanation lies in the first two factors, and probably in the first factor.

TABLE 7

Rat	Trials prior to the 1st perfect run	Trials prior to 3 correct runs in succession
1	14	16
2	27	27
3	12	20
4	10	10
5	30	35
7	23	63
8	71	115
9	12	12
10	(never in 250 trials)	(never in 250 trials)
11	17	26
12	49	79

Here, as in the previous maze, learning was delayed, or prevented in the case of rat 10, by the difficulty of the second cul-de-sac. In the present maze the correct run was *llrr*, and the persistent type of response was *lrrr*. It is again to be noted that the erroneous response at the second cul-de-sac was identical with what would be a correct response on the last two units of the maze. Apparently the great difficulty which the rats had was to inhibit the kind of a response which was immediately conditioned to the food-getting. No record of *llll* was ever secured, but the response *rrrr* was occasionally made.

All rats passed through a plateau of greater or shorter length during which only one error was made, and this error was usually at the second cul-de-sac. Rat 10, who failed to master the maze, reached a level of one error per trial after the 13th trial. Since it received 250 trials, there were 237 more trials given. Of these 237, 166 were run as *lrrr*, 70 were run as *rrrr*, and one was run as *rrrl*. The 70 trials with *rrrr*, two errors, were sometimes interspersed

with the others and sometimes constituted a plateau six or seven trials long. The plateau for rat 2 lasted for 15 trials, during which it ran *lrrr*, and after which it ran *llrr* three times in succession. Rat 12 reached the error plateau after 10 trials. It stayed on the plateau with minor deviations for 69 trials. The record for the 69 trials is as follows: *lrrr*, 57 times; *llrr*, 4 times; *rrrr*, 7 times; and on one trial many retraces and other errors were made. The above records are typical for the group. Since the difficulty which caused the plateau was mastered by all rats but one, we must either assume that learning was taking place during the plateau, or that learning occurred suddenly at the end of the plateau. It is a very striking fact that one specific error could be made for so long an interval as that represented, for example, by rat 12's plateau, and then be mastered without any change whatsoever in the experimental situation.

After rats 1, 3, and 9 had run the maze correctly for 8 trials out of 10, they were tested in semi-darkness with the light over the maze turned off. Three such control tests were made with rats 1 and 9 and five tests were made with rat 3. All records were undisturbed except for one day with No. 1, and the error here may not have been due to the darkness.

After mastery of the maze, the rats were blinded by removing the eyes. The following tabulation exhibits the status of the maze habit for each rat before it was blinded:

OF  $x$  TRIALS BEFORE BLINDING,  $y$  TRIALS WERE IMPERFECT FOR RAT  $z$

$x$	$y$	$z$
14	3	1
10	1	2
14	2	3
15	3	4
23	2	5
20	2	7
15	3	8
16	1	9
11	0	11
12	1	12

Twenty-four hours after blinding the animals were in excellent condition and were this day and thereafter again given trials on the maze. Table 8 shows the performance of each rat for the first five trials after blinding. On the first trial, 5 rats made perfect runs.

Three of these also made perfect records on the second trial. Only two of these still made perfect runs on the third trial. If any change in the condition of the rats was apparent, it was a change for the better and was indicated by the healing of the wounds caused by the operation. Table 8 indicates that some rats can run the present maze without the aid of vision, although the maze was

TABLE 8  
RESPONSES ON THE FIRST FIVE TRIALS FOR EACH RAT AFTER BEING BLINDED

Rat	1	2	3	4	5	Trials necessary for relearning to 3 correct in succession
1	r l r r	r l r r	r l l r	r l r r	<b>l l r r</b>	42
2	<b>l l r r</b>	<b>l l r r</b>	l r r r	l r r r	l r r r	150
3	<b>l l r r</b>	<b>l l r r</b>	<b>l l r r</b>	<b>l l r r</b>	<b>l l r r</b>	0
4	r r r r	l r r r	r r r r	l r r r	r r r r	40
5	l l l r	----*	----*	l r r r	l l l r	18
7	<b>l l r r</b>	<b>l l r r</b>	<b>l l r r</b>	<b>l l r r</b>	<b>l l r r</b>	0
8	<b>l l r r</b>	l r l l	<b>l l r r</b>	l r r r	l r r r	30
9	<b>l l r r</b>	r l r r	<b>l l r r</b>	r l r r	<b>l l r r</b>	9
11	----*	l l l l	----*	l r r r	l r r r	164
12	l r l l	<b>l l r r</b>	l r r r	r r r r	r r r r	52

\*These records followed no definite pattern and contained many errors. Correct responses are in bold-faced type.

learned while the rats were normal. The loss of the perfected habit coincident with the loss of the eyes would suggest a dependence upon vision. The behavior of the animals did not indicate that the result could be due to shock or irritation. I am unable to account for the fact that some rats who were perfect on the first trial after blinding were imperfect thereafter and had to relearn the problem.

