

CHAPTER XVII

THE ANALYSIS OF MAZE LEARNING

THE SENSORY CONTROL OF THE MAZE HABIT

One of the first problems which arises in connection with maze learning is that of determining what differential sensory experiences an animal uses when it runs a maze. This problem immediately suggests a variety of experiments. For example, one may change one sensory condition, leaving all others the same, and observe whether such a change alters (*a*) the performance of an animal in a previously well-learned maze, or (*b*) the learning rate of a new maze. The sensory condition may be altered in two different ways. In the first place, one may remove, alter, or exaggerate the stimulus characteristics which give rise to the sensory condition in question. In the second place, one may alter the animal by operation, and so make it insensitive in the sensory mode that is to be tested.

There are three possible effects that such changes may have on the behavior of the animal and each of the possibilities has different consequences: (1) If each of the two types of change has no effect, we know that the particular sensory condition in question is not essential to the performance, but we cannot conclude that it is not an adequate sensory condition for learning. It might well become the basis for learning in the absence of other sensory conditions. (2) If the changes make the learning of the maze impossible, we know that the removed sensory condition is essential. (3) If the modified condition merely makes the performance less perfect, or affects only some of the animals tested, no satisfactory conclusions can be drawn. Poor performance may be the result of distraction or of additional difficulty introduced by the modified conditions. If the method of extirpation of sense organs has been used, it is difficult to ascertain whether the operation has merely removed a sensory modality or whether the animal's physical condition has been altered in some other essential way.

From this discussion it is evident that our problem is a rather difficult one. One must therefore interpret with care the experimental results which follow.

Experiments Which Stress the Fundamental Importance of Kinesthesia.—When Small (1901) used the Hampton Court maze (see Fig. 78) to study the mental processes of the rat, he became convinced that running a maze was primarily a kinesthetic habit. By using sawdust on the floor of the maze and changing this from time to time, he convinced himself that rats did not smell their way through the maze. He also modified the visual situation by (1) changing the position of the light above the maze, and (2) introducing red posts at the junctions of the maze. These modifications seemed to have little or no effect upon the rat's performance. He also tested blind rats and rats with vibrissae removed, and obtained no substantial differences in performance between these and normal rats. Since only kinesthesia and tactual sensations were present in all cases, he concluded that they furnished the essential data for the necessary discriminations.

Watson (1907) reported a detailed investigation on the sensory control of the rat in the Hampton Court maze. He established certain norms for the learning of the maze by rats under ordinary conditions and compared these norms with the records made by rats tested under various experimental conditions. He found that darkening the room, blinding the rat, destruction of the olfactory bulbs, destruction of the middle-ear bones (producing partial deafness), removal of vibrissae, anesthetization of the soles of the feet or noses, and the introduction of air currents and temperature differences in the maze had no final detrimental effect on the rat's performance.

A rat which was blind, anosmic, and without vibrissae finally, after considerable difficulty, learned to run the maze very accurately.

The above results indicate that maze learning can be quite independent of visual, auditory, olfactory, and tactual sensations, but other of his results seem to be in disagreement. Thus rotating the maze 180 deg. confused normal, anosmic, and partially deaf animals, but not blind animals. However, rotation through 90 deg. also slightly confused blind rats. As rotation changes the visual and perhaps the auditory environment, it seems that these results indicate that vision, in some way, is functional in maze running.

Taking the results as a whole, it is rather difficult to draw any specific conclusions. Watson realized the danger in dogmatic statements about the sensory modes which were used by the rat, and claimed only to have demonstrated which sensations were *not*

essential to maze learning. He believed, however, that the maze habit was kinesthetically controlled and that kinesthesia was perhaps coupled with certain organic and static sensations. Since, however, all extraorganic sensations were never excluded at one and the same time in any rat, their contribution to maze learning can merely be regarded as a possibility. Maze junctions differ in many ways, and unless all differences are excluded at once, with the breakdown of the habit as a consequence, it is difficult to decide on the importance of any one of them.

Positive evidence of the use of kinesthesia in maze running was obtained by Carr and Watson (1908). They found that if the alleys of a maze which had already been learned by rats were either lengthened or shortened, the rats were greatly disturbed. In the case of shortened alleys, the rats often ran head long into the end walls, and in the case of lengthened alleys they tended to make their turns at the points where the junctions had previously been. These results seem to indicate definitely that the rats were running the modified form of the maze on the basis of the kinesthetic sense.

Experiments Which Indicate that Kinesthesia Is Supplemented by Other Senses.—Bogardus and Henke (1911) took records of the number of times blind rats and rats without vibrissae made contacts with their noses at junctions during maze learning. They found that in new mazes and in slightly altered familiar mazes, the number of contacts paralleled the number of errors. They believed that the number of contacts were, therefore, sources of sensory data to which the rat resorted when it became confused. As contacts were not present during perfect performance, kinesthesia seemed adequate. They concluded that the maze habit depends on tactual sensations during the process of learning, but that the sensory control is gradually transferred to kinesthesia.

Vincent (1912, 1915 *a*, *b*, and *c*) found that by exaggerating certain sensory factors the total number of errors made in learning the maze could be modified. Thus differentiating the true paths from blind alleys by making one black and the other white, or by laying an olfactory trail (*e.g.*, cream cheese rubbed on the floor) on one set of paths (*e.g.*, the true paths) and not the other (*e.g.*, the blind alleys), tended to reduce the total number of errors produced during learning. The removal of the side walls of the maze (thus forming an elevated rather than an enclosed maze) produced a slight saving in learning. This saving, Vincent concluded, is attributable to

the fact that the open maze requires more tactual control, and so the tactual sensations become exaggerated. Thus the exaggeration of any sense department for which the true paths and the blinds are different seems to be an aid in maze learning.

She also found that blind rats and rats lacking tactual sensitivity in the nose (fifth cranial nerve cut) made about twice as many errors as normal rats in the open maze. Rats without vibrissae made scores about equal to normal rats, but blind rats without vibrissae were the most handicapped.

These results thus furnish further evidence of the function of sensory processes other than the kinesthetic operating in maze performance, but they still furnish no evidence bearing upon the essential importance of these. Vincent favors the view that kinesthesia is fundamental and that other sensations function primarily in the early stages of learning.

Carr (1917*b*) summarized the evidence obtained in previous studies by stating that the rat learns the maze primarily in terms of touch and kinesthesia, but that touch gradually drops out as the maze becomes mastered. He confined his investigations (1917 *b, c, and d*) to a study of the effect of changes in the environment outside the maze upon the maze performance of normal, blind, and anosmic groups of rats. These changes involved the position of the experimenter when placing the rat in the maze; covering and uncovering the maze; rotating the maze so as to change the points of reference in the room; and changes in lighting both inside and outside the maze. The groups of animals showed no marked differences in performance, but the results indicate that visual changes affected blind rats the least. Cleaning the maze affected blind rats the most and anosmic rats the least.

Carr found further that learning efficiency was reduced in normal rats when the maze was rotated each day. His results also showed, contrary to previous studies, that blind rats were less efficient in maze learning than normal rats. He attributes this inferiority, not to loss of important visual experiences, but to either the probable loss of certain tonic effects which visual sensations may exert, or the possible injurious effect of the operation. Carr points out that instead of being useful, vision is often a handicap because certain visual changes might distract the animals.

All of Carr's rats showed marked individual differences in their reactions to the changes he introduced. This suggests that none of his changes involved a fundamental sense department, but rather

that all sensory modes may have played some part. Certainly he presented no conclusive evidence to the contrary.

The most recent defender of the fundamental importance of kinaesthesia is Dennis (1929). He used a simple maze with wide alleys and found that vibrissaeless rats could not perfect a maze habit without resorting to contact with the walls. He regards contact and vision to be the senses which are necessary to elicit the turn, but kinaesthesia to be the sense which controls the direction of the turn.

Experiments Which Question the Importance of Kinaesthesia.—In the experiments thus far reported, the fundamental importance of kinaesthesia has been largely inferred, although some convincing positive evidence for it was found. If kinaesthesia is important, a marked modification of muscular sensations should greatly disturb maze performance. In an experiment by Lashley and McCarthy (1926) rats which had previously learned a maze were retested after cerebellar injuries. Such injuries destroyed the rats' equilibrium and coordination. As a consequence the behavior was greatly modified. Some of the rats literally rolled their way through the maze. Nevertheless, the route through the maze was perfectly retained. Even rats which were blinded in addition to such injury, and were thus unable to use visual reflexes, made no entrances into blind alleys on the retest.

Similar negative results were obtained by Lashley and Ball (1929) and by Ingebritsen (1932) with injuries to the spinal cord of the rats. Kinaesthetic, organic, and tactual sensations from regions below the neck reach the brain by way of the cord; yet severing any group of such conduction paths neither destroyed maze retention nor affected the learning ability of the rats.

Hunter (1929) argues that if the maze is learned on a purely kinaesthetic basis, a rat should be unable to learn a maze in which it must make two right and two left turns in sequence, if all other sensory differences in the maze are eliminated. In such a maze the turn to the left is followed by another turn to the left, but this second turn to the left is followed by a turn to the right. Since each left turn must produce kinaesthetic effects which are alike, it is difficult to understand how two like forms of stimulation can sometimes produce a response to the left and sometimes a response to the right. It could, of course, be that the two responses to the left together produce the stimulation for the right turn, but Hunter regards the rat as too simple a creature for such a complex process.

Because a maze with three pairs of right and left turns (*rrllrr*) was learned by three of his six rats, he suspected that some other sensory factor must have supplemented kinesthesia, and so produced pairs of sensory effects which were actually different. As his rats were blind and without vibrissae, and as the elevated poles which constituted the pathways of the maze were well machined and carefully

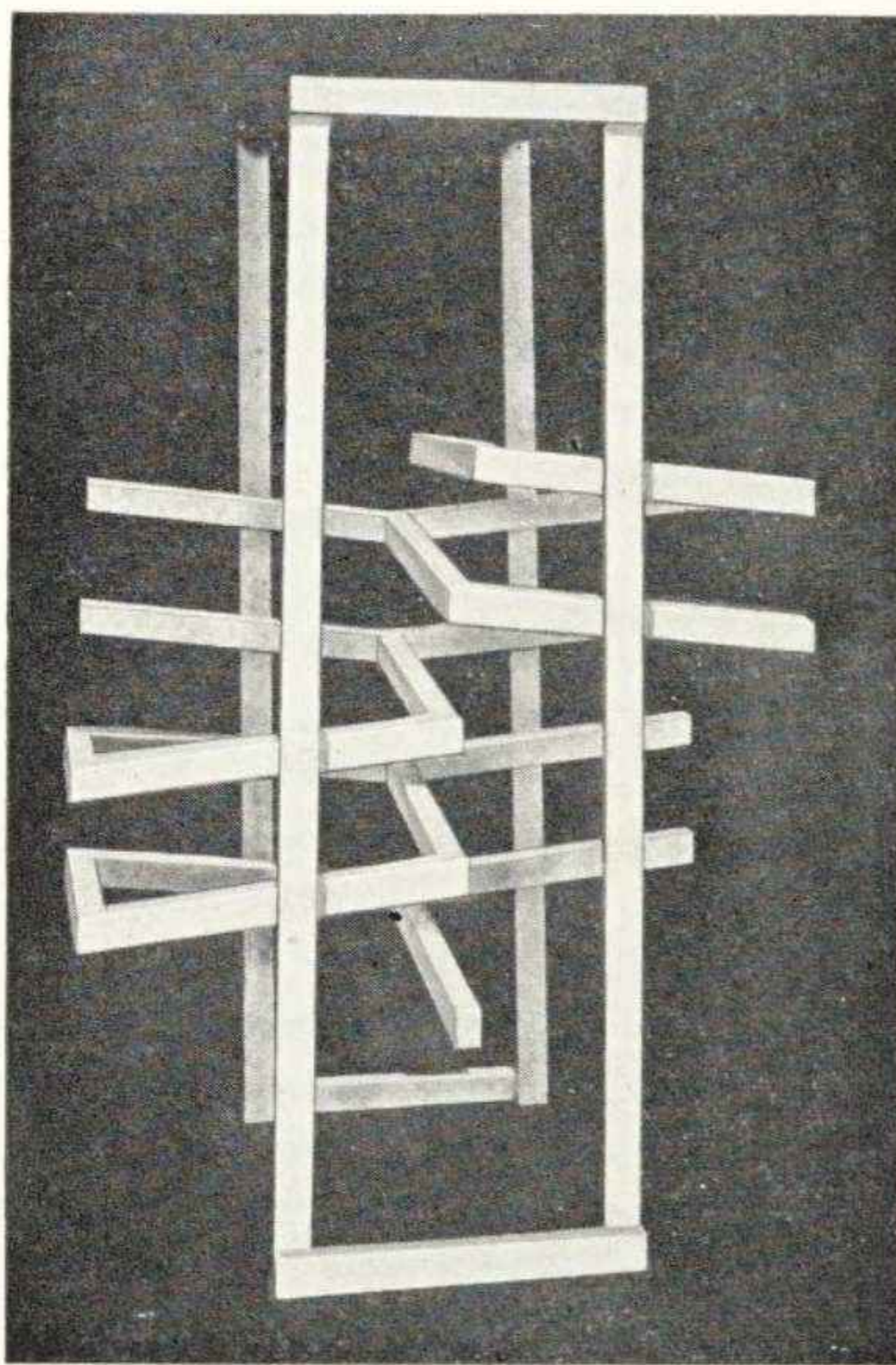


FIG. 79.—The tridimensional maze. (From Hunter, 1929, p. 518. By permission of the *Journal of Genetic Psychology*.)

washed each day, he believed that a constant noise from one side of the room caused some difference in experience for the rats when making the two turns to the same side. To eliminate this possibility he built a tridimensional maze. (See Fig. 79.) In this maze, progress, instead of being forward, was upward, each leg of the maze being slightly on the incline. Only four junctions were present (*rrll*). Of 23 normal rats, only 6 succeeded in making one perfect run. This procedure made the problem more difficult, but the

disturbing fact was that some of the rats still learned the maze. On repeating the experiment with the order of the turns changed (*llrr*) 10 out of 11 rats learned the maze. Because these rats had to relearn the maze after being blinded, Hunter concluded that vision must have been important.

The temporal maze was the only one with which Hunter was able to obtain perfect runs which were so scarce that they might have been due to chance. A diagram of this maze is shown in Fig. 80. Rats started at *S* were required to run in a circuit to the right (*S-A-B-C-S*) twice in succession, and then make a circuit to the left (*S-A-D-E-S*) twice in succession. In this maze Hunter believed he

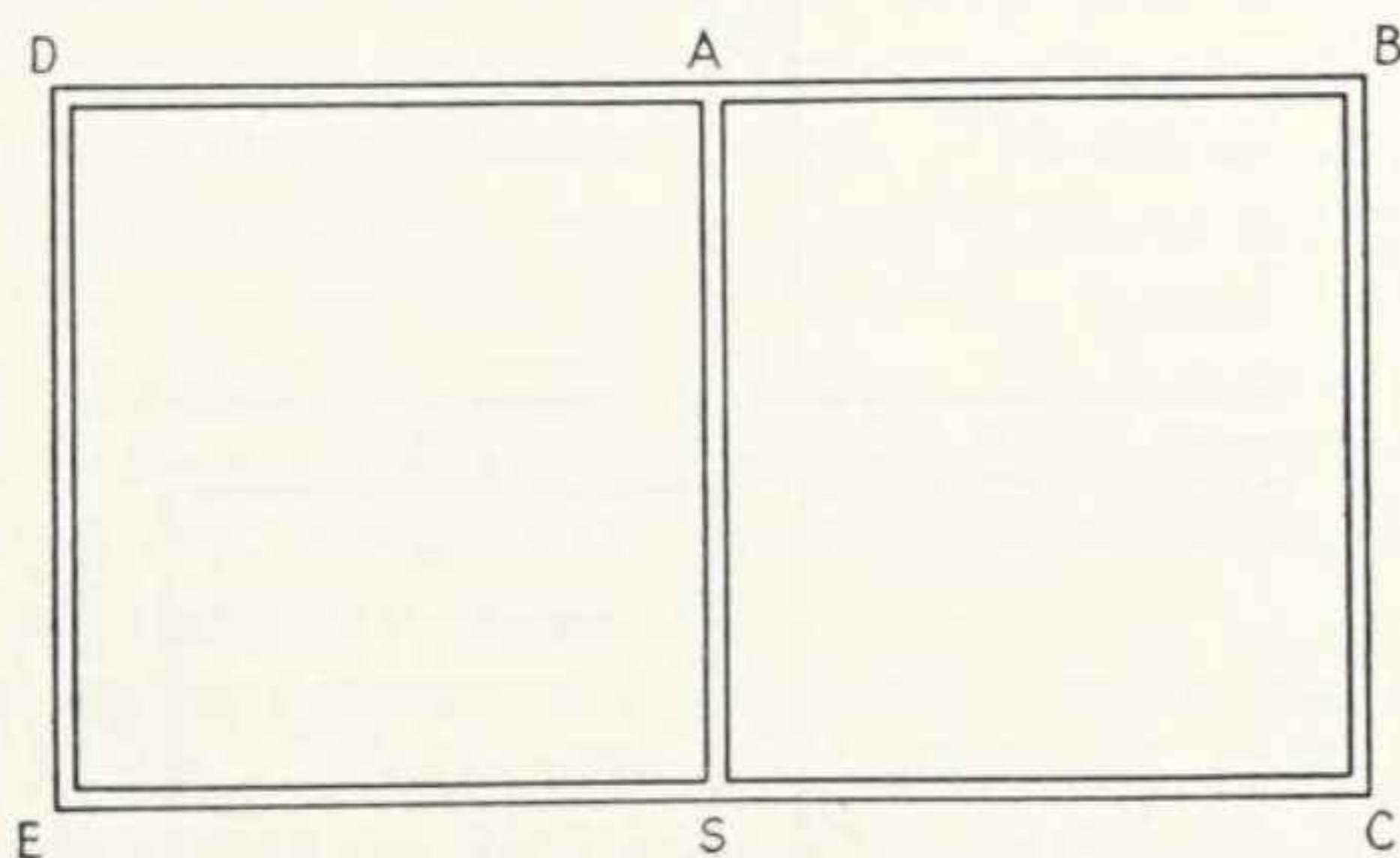


FIG. 80.—Diagram of the temporal maze. The pathways consist of elevated poles. The animal is required to run two right circuits (*S-A-B-C-S*) and two left circuits (*S-A-D-E-S*) in succession after which it is rewarded. During the training the direction of the animal's progress is controlled by blocking off the incorrect route. (*Modified from Hunter, 1929, p. 527.*)

had a perfect case in which the animal must make a turn in one direction after a certain pattern of kinesthetic stimulation, and then make a turn in the opposite direction after the same sensory effect. (A circuit to the right should always produce the same kinesthetic stimulation.)