After blind rats 1, 3, 7, and 9 were again perfect, two controls were introduced before the final experiment to be described in the next section was undertaken. One control consisted in blowing out the enclosure of the maze, from the floor upward, with an electric fan for two minutes prior to each trial. This was done in order to disturb any olfactory and temperature strata that might be present in the vertical section of the environment occupied by the maze. The behavior of the rats was not disturbed by this change in the experimental conditions. Two of the four screens which surrounded the maze were removed, and rat 3 was tested with the maze thus exposed. Some slight evidence of a disturbance was present.

## THE TEMPORAL MAZE

*Subjects.* Rats 1, 3, 7, 9, and 12 of the previous experiment were utilized. The first four were the only animals who mastered the previous maze so thoroughly that they could run correctly at least 9 out of 10 successive trials. No. 12 did not attain this degree of proficiency, but it was given certain trials on the temporal maze as will be described later.

*Apparatus and Method.* Figure 6 is a line-drawing of the present maze. The length, width, and thickness of the wooden runways were exactly identical with those of the preceding tridimensional mazes. There is no slope to the runways here, however. Wall-board screens surrounded the maze on three sides. It was necessary for the experimenter to stand at the open side. Two trials daily were given. At the beginning of a trial the rat was placed on the central runway with the alley-stop (to be described later) in such a position that the rat must run forward on the central alley. When

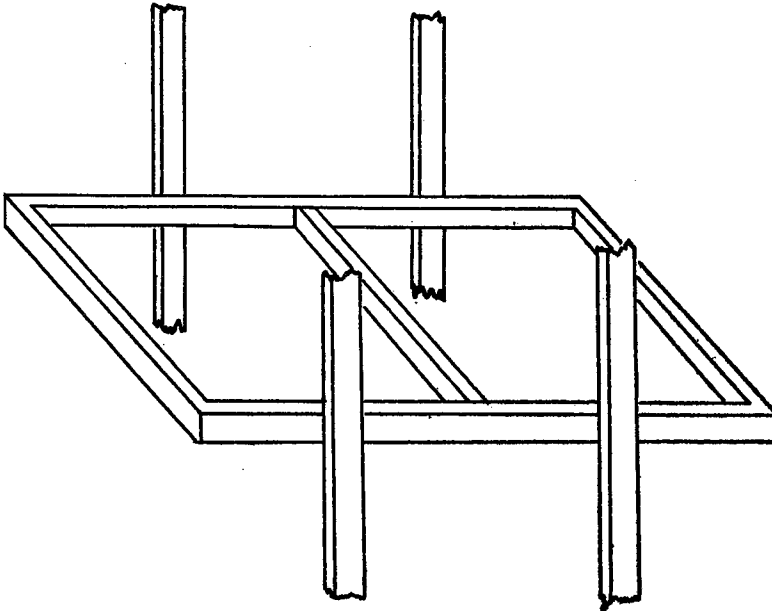


FIGURE 6  
THE TEMPORAL MAZE OF THE PRESENT EXPERIMENT

it reached the end of this alley a turn either to right or left was possible. If it turned right, the alley-stop blocked further progress at the first corner, and the rat must turn back. If it returned into the central alley its path was again blocked, and it must go forward again. When the rat ran through the central alley and turned left, it finally returned to the starting-point. If it did not then turn freely into the central alley, the alley-stop, by blocking its path in any other direction, forced it so to turn. The alley-stop was *never* used, except at the beginning of a trial, unless necessary in order to block errors. The alley-stop was made of a square piece of wood, about 36 square inches in area, nailed to a handle about 2 feet long. The experimenter could manipulate this without any noise whatever. The alley-stop was never placed in contact with the maze, but it was held close enough to the maze to prevent further progress of the rat.

In the previous experiment rats 1, 3, 7, 9, and 12 had learned to run *llrr* on the tridimensional maze. Would they continue to run *llrr* on the present maze? If they did not do so, could they be trained to the point of mastery? There were many factors which might lead to a failure in the new maze. The wood, although of the same size and smoothness and although kept clean and sandpapered, was still different wood and might give rise to distracting stimuli. There was no slope in the new maze, and again the new maze involved the use of an alley-stop, whereas progress on the previous maze had only been blocked by the sheer end of the pathway. These factors might cause the rat to fail when first tested, but they should not cause a failure to learn the new maze.

*Results.* Rat 1 had run the tridimensional *llrr* maze 14 times in succession when it was started on the *llrr* temporal maze. It was given 109 trials on the temporal maze, but never made a single correct trial. At no time did the animal respond *llll*. With but few exceptions the responses were either *lrrr* or *rrrr*.

Rat 3 had run the tridimensional maze 9 times correctly out of 10 successive trials when it was started on the temporal maze. It was given 180 trials (90 days' work) on the temporal maze. Seven of the trials were successful. On one occasion two trials in succession were correct, but the other correct responses were widely scattered. No correct runs were made in the last 72 trials. Thirty-one trials preceded the first correct trial. The following comments are offered on each of the seven perfect runs: (1) On the first



perfect run the alley-stop was used at the beginning of the trial and at the beginning of each run through the central alley in order to turn the rat into this alley. (2) On the second perfect run, the alley-stop was used at the beginning of the trial and again after the animal had run *llr* in order to turn it into the central alley. During the *llr* run, the rat received absolutely no stimulation from the alley-stop. (3 and 4) The third and fourth perfect runs were like the second. (5) The fifth perfect record involved the use of the alley-stop at first and then after the rat had once run to the left. The following three turns, *lrr*, were made with no stimulation from the experimenter. (6) The sixth correct run was like the second. (7) The seventh correct trial was like the fifth.

Rat 7 had run the tridimensional maze 23 times correctly out of 24 successive trials before beginning work on the temporal maze. It was given 138 trials on the temporal maze, but it never made a single correct run.

Rat 9 had run the tridimensional maze correctly 18 times out of 19 successive trials before beginning work on the temporal maze. It was given 122 trials on the temporal maze. Correct responses were made on four trials, the 29th, 86th, 90th, and 118th trials. (1) The first correct trial was made without any use of the alley-stop except at the beginning of the trial. (2) The second correct trial involved the use of the alley-stop not only at the start of the trial but after the first *l* response in order to guide the rat into the central alley. After this it ran *lrr* without further aid. (3 and 4) The third and fourth correct trials were like the first.

It was necessary to start rat 12 on the temporal maze after it had run 7 correct trials out of 8 in succession on the tridimensional maze. The following tabulation shows how this animal was tested first on one maze and then on the other: TEMPORAL MAZE, 3 trials: *llrr\**, *llrl\**, *lrrl*. TRIDIMENSIONAL MAZE, 8 trials: *lrrr*, *llrr*, *lrrr*, *llrr*, *llrr*, *llrr*, *lrrr*, *llrr*. TEMPORAL, 2 trials: *llrr\**, *lrrl*. TRIDIMENSIONAL, 10 trials: *llrr*, *lrrr*, *llrr*, *lrrr*, *lrrr*, *llrr*, *llrr*, *lrrr*, *llrr*, *lrrr*. TEMPORAL, 1 trial; *llrl\**. TRIDIMENSIONAL, 6 trials: *llrl*, *llrr*, *llrr*, *llrr*, *llrr*, *llrr*. TEMPORAL, 1 trial: *lrl*. TRIDIMENSIONAL, 2 trials: *lrrl*, *llrr*. TEMPORAL, 4 trials: *lrrl*, *lrrl*, *rlrl*, *lrl*. TRIDIMENSIONAL, 2 trials: *lrrl*, *llrr*. TEMPORAL, 1 trial: *lrrr*. TRIDIMENSIONAL, 1 trial: *llrr*. TEMPORAL, 1 trial: *rrrr*. TRIDIMENSIONAL, 1 trial: *lrrr*. TEMPORAL, 1 trial: *lrrr*. TRIDIMENSIONAL, 1 trial: *llrr*. TEMPORAL, 1 trial: *rrrr*. TRIDIMEN-

SIONAL, 54 trials of which only 9 were correct. All but 11 of the 54 trials were *lrrr*. I hoped that by shifting the rat from one maze to the other I might accustom him to the change and possibly profit by the double alternation on the tridimensional maze in a way that had not been possible when all the training was carried out on the temporal maze. If this was ever true, it occurred in the first part of the above record. The following comments refer to the *starred* records in order beginning with the first trial starred.