However, if it is supposed that the rat's sensory discrimination is so keen that it is aware of the fact that it is repeating its route in this maze, and that it was not repeating its route in spatial mazes, then the rat may refuse to make an unnecessary circuit when it comes to the proper junction for the same reason that it learns to avoid blind alleys. Since point *A* is the same for each circuit a turn to the right is equivalent to entering a blind alley. In that event failure would not be due to a lack of sensory discrimination,

but rather it would be due to its very marked presence. And this is exactly what seems to be the case. Shepard (1931) has demonstrated that the rat refuses to run in a circuit. If a door opening to alley *F* of Fig. 81 is left closed until the rat has passed it and has completed the circuit *B-C-D-E*, the rat soon refuses to make the unnecessary trip, but waits in front of, or scratches at, the closed door which it found open on previous occasions after making the circuit. Control experiments eliminated the possibility that the door was located by any characteristic markings, rather, the rat

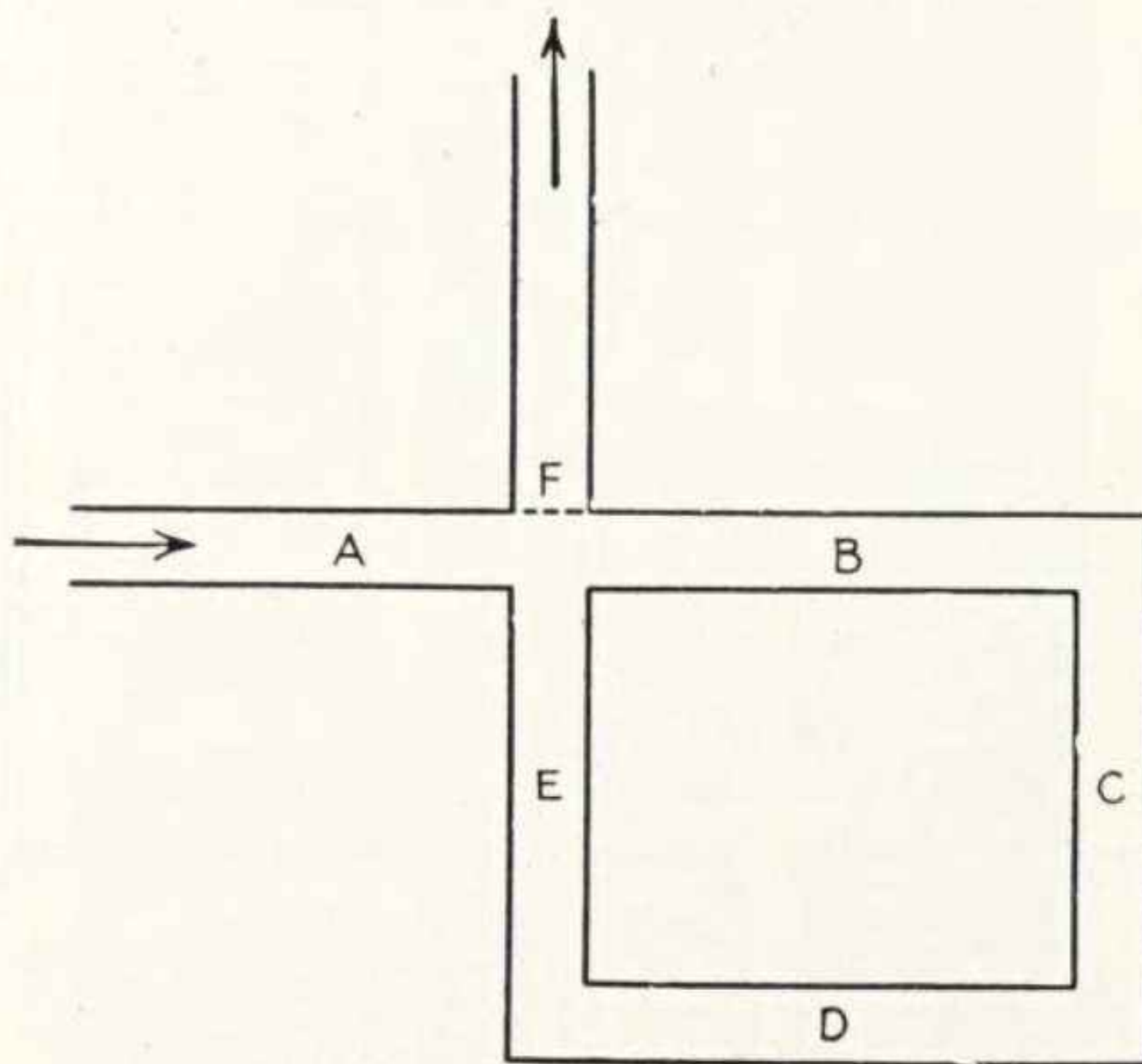


FIG. 81.—Diagram of circuit rats refuse to run. As the rat approaches *A* the opening into alley *F* is closed until the rat has progressed beyond alley *B*. On arriving at *E* it continues to *F*. After several repetitions, the rat refuses to run *A-B-C-D-E-F*, but attempts *A-F*. (Courtesy of J. F. Shepard.)

recognized the junction. Thus, despite the fact that alley *F* was at first entered from *E*, this alley, although closed, was soon reacted to by the rat when it emerged from *A*.

Experiments Which Attempt to Exclude the Function of All Sensory Processes Other than Kinesthesia.—After many years of work in the analysis of learning of various types of mazes, Shepard built a "unit" maze, a typical form of which is shown in Fig. 82. (The points indicated by *X* represent doors which join adjacent units.) This maze pattern consists of a succession of identical maze units, from each of which the rat can pass into the next by making a characteristic turn at the junction (*e.g.*, always taking the alley to the left). However, one of the turns is an exception to

this rule (the last unit in which the turn is to the right). In order to pass through all units without error, this exceptional junction must be located and responded to differently. If the units are actually alike, the exceptional unit can be located only kinesthetically. That is, the rat must experience a certain rhythm, at the end of which it makes the exceptional response. Recognizing the exceptional unit in this way would correspond to the way we recognize the last step of a familiar stairway in darkness.

To the surprise of the experimenter, rats not only learned these mazes, but they learned them with ease. At first the characteristic general response to the junctions was learned and was even applied to new parts of the maze. Next the exceptional unit was located and the appropriate turn made. Increasing the number of units to as many as 29 did not produce failures. This demonstrates either a remarkable kinesthetic sense or the presence of some unknown uncontrolled sensory difference. Tests involving changes in the visual and olfactory situation proved negative. The maze was torn down, the wall sections interchanged, and the maze rebuilt in order to test whether the rats were using any characteristic difference in the walls. Again the results were negative.

A test of the presence of a kinesthetic rhythm was then made (Shepard, 1929). As the units were all alike in construction, any unit could be made the starting point by merely closing the entrance (indicated by *X* in Fig. 82) to that unit. The different possible starting points are indicated in the diagram of the maze. Since different starting points vary in their distance from the exceptional unit, a kinesthetic rhythm would be useless for locating the exceptional unit. It was found that no matter from which unit the rats were started, the exceptional unit was successfully located. This meant that despite the various tests to the contrary, some local sensory discrimination, other than that based on a kinesthetic pattern, was present.

Changes in the composition of the floor were then introduced; and as a consequence errors resulted. The floor structure, beneath the linoleum sections on which the rats were running, had been supplying them with different sensory effects in the various units. As the rats had no immediate contact with this subfloor, Shepard believed the differentiation to be auditory in nature. Different parts of a flat surface vary in their vibration rates, and the pattering of the rats' feet seemingly resonated differently on different parts of the

floor. In any case this differential experience from the floor very nicely explains the difficulties and inconsistencies which arose in the previous experiments.

Having located this sensory difference, the next step is to eliminate it and force the rats to rely on kinesthesia alone. If they can still learn the maze effectively, the results will not be conclusive, because the learning may be due either to kinesthesia, or to some other unexpected discrimination. If, however, the elimination of the sensory differences from the floor breaks down the learning in some

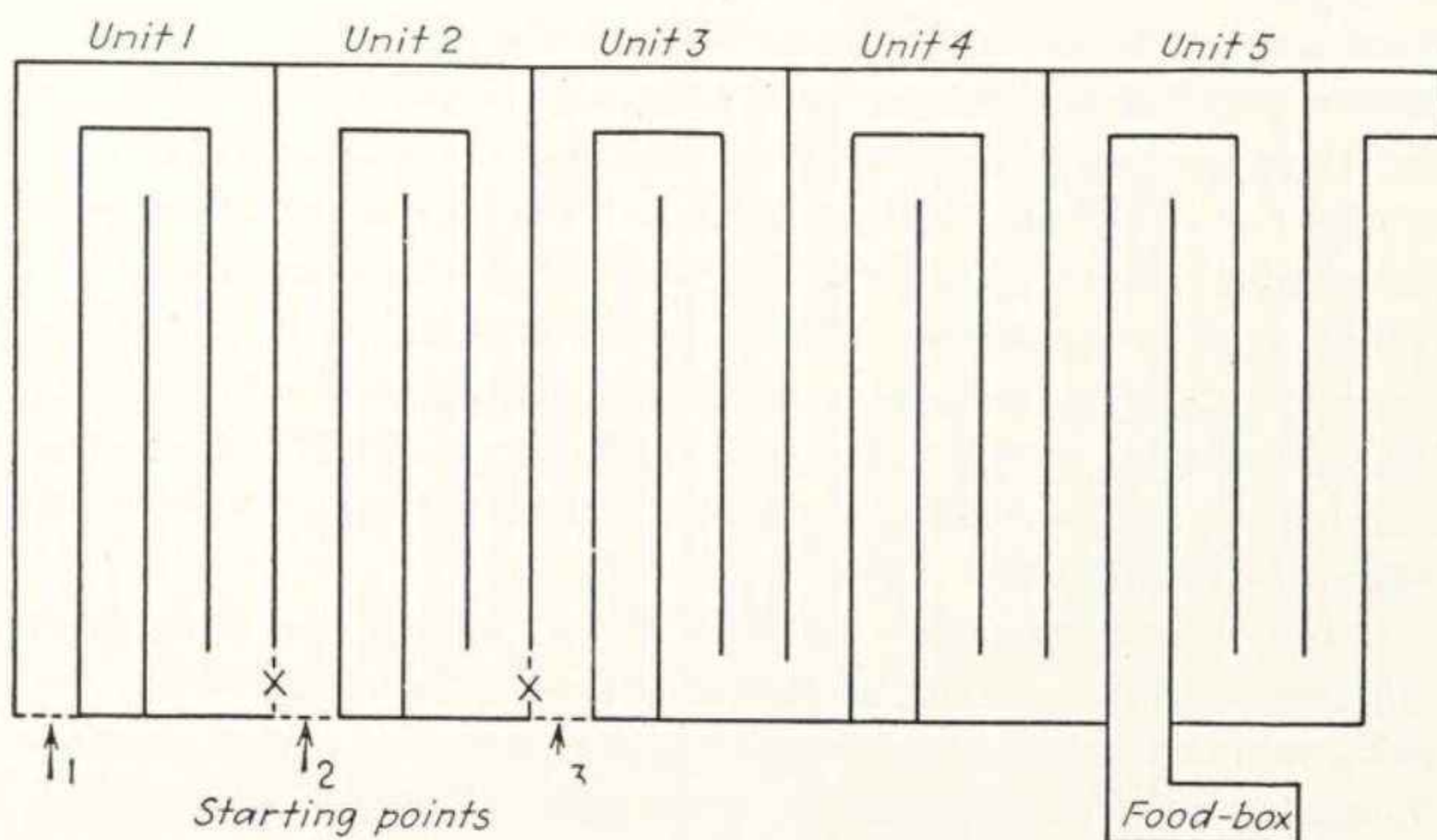


FIG. 82.—The unit maze used by Curtis. The arrows indicate different starting points which may be used. The sections marked X are removable. They are inserted only when the latter part of the maze is used. (Courtesy of Q. F. Curtis.)

detectable fashion, or makes the learning of long unit mazes impossible, the results may be given a definite interpretation.

The Elimination of the Floor Cue.—The task of constructing a maze in which the sensory differences arising from the maze floor were to be eliminated was undertaken by Curtis (1931). In order to eliminate the vibrations from the maze floor, he covered the concrete floor of the building with sand to a depth of $1\frac{1}{2}$ in. The sand was then covered with black oilcloth. Upon this floor he built the unit maze shown in Fig. 82. Lights were equally spaced in each unit so as to eliminate any visual differences either inside or outside the maze. The last three units of the five-unit maze were used during the learning period, the last unit having the exceptional junction. Thus at

the junctions the rat had to turn left at the first two units and right at the third.

Ten rats which had mastered the five-unit maze in an average of 5.3 trials, now required an average of 72.25 trials in order to learn three units. Not only were more trials required before three consecutive errorless runs were made, but the perfect runs were made with much more hesitancy. Further, two of the rats failed to reach the criterion of learning in more than 100 trials. As the possible number of errors is small, the criterion for learning is not a difficult one. (In more complex mazes the criterion of learning is often 10 consecutive errorless runs.) These results therefore show a marked increase in the difficulty of maze learning because of the change in the floor.

After the maze had been learned, a series of tests were made in order to determine how the rats had learned it. If the units are alike for the rat, the starting point and the exceptional junction are characterized only by being in the first and third units, respectively. If the units are different in sound effects, visual appearance, smell, or touch, then the exceptional unit occupies a certain fixed position in the maze series. Therefore, when the rat is introduced into the maze at various points, it should make the exceptional response at the third unit from the starting place, provided it has learned the maze kinesthetically; but it should make the exceptional response at the last unit if it has learned the maze in terms of local sensory differences.

The results of a series of tests of this sort showed that the exceptional response was made in the third unit as often as it had been in the learning runs. The rats showed no signs of strangeness when started in the various units, and behaved as if there had been no changes. The responses, therefore, were not made to a particular part of the maze, but rather to a *particular part of a kinesthetic pattern*.

The Elimination of Kinesthesia.—In a later study (unpublished), Curtis trained rats on a similar maze, but from the outset eliminated any use of kinesthesia. The position of the food box was always the same, but the starting point varied, so that the rat was required to run 2, 3, or 4 units before reaching the food. Mastery of this problem required the use of some local sensory difference in locating the food unit which contained the exceptional turn. Most of the rats trained in this manner learned the maze to a point better than

chance, but not to perfection. Various changes in the floor produced only temporary disturbances. Since kinesthesia was eliminated, some undiscovered sensory differences must have been available to the animals, although these were apparently somewhat unreliable since the number of perfect runs was limited. In the first study of Curtis these sensory differences were not used by the animals. This is not surprising since kinesthesia was available to them.

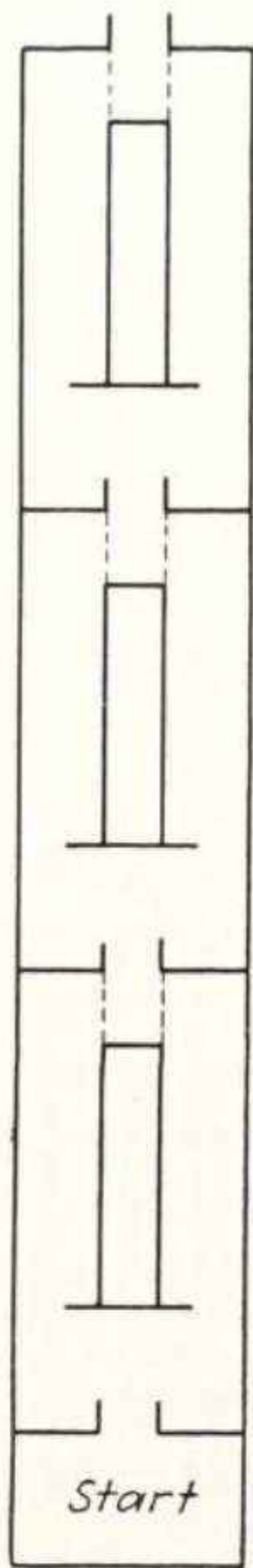


FIG. 83.—Walton's Sectional maze. Any number of units may be placed end to end and either the right or left route through a section may be blocked by inserting a board at any of the points indicated by broken lines. (*Modified from Walton, 1930, p. 55.*)

Anticipatory Behavior and Its Relation to Kinesthetic Sensitivity. That kinesthesia is used by animals in maze running, but that it must be supplemented by other sensory differences in order to obtain high efficiency in the maze, is further demonstrated by an experiment of Spragg (1933). He used an eight-unit maze, three sections of which are illustrated in Fig. 83. The various local sensory differences were eliminated by interchanging the units from time to time. This forced his rats to use kinesthesia. In this experiment the rat was required to make seven right turns followed by a left turn. The exceptional turn was thus characterized by being the eighth junction. After 100 trials the maze was still unlearned, each rat averaging 1 error per trip in the last 25 runs. The majority of the errors were made at the seventh unit. The rats tended to turn left in this unit in anticipation of the last exceptional unit. Apparently the seventh unit could not be discriminated from the eighth unit on the basis of a temporal kinesthetic pattern.

In Table 25, Spragg's data obtained from four rats have been analyzed to bring out this point. The errors made by the four rats at each unit have been grouped for each successive 25 runs. From the table it can be seen that during the first 25 trials the errors were concentrated in the last four units, during the next 25 trials they are limited largely to the last three units with a concentration at the seventh. This concentration at the seventh unit increases during the third group of 25 trials and in the last 25 trials the errors are

primarily at the seventh unit. The rat has apparently learned that an exceptional turn must be made, but its ability to form the neces-

TABLE 25.—ANALYSIS OF RESPONSES BASED ON KINESTHESIS (DATA OBTAINED BY SPRAGG, 1933)

Unit	1	2	3	4	5	6	7	8	Total
Response required (right or left turn)	<i>r</i>	<i>r</i>	<i>r</i>	<i>r</i>	<i>r</i>	<i>r</i>	<i>r</i>	<i>l</i>	
Errors in 1st 25 trials	21	11	9	9	15	29	33	48	175
Errors in 2d 25 trials	14	4	7	4	5	33	46	31	144
Errors in 3d 25 trials	5	3	6	5	11	26	72	18	146
Errors in 4th 25 trials	3	2	2	3	2	14	67	7	100
Total errors	43	20	24	21	33	102	218	104	565

sary discrimination is not adequate. At the outset the rat learns to make right turns. This is shown by the fact that errors are made largely in the eighth unit during the first 25 trials. Next it learns to make an exceptional turn, but the limitations of kinesthesia prevent it from making this turn at the proper unit.¹

In a later study Spragg (1934) used a unit maze in which rats could go either right or left in the first seven units, but were forced to go left in the last unit. As learning progressed, left turns at all units were found to increase, but the increase was more marked in the last few units. When the last turn was changed to a right turn, the number of left turns at each junction decreased with trials, and the decrease was most marked in the last half of the maze. In this experiment fine discrimination was not required since turns to either side were possible in the first seven units. This explains why the "anticipatory" response was spread over the last half of the maze rather than concentrated at the seventh unit.