(1) During this trial no possible cue could have been secured from the manipulation of the alley-stop after the beginning of the trial. The rat went around the corners as nicely as it had done on the tridimensional maze. (2) This trial was not perfect as a whole. However, the first three parts, *llr*, were perfect and the alley-stop was used only at the beginning of the trial. (3) In this trial it was necessary to use the alley-stop each time that the rat came around to the entrance to the central alley in order to make the animal enter the alley and not run past. (4) This trial was like the second starred record. After the beginning of the trial the alley-stop was used only at the beginning of the fourth response in order to turn the animal into the central alley.

*Conclusions.* Of the five animals tested upon the double alternation temporal maze after having mastered a similar tridimensional maze, two failed to make a single perfect run. The other three subjects made 13 correct trials in all. Of these 13 trials particular attention should be paid to the following: for rat 3, correct trials 2, 3, 4, and 6; for rat 9, correct trials 1, 3, and 4; and for rat 12, the 4 starred trials. These 11 trials all involved at least two turns to the left and then one turn to the right unaided by the alley-stop. The significance of these results will be developed later in the section devoted to interpretative comments.

#### EXPERIMENTS WITH A TRIDIMENSIONAL *rrllr* MAZE

Before beginning the interpretation of the foregoing experiments, I wish to present an experiment carried out to test further the possible influence of the final turn in the maze upon the type of error made. It will be recalled that with the *llrr* maze the typical run was *lrrr*. With the *rrll* maze the typical run was *rlll*. In each case the chief difficulty came at the second cul-de-sac. Here the rat made the same response which he made later in the maze at the third and fourth points of choice. What will happen if an additional *r* unit is added to the *rrll* maze?

The apparatus and method was as heretofore described for the tridimensional mazes, except that the extra unit, requiring a turn to the right, was added.

Eleven normal, untrained rats 35 days of age were given 38 trials on this maze. After the first 11 trials all animals were making either one or two errors per trial. Seven animals were on a definite plateau caused by an error in the second cul-de-sac. Two animals were on a definite plateau of two errors caused by failure to master the second and fourth culs-de-sac. And two animals belonged sometimes with the former group and sometimes with the latter. Table 9 gives the details.

TABLE 9  
LAST TWENTY-SEVEN TRIALS OF MAZE *rllrr*

Rat	No. of <i>rllrr</i> trials	No. of <i>rllrr</i> trials	
1	25	1	(Those trials of each animal's 27 which are unaccounted for involved other combinations of turns. They were few in number.)
2	16	11	
3	18	7	
4	24	1	
5	2	20	
6	18	8	
7	4	22	
8	16	10	
9	22	4	
10	25	0	
11	22	4	

All animals found the second cul-de-sac difficult. Two animals had great difficulty also with the fourth. The latter case is in harmony with the hypothesis that the error is due to an anticipation of the final response; but the former case, which is the more characteristic one, cannot be so explained. So widespread a phenomenon as the difficulty of the second cul-de-sac has proved to be in this series of experiments demands explanation, but I confess that I have none to offer. This type of response has not been described before so far as I know. However, the *rllrr* response is the same type of alternation habit which I described in 1914 (6, p. 216) as *alternation after success*. At that time I wrote of one rat, "He would go to the right and, if successful, would go to the left in the next trial. Had he failed on the right, though, he would have continued to go there until he succeeded. He would then have gone to the left where the same type of performance would be again gone through."

This is what happened in the present instances of *rllrr* behavior. The rat first went right and was not blocked by the end of the alley. The next turn it went left but was blocked by the end of the alley. The third response was again to the left. This response was successful, i.e., the end of the path was not encountered, so the next response was a simple alternation to the right. With this response the rat encountered the blind end of the alley, and so the next response was also to the right. This, I recognize, is a description and not an explanation of the behavior. (It is to be noted that the response *rllrr* is not a double alternation within the meaning of the term as used in these experiments, because the doubleness is produced by the blind end of the alley and does not represent an unimpeded running of the double alternation pattern of response.)

#### INTERPRETATIVE COMMENTS

The double alternation bidimensional spatial maze A, the double alternation tridimensional spatial maze, and the double alternation temporal maze could not have been mastered on a proprioceptive basis. I rest this conclusion upon the assumption that one stimulus cannot in and of itself produce first one response and then another. In order for such a variation in response, such a recurrent pattern of response, to occur it is necessary that the stimulus be supplemented in some manner either by other stimuli or by some neural process. In the above mentioned mazes the proprioceptive stimulation from one straight section of each maze was exactly like that from any other section of the same maze. Differences in the tactual and olfactory components of the trail were presumably eliminated by careful machining and by washing or sandpapering. Only the turns differed, being arranged in the order *rrll* or *llrr*. This general problem I have discussed at some length in connection with the responses of raccoons in a temporal maze (9). Figure 2, I and II, diagrams the double alternation problem under the conditions where it cannot be mastered and where it can be mastered. In the latter case the stimulus supplement, if a neural engram, might represent the cumulative effects of the previous stimuli encountered in each trial or it might represent the general pattern of the total response to be made.

I am unable to say just what stimuli controlled the running of the bidimensional maze A, nor can I say whether some neural engram or symbolic process was involved. This inability rests, in the

latter case, upon the fact that as the rat ran through this maze new portions of the maze and of the environment were entered, portions not previously encountered during any one trial. This always makes possible the influence of stimuli which are difficult, if not impossible, to control. We have already commented upon the possibility that a directional factor from the environment may have been present.

In the double alternation tridimensional maze, again, proprioceptive stimuli could not have afforded the basis for mastery. It also seems doubtful that differential tactual or olfactory stimuli were encountered on the maze itself. Any directional stimuli would need to have been to some extent vertical in this maze. Controls indicated that possible temperature and olfactory strata in the environment were not influential. As the rat ran through this maze new vertical portions of the environment were encountered and also new segments of the wood of the maze. And again, as a result of these two sources of new stimuli, we must note the great difficulty of eliminating all of the differential stimuli which might be encountered in the maze or in the environment.

In the experimental section we noted the results of blinding the rats who mastered this maze. Five animals of the 12 blinded made perfect runs after the operation, but only 2 of these continued the perfect responses through three trials. This suggests very definitely that the original habit was partly controlled by visual stimuli for all but two rats. An examination of Figure 5 will show that the general pattern of visual stimulation changed as the rat ran higher and higher in the maze. While therefore we can exclude proprioceptive stimuli from the essential control of the habit, *we cannot rigidly exclude the possibility of new stimuli from the new portions of maze and environment.* It therefore remains uncertain whether or not a control was exercised by some central neural process representative either of the pattern of the maze or of the cumulative effects of the successive turns.

Let us turn then to a consideration of the temporal maze. Of the 34 rats trained on the two double alternation tridimensional mazes, only 6 mastered the problem thoroughly. Of these, four were tested on the temporal maze. One other animal, No. 12, was also utilized, although he had not mastered the maze so well as the others. The preceding experimental section has given the details of this work and has shown two things: (1) that the problem is of

very great difficulty; and (2) that only 11 records in all were secured of the type *llrl* or *llrr* when no extraneous cues were possible. The temporal maze gives a rigid control of those possible differentiating stimuli from new portions of the maze and environment to which we have referred previously. This is true because in the temporal maze the rat runs through the identical portions of the environment and over the identical strips of wood during the first two units of the response, *ll*, and again during the last two units, *rr*. The 11 runs referred to above may have been due to chance. *They cannot be explained upon a stimulus-response chain-reflex basis. If the 11 runs were not due to chance, their explanation requires the assumption of some symbolic process or some central neural process.* (Perhaps these two are identical.) The argument in support of this conclusion is partly sketched in terms of Figure 2. It is further elaborated in the paper on raccoons (9) and need not be repeated here.

Is the maze habit a proprioceptively controlled response? In the present mazes it could not be, because of the way in which the proprioceptive stimuli were equated. In the ordinary maze with alleys of different lengths, or with nothing more complicated than simple alternation, proprioceptive control is theoretically possible, although the work by Dennis indicates that either vision or contact must function also. The rat has shown his ability to master any complexity of bidimensional spatial maze. In the temporal maze he can master only with great difficulty, if at all, a combination as simple as *llrr*.<sup>3</sup>

And even so, the results have not indicated that the rat can make this response perfectly, trial after trial, as he can in the usual maze. It is not merely the turning round and round which makes the temporal maze difficult, because this is a characteristic also of the tridimensional mazes. Rather the difficulty lies in two places: (1) in the control of environmental and maze stimuli through the utilization of the same path over and over again; and (2) in the combination *llrr* which as our Figure 2 indicates cannot be learned on the basis of the stimuli directly aroused by, or encountered during, each run.

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<sup>3</sup>In the earlier work with the rat on the double alternation temporal maze (8) I secured negative results only. The positive results of the present paper, slight as they are, may be due to individual differences in the rats, to more extended training, or to differences in the preliminary training.