Conclusions.—From the foregoing experiments one may conclude that when the rat is deprived of all other sensory differences it can learn a maze on the basis of kinesthesia; but the learning is more difficult and as a result more trials are required or perfection is not reached. Because of the limited efficacy of this sense we cannot

¹ Spragg regards the error at the seventh unit as due to anticipation. This seems unlikely since anticipation is also present in other mazes. Rather, the inability to make the necessary discriminations causes the rat's anticipation to become evidenced.

regard the learning of complex mazes as a purely kinesthetic-motor habit. Other sensory differences will be used by the rat whenever available, and these other differences are not merely supplementary, but form a real basis for maze learning.

By constructing unit mazes of the above types and introducing various sensory differences, one at a time, we can determine just what sensory processes the rat is capable of using. We have, therefore, just arrived at a point in our knowledge where a constructive study of the sensory control of the maze may begin. The overemphasis on kinesthesia must be abandoned and much of the earlier work charged to experience. It is most likely that all sensory differences, when above the rat's threshold of discrimination, will be utilized. Which sensory differences are most effectively utilized, which preferred, and other questions of this sort must be answered by future work.

This discussion has entirely centered about the rat. It is a typical mammal and generalizations having to do with its sensory control are very probably applicable to other animals. Until thorough work with other forms is forthcoming we must rest content. Animals with finer sensory discrimination may show quantitative differences. Those with more intelligence may make different uses of their discrimination ability. But the fact that maze learning is not a kinesthetic-motor habit unless all other sensory differences have been eliminated, has been demonstrated. How great a kinesthetic temporal pattern an animal can master may vary greatly among the mammals, and the extent of this pattern may be a function of intelligence. However, even in the rat the responses are often dependent upon complex temporal stimulus patterns and need not be a simple response to a preceding stimulus as behaviorists have contended.

QUANTITATIVE DIFFERENCES IN MAZES AND THEIR EFFECTS ON LEARNING

Introduction.—When we place a hungry animal in the maze we assume that it will go through the maze as efficiently as it is able. Accordingly, if the animal is properly motivated but nevertheless continues to make errors, we conclude that the errors are an expression of incomplete learning. Persistence in errors is consequently regarded as due to inability to distinguish (at that particular stage of learning) the efficient from the inefficient route. That a rat will

choose, as far as it is capable, a line of activity which most effectively removes its hunger is assumed whenever we test an animal. When it does not behave in this fashion we are satisfied that it cannot distinguish between the efficient and the inefficient manner of satisfying its need.

Nevertheless, the literature contains several studies which claim to demonstrate that the rat will prefer the course of least action. Gengerelli (1930a) and Tsai (1932) have shown experimentally that excessive effort is eliminated by animals during the course of learning and have formulated the principle of *minimum effort*. However, the experiments really demonstrate nothing more than the rat doing what the experimenters regard as most efficient. The study of the animal's preference for one of several ways of reaching a goal, therefore, becomes a study of discrimination ability. If a rat is to learn a maze, it must discriminate between alternative routes. According to DeCamp (1920) two alternative routes must differ in length by at least $\frac{1}{10}$. Yoshioka (1929) performed a careful experiment to determine whether the ability to discriminate the spatial difference between a short and a long route satisfied Weber's law. He found that the absolute lengths of the routes were unimportant. As long as the ratio between the long and the short routes was approximately 1.14:1 or greater, the discrimination was made.

When a maze contains blind alleys, the true path is not only the shorter route, but it is also the only route which does not lead to a block and subsequent retracing out of the blinds. It therefore becomes necessary in our analysis to determine whether the experience of the block, the experience of retracing, or the experience of greater distance traversed is the cause for the elimination of blind alleys. The solution of these and other problems depends upon a careful study of the behavior of animals in a great variety of mazes differing in both quantitative and qualitative aspects.

The Elimination of Short and Long Blind Alleys.—Peterson (1917a) compared the relative ease with which rats eliminated 22-in. and 9-in. blind alleys, and found that the shorter ones were eliminated first. In both types of alleys there was a period of partial entrances which preceded complete elimination.

White and Tolman (1923) using somewhat longer alleys and in addition having a right-angle elbow in the alleys, obtained just opposite results. They found that long alleys were eliminated more readily than short and explained Peterson's results by calling atten-

tion to the possibility that his rats could see the ends of the blinds. In such case one would expect the short to be eliminated before the long blinds.

Shepard (unpublished study) has studied the elimination of short and long blinds by rats experienced in maze running. His long blinds were sometimes 30 ft. long and contained many turns. The short blinds were very much shorter than the long ones and had but a few turns. Thus the inconvenience caused by retracing in long blinds was much greater than that caused by the short. The results, however, show but a slight difference—the shorter blinds, on the whole, being eliminated first. In all cases the blinds were gradually eliminated.

From the above results it seems that the length of a blind alley plays only a minor role as far as difficulty of maze learning is concerned. This suggests that a blind alley is primarily eliminated because it blocks progress rather than because it increases the length of the route to food. Since the blinds are gradually eliminated it seems that the entrance into a blind soon causes the animal to anticipate¹ the closed end. More learning means that the end is anticipated sooner. The blind is completely avoided when the end is anticipated at the junction (*i.e.*, when the sensory control for the response has been transferred to the junction). The efficiency of the anticipation seems to depend more upon the character of the blind alley than upon the distance from the end of the blind because on the whole the short blinds are not eliminated with markedly greater readiness than the long ones.

The Learning of Mazes Having Different Numbers of Blind Alleys. The maze may also be quantitatively varied by changing the number of blind alleys. Warden and Hamilton (1929) studied the relative ease with which various groups of untrained rats each learned a simple maze having either 2, 4, 6, 8, or 10 blind alleys. They found no reliable difference in score between the groups in learning the different mazes. This would seem to indicate that all of the mazes studied were so simple that the learning in each case was negligible. As many as 15 trials were required before a group of rats reached a criterion of four perfect runs in five, but this score seems little more

¹ To anticipate merely means that the response originally made to the end of the blind is made to some other part of the blind alley. This is to be expected because other parts of the blind alley are in contiguity with the end of the alley and this contiguity is the condition for learning.

than what is required by the rat before it completely adapts to the maze situation.

TABLE 26.—THE EFFECT OF LENGTH OF MAZE ON THE LEARNING OF NORMAL AND PARTIALLY DECORTICATED RATS. (LASHLEY AND WILEY, 1933)

Size of maze	Normal rats		Partially decorticated rats	
	Trials	Errors	Trials	Errors
4 culs-de-sac	24.3	22.0	77.7	246.7
8 culs-de-sac	33.8	66.7	103.8	921.1
12 culs-de-sac	42.1	85.7	114.6	1039.1
16 culs-de-sac	61.3	121.5	109.0	1382.9

Lashley and Wiley (1933) compared the learning of 4, 8, 12, and 16 cul-de-sac mazes by normal and partially decorticated groups of rats. The results are shown in Table 26. To learn a series of mazes having different numbers of blind alleys, both groups required more trials and made more errors when the number of blind alleys was increased. But the increase in the number of trials and errors was no greater for the operated than for the normal animals. As the mazes increased in complexity in the ratio 1:2:3:4, the error score of normal rats increased in the ratio 1:3:4:5, and the error score of operated rats increased in the ratio 1:3.7:4.2:5.6. This indicates that the relative difficulty in learning does not increase with the number of blind alleys. If the difficulty or qualitative complexity of the problem increased out of proportion to the number of blind alleys, the rats with inferior ability should be at a relatively greater disadvantage with an increase in the number of blinds. Problems of increasing complexity in all other situations cause the difference in score between normal and partially decorticated rats to increase.¹

¹ The method of scoring partly explains the increase in errors and trials of both groups of rats as the number of blinds was increased. A maze was considered learned when ten consecutive errorless runs were made. But the possibility of errors in large mazes is greater than in small mazes. Thus in the 12-cul-de-sac maze a total of 120 errors had to be avoided before the criterion was reached. In the 4-cul-de-sac maze the possible number of errors in 10 trials was only 40. When a certain number of perfect runs is regarded as evidence of learning, the criterion for learning is actually much higher for large than for small mazes.

We may, therefore, conclude that increasing the number of blinds may make a maze more difficult, but it does not make the maze qualitatively more complex. In fact, the longer mazes are relatively easier to learn, according to Ballachey (1934) who found that errors per unit of maze were less for long than for short mazes. As his mazes consisted of alternate right and left turns, this reduction in relative complexity may be attributed, at least in part, to the setting up of alternation habit which is as effective for long as for short mazes. Studies using mazes with more junctions and having patterns that are not repeated are required to satisfactorily solve this problem.

QUALITATIVE DIFFERENCES IN MAZES AND THEIR EFFECTS ON LEARNING

Maze patterns may be qualitatively different in the following three ways: (1) the type of junction used; (2) the patterns of true path; and (3) the kind of blind alley employed.

The Effect of Different Types of Junctions on Maze Learning.—Hubbert and Lashley (1917) found that in their use of junctions of the type shown in Fig. 84A, rats, in their first trip through the maze, went through the opening to *b* or *c* three times as often as they went past it and into *a*. They also went to *b* more often than to *c*. On the other hand, Dashiell (1920a) found that in mazes with junctions such as shown in Fig. 84B, rats, when in a maze for the first time, had a tendency to go forward rather than to turn. The ratio of the number of times that an alley opening to the side was passed to the number of times it was entered was 5 to 3. If the forward leading alley directed the rat into a blind, the animal, on emerging, continued correctly 3 times in 5. If the alley leading off to the side took the rat into a blind, the rat, on emerging, continued correctly 7 times in 9. By going straight ahead on emerging from the blind in the first case the rat was started toward the starting point, but in the second case it had to turn at the junction, and in this case it was less likely to retrace in the direction of the starting point.

Both studies indicate that the nature of the junction and the direction of approach to the junction partially determine a rat's response, but Dashiell's study indicates a "forward going" tendency, and Hubbert and Lashley's a tendency to enter an opening. As the mazes used in these studies are very different in pattern it is difficult

to determine whether or not these results are contradictory. In both studies the rats were inexperienced, and the mechanics of running and lack of attention on the part of the inexperienced rats may have had much to do with their entrances. Such tendencies are very probably not so markedly present in experienced rats.

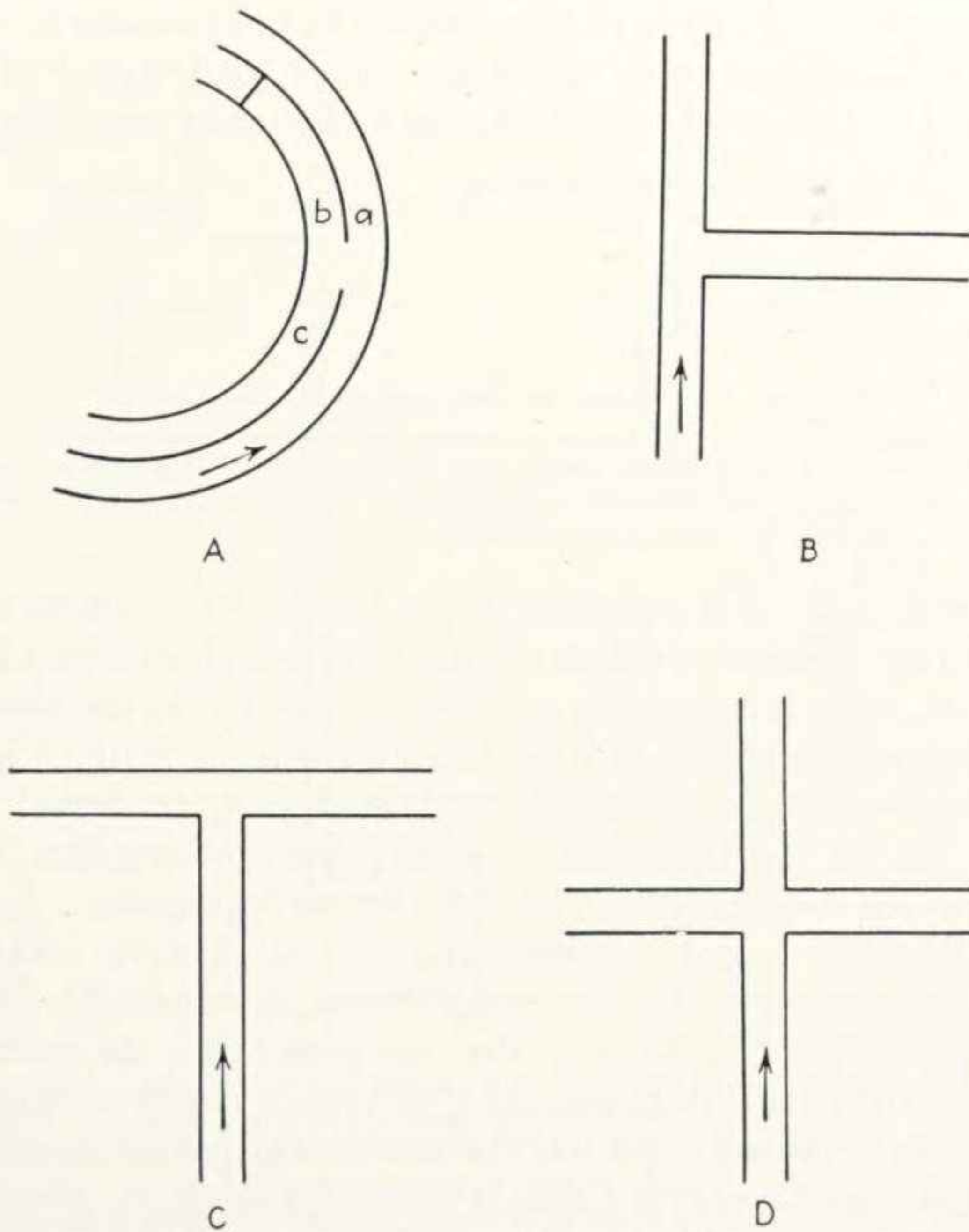


FIG. 84.—Types of maze junctions. The arrow indicates the direction of approach to the junction. (See text.)

There are also individual differences in rats as regards the preference for right or left turns at junctions such as in Fig. 84C. Yoshioka (1928) found that some rats prefer right turns, some left turns, and this preference seems in part to be due to the shape of the skull bones. None of the natural tendencies of the animal seems to be of major importance.

Junctions of the type shown in Fig. 84D are the most difficult, but this is probably due to the fact that such junctions present the animal with more opportunities for errors.

The Effect of the Maze Pattern upon Behavior in the Maze.
The Centrifugal Swing.—The conditions arising from the nature of the maze pattern are of even greater importance in determining maze behavior. We have already referred to what Schneirla (1929) called the *centrifugal swing* in our analysis of the behavior of ants (pp. 160*f.*). This tendency which is set up by the nature of the turn

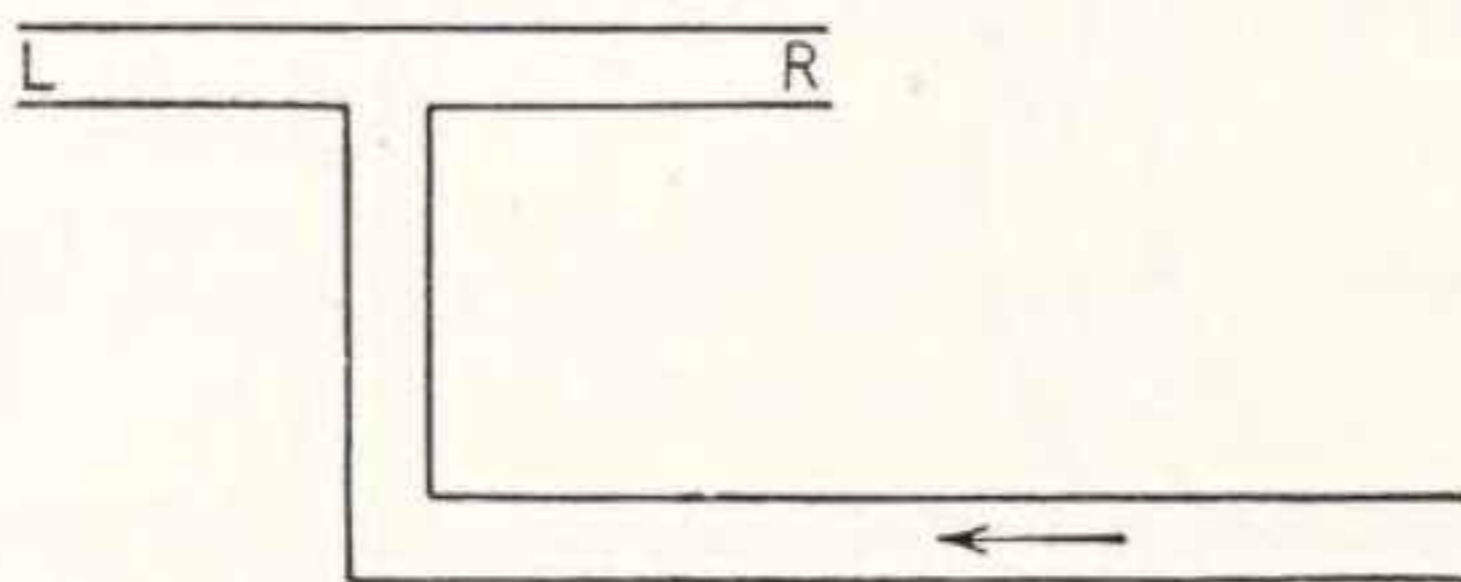


FIG. 85.—A maze alley which determines the animal's choice at the junction. The arrow indicates the direction in which the animal is traveling. When it reaches the junction it tends to turn toward *L*.

in the true path, is also present in the case of rats. Dashiell and Bayroff (1931) observed that if rats are run through an alley such as in Fig. 85, there is a tendency for them to turn left at the junction. This the authors regard as a tendency for rats to continue in the original direction and is called the *forward going* tendency. The elbow turn in the true path is a temporary obstruction which interferes, for the time being, with the direction of progress. According to Schneirla (1933*b*) however, the rat's momentum, which is a contributing factor to the centrifugal swing, is responsible for the above behavior. The elbow in the true path forces the animal to the outer wall, and this causes the turn toward that wall, which in this case is to the left. To test the two alternative interpretations Ballachey and Krechevsky (1932) devised a maze in which the centrifugal swing would cause the rats to turn in a direction opposite to that in which the forward going tendency would cause them to turn. A section of their maze is shown in Fig. 86. Their results show that the predominance of turns is to the side expected if we assume the principle of centrifugal swing.