Is the maze habit a chain-reflex type of response even though it is not, or need not be, proprioceptively controlled? A successful run in the double alternation temporal maze cannot be a chain-reflex where the sensory consequences of one response constitute the stimulus for the next response, and so on through the series. However, the conditions in this maze were set in such a way (by equating the proprioceptive stimuli and by utilizing the same parts of the maze and of the environment over and over) as to exclude the possibility of such an explanation of the correct runs. In all the other mazes used, the possibility of a chain-reflex type of response is present because of the practical difficulty in eliminating new stimuli as the rat enters new parts of the maze and of the environment. *The very difficulty which the double alternation maze presents may well constitute one of the strongest arguments for the chain-reflex character of the usual maze habit.*

The present paper should not be concluded without some comment on the problem of the insoluble maze (10). It is possible to arrange an insoluble discrimination problem where light, for example, is the stimulus. All that is necessary is to make the lights used identical, or so nearly identical as to lie below the threshold for differential behavior. If the rat's behavior in the maze is controlled by proprioceptive stimuli, it should be possible to equate these stimuli and thereby prevent the establishment of the maze habit. The only method which does this, so far as I know, and which at the same time eliminates the possible influence of differential cues from the maze and the environment is the double alternation temporal maze. (A temporal maze having more than two turns in the same direction, for example *llrrr* or *llrrllll*, would also have this merit.) If the rat can learn this maze, it would seem impossible to construct a maze which *in its elemental form* could not be mastered. This impossibility arises from the fact that the mastery of the double alternation temporal maze is apparently only possible for an animal who can supplement proprioceptive and exteroceptive stimuli with some symbolic process or with some central neural process.

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#### LE CONTRÔLE SENSORIEL DE L'HABITUDE DU LABYRINTHE CHEZ LE RAT BLANC

(Résumé)

L'auteur met à l'épreuve la théorie que l'habitude de parcourir le labyrinthe est contrôlée d'une façon proprioceptive et que c'est un type de réponse chaîne-réflexe. On a construit des labyrinthes avec l'ordre des tournants en alternation double et avec les sections droites égales en longueur. On a eu beaucoup de soin d'éliminer les suggestions différentielles tactiles et olfactives. On a éliminé la vision en aveuglant les rats. On constate que les procédés proprioceptifs n'auraient pu contrôler le comportement parce que ces stimuli ont été identiques et n'auraient pu déterminer les réponses à la gauche et à la droite. Quelques animaux ont pu apprendre le labyrinthe temporel à alternation double. On ne peut expliquer leur comportement ni comme contrôlé d'une façon proprioceptive ni comme du type chaîne-réflexe. L'explication exige la supposition de quelque processus central des nerfs lequel rend plus complets les stimuli et représente le type total du comportement ou les effets cumulatifs des réponses faites pendant chaque épreuve dans le labyrinthe. Ce processus des nerfs peut être identique avec ce qu'on a appelé jusqu'ici un processus symbolique.

HUNTER



DIE SENSORISCHE KONTROLLE DER LABYRINTH GEWÖHNUNG  
BEI DER WEISSEN RATTEN

(Referat)

Der Verfasser prüft die Theorie dass das gewohnheitsmässige Durchlaufen des Labyrinths proprioceptiv kontrolliert wird und ein Kettenreflex-typus der Reaktion ist. Man konstruirte Labyrinthe mit Wendungen von doppelter Abwechslung und mit graden Abteilungen von gleicher Länge. Mit grosser Sorgfalt vermied man Unterscheidungszeichen der Berührung oder des Geruchs. Das Sehen war ausgeschaltet durch Blenden der Ratten. Man beweist, dass propriozeptive Vorgänge das Verhalten nicht kontrolliert haben konnten, weil diese Stimuli identisch waren und nicht beide Reaktionen links und rechts bestimmen konnten. Einige Tiere vermochten die doppelte Abwechslung des Zeit-Labyrinths zu erlernen. Ihr Verhalten kann man weder als propriozeptiv-kontrolliert, noch als Kettenreflextypus erklären. Eine Erklärung benötigt die Annahme eines zentralen Nervenvorganges, der die Stimuli begleitet und der entweder das Totalmuster des Verhaltens, oder der angesammelten Wirkungen der Reaktionen, die bei jedem Versuch mit dem Labyrinth vorkamen. Dieser Nervenvorgang möchte identisch sein mit dem was man bisher einen symbolischen Vorgang genannt hat.

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