The validity of the centrifugal-swing concept in the maze behavior of rats is further strengthened by the results of Ballachey and Buel (1934). They found that the path traversed by a rat in an alley containing elbow turns was toward the outer wall.

From the foregoing analysis it seems that the length of a straight alley determines the rats' momentum, and the direction of the elbow turn brings the centrifugal force into play. The operation

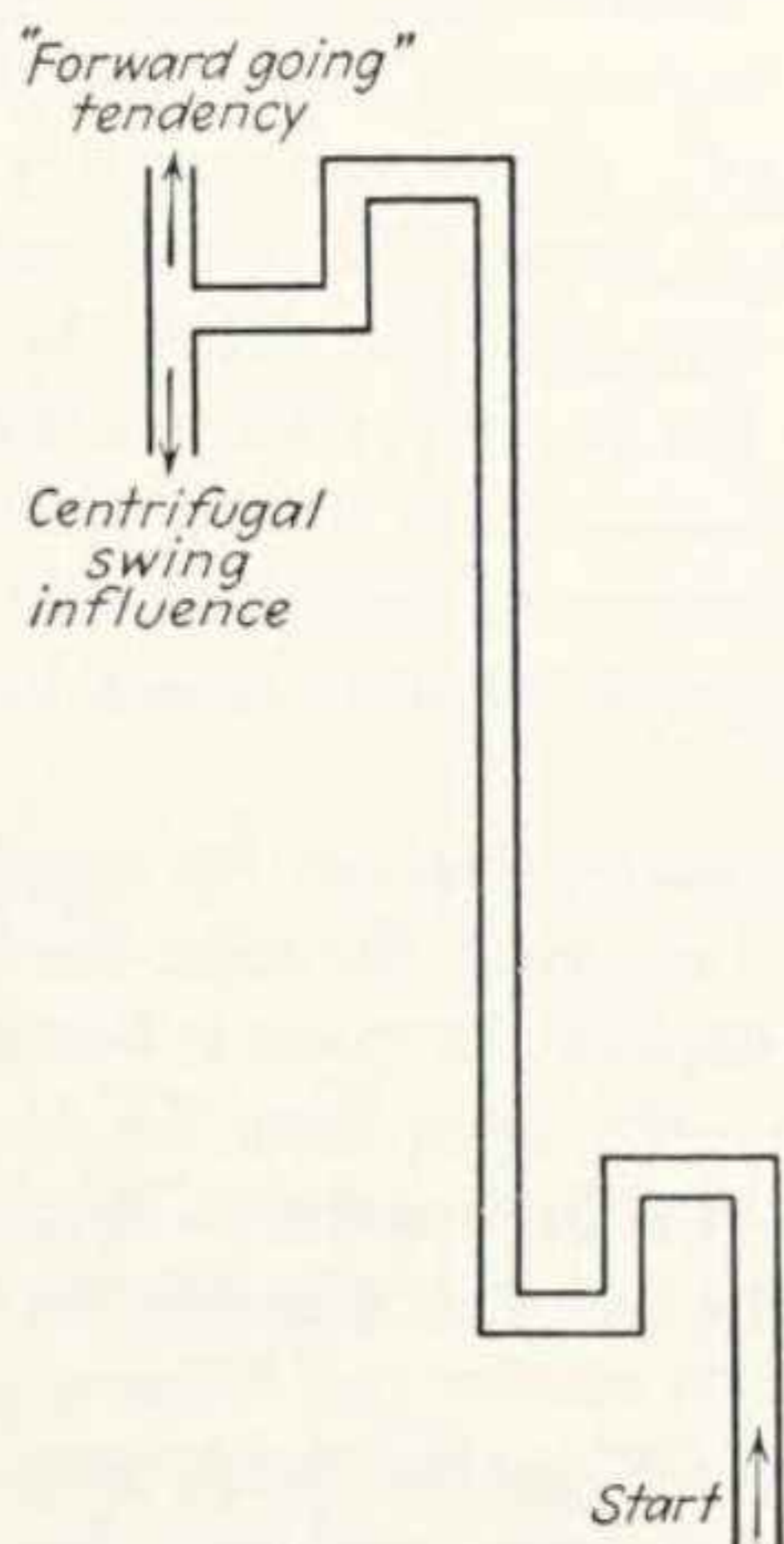


FIG. 86.

FIG. 86.—Maze plan in which the "forward going tendency" and the influence of the "centrifugal swing" are opposed. The nature of the choice made at the junction indicates whether the animal is influenced by the direction assumed in the long alley; or whether the turns preceding the junction force the animal toward the wall and into the alley labeled "centrifugal swing." (Modified from Ballachey and Krechevsky, 1932, p. 88.)

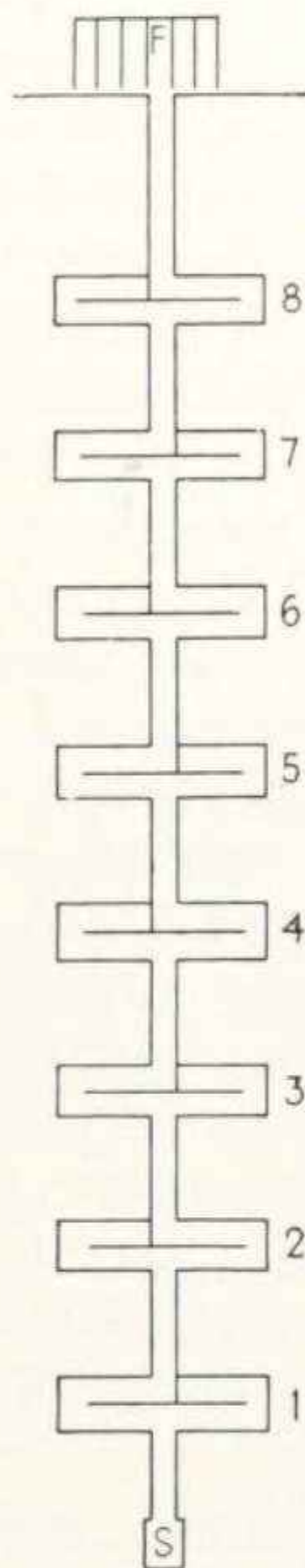


FIG. 87.

FIG. 87.—Plan of linear maze. The location of the food cannot influence the direction of an animal's choices in this maze since none of the choices point in the direction of the food. (Modified from Buel, 1934, p. 186.)

of these two factors, represented by centrifugal swing, depends upon the pattern of the alleys preceding the junction and greatly determines the choice the animal will make at the junction.

The Direction of the Food Turn.—Another tendency which has been regarded as important is the preference for turns lying in the direc-

tion of the food box. Dashiell (1930) has found that if the final choice which leads to food is to the right rather than to the left, rats will tend to turn right in earlier parts of the maze whenever they have a choice between right and left turns. Dashiell regards this as evidence that the rat has a general sense of direction. This sense causes the rat to make characteristic errors. That this tendency to turn in the direction of food is due to some general orientation toward the food may, however, be questioned.

Maier (1929*a*, Experiment 9) has shown that if rats experience the position of food with reference to the starting point they will not turn more often in the direction of the food than away from it, when running over an unfamiliar pathway. If the rat uses a general-direction sense when running a maze, familiarity of the pathways should not be a prerequisite. As a matter of fact, Yoshioka (1933) has found that in a maze in which the pathways form a diamond, rats do not tend to run from opposite points of the diamond along the side that corresponds to the side where the food is placed. Food to the right of the diamond does not cause the rats to run around the right side of the diamond.

Dashiell's results can be equally well explained by assuming a tendency on the part of the rat to anticipate the turn toward the food. As we shall see later in the chapter, the maze is learned in a backward order. If the rat learns the turn into the food box before it learns which way to turn at other junctions, it is reasonable to suppose that it will use the learned response at earlier junctions.

An experiment of Buel (1934) demonstrates this point very nicely. Buel used a maze in which rats had to make either a right or left turn at each junction. The last turn led to a food box, the position of which was straight ahead, as shown in Fig. 87. In analyzing the errors it was found that when the food turn was to the right (as in Section 8 of this figure) most of the errors were due to a tendency to turn right, and when the food turn was left, most of the errors were due to a tendency to go left. As the actual position of the food was the same in all cases, direction orientation could not have determined the turns. Rather the response at the last junction tended to be applied to other junctions.

The Kind of Blind Alley Used and Its Effect on Behavior.—The third way in which the maze pattern may be changed is the use of various kinds of blind alleys. Shepard (unpublished studies) has

extensively used mazes which may be characterized as having "dead-end" blinds, "circle" blinds, and "long-short" pathways. Examples of parts of such mazes are given in Fig. 88.

In the *dead-end blind* the animal comes into an alley which has a closed end and it must turn about and retrace its steps in order to continue. In the *circle blind* there is no closed end. After entering such a blind, the animal may continue in a circle, or it may retrace a few units and get out of the blind. (From the figure it can be seen that the rat may enter *A* and so arrive at *B* or *D*. It can now run a circle in either direction or go back to *A*.) In order for

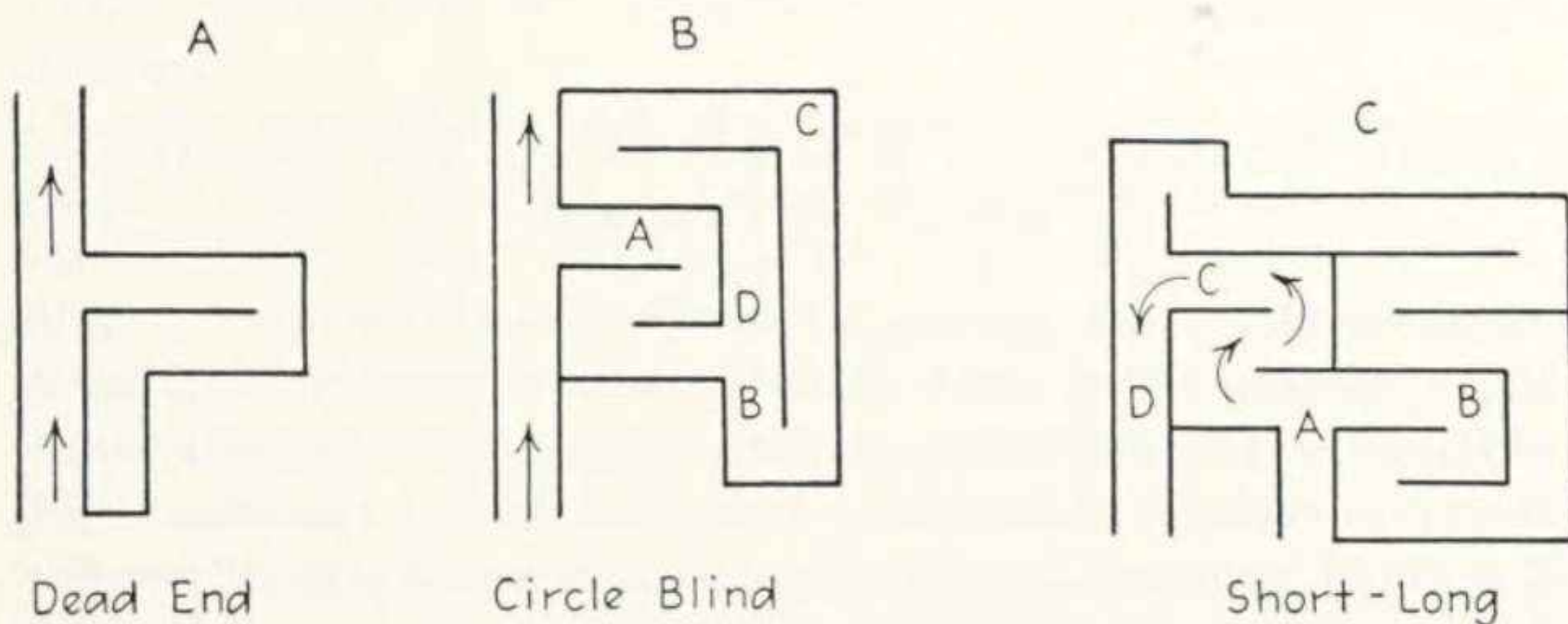


FIG. 88.—Types of blind alleys.

the animal to learn that it is not making progress, it must either experience the fact that it is running over the same area, or it must in some general way experience a lack of progress. In the *long-short* type of maze there are no blinds in the strict sense. Two alternative routes, one long, the other short, each lead to the same point. For the sake of rapid progress the long route must be avoided. The long routes may be regarded as blinds in the sense that entrance into them increases the distance to the food. In addition to having a long route, such mazes also make it possible for the animal to run a circle. The rat may, for example, take the longer route from one junction to the next, and then instead of continuing to a new part of the maze, may enter the short route and get back to the junction it has just left. (From the figure it can be seen that the rat may go from *A* to *B* and around and then choose *C* rather than *D*, and so again arrive at *A*.)

The relative difficulty of these various types of mazes has not been exactly determined, but the dead-end type of maze is markedly less

difficult to learn than either of the two other types which are about equal in difficulty. In the long-short type of maze the rats tend to run in a circle, and it is this running in a circle which they revolt against and therefore tend to avoid. Whether the dead-end blinds are less difficult because of the closed end which blocks the animal's progress, or because the opportunities for errors and confusion are less in such mazes cannot be said. The indication is that the end wall furthers learning because the place causing the trouble is easily located and for this reason reduces the confusion. When the place causing the difficulty is not definite, the task of selection is greatly complicated.

THE SERIAL POSITION OF BLINDS IN THE MAZE AND ITS EFFECT ON LEARNING

Introduction.—The ordinary maze contains a number of blind alleys. The question which naturally arises from this condition is whether there is a difference in the elimination of blind alleys due merely to their serial position. It is possible that the maze habit is (1) built up from the starting point and learned primarily in the forward direction; (2) established with reference to the food box and learned primarily in the backward direction; or (3) acquired without reference to either end and learned equally well in all parts. Thus if the serial position of a blind alley is a factor in its elimination, different parts of the maze should be mastered at different rates.

The study of the order of the elimination of blinds has several difficulties. As we have already seen, there are certain factors which make different parts of the maze of unequal difficulty. Unless these factors are taken into consideration and eliminated as much as possible, the data on the order of elimination of blinds will not solve the problem. A second type of difficulty is that resulting from an animal's retracing parts of the maze. During the early stages of learning the rat gets lost and may find itself back at the starting point on many occasions. Because of this, the early part of the maze is traversed in both directions more often than the later parts. An animal, therefore, has more opportunities for making errors in the first than in the last part of the maze, and may also become confused because of traversing it in both directions. If we count

The number of entrances into the various blinds, we shall not have a true measure of their relative difficulty because the early stages of the learning activity are primarily limited to the first part of the maze. The number of trials required before the various blinds are eliminated is also an unsatisfactory measure because each trial (a trip from the starting point of the food box) may include much more contact with the first than with the last part of the maze. This additional contact in the first part of the maze should be of aid in learning it. If retracing in the maze were eliminated (*e.g.*, by a series of doors which would close behind the animal as it progressed) a more reliable index of the order of elimination of blinds could be obtained.

Results from Mazes with Fixed Patterns.—Carr (1917*a*) made a careful study of his own and other data obtained from rats while learning similar mazes, and found that the distribution of errors was a function of the spatial order of blinds, sometimes with reference to the food box, and sometimes with reference to the starting point. He also found that, in all cases, the blinds which were least attractive (*i.e.*, the least frequently entered) were the first eliminated.

Warden (1923*a*) studied the order of elimination of blinds by counting the number of trials required by rats before a blind was no longer entered. He interprets his results as showing no indication of a particular order of elimination. He verified Carr's findings regarding the ease of elimination of blinds infrequently entered but, unlike Carr, regards it as the basis for the irregular elimination of blinds.

If, however, we analyze Warden's data in a different way, the relation between the elimination of blinds and their serial position in the maze is rather striking. By dividing the nine blinds of his maze into groups of three, we can partially average out any individual differences in difficulty among the various blinds. When we do this, we find that the average number of trials required to eliminate the first three blinds is 29.9, the middle three blinds, 32.5, and the last three blinds, 13.6. These figures show a strikingly small number of trials required for the elimination of blinds in the vicinity of the food box. The first part of the maze seems slightly easier to learn than the middle portion. If we take the individual records of the 35 rats we find that 94.3 per cent of them made their lowest score on the three blinds nearest the food box. Only 45.7

per cent of them made lower scores on the first part than on the middle part of the maze. Considering Warden's results in this manner, there seems to be good evidence for the easy elimination of blinds near the food box. Blinds farther away are more difficult, but all of these seem to be eliminated about equally well.

By using a maze which consisted of a succession of V junctions in which one of the paths led to a blind and the other to another junction of the same type, Warden and Cummings (1929) attempted to eliminate the individual differences among the various junctions. In this maze the blinds differed only in their proximity to the food box. Their results show that the blinds in the second half of the maze were eliminated before those in the first half, but the order of elimination was not perfectly backward. For the 10-cul-de-sac maze the order of elimination from first to last was alleys number 10, 8, 4, 6, 5, 3, 7, 9, 2, 1. Because the order is not exactly backward in a maze having blind alleys and junctions all alike, the authors believe that they have evidence against the backward order of maze learning. The fact that there is a higher average error score in the first than in the last half of the maze is explained as being due to retracing; the retracing being primarily confined to the first part of the maze.

The irregular order of elimination shown above becomes clear, however, when we consider the character of the last turn in a maze and its influence on maze performance. The maze used consisted of a succession of right and left turns. The odd-numbered blinds turned to the left as did the food box, whereas the even-numbered blinds turned to the right, opposite to the food-box turn. If the turn into the food box is anticipated, then the odd-numbered blinds should cause difficulty. This is exactly what the above results show. Blinds 7 and 9, which are near the food box, were eliminated relatively late, whereas blind 8 is eliminated early. The individual differences in the junctions were therefore not eliminated as the experimenters believed. When corrected for anticipation, however, the order is backward. (See Buel, 1934.)

Results from Mazes with Variable Patterns.—Borovski (1927) adopted a rather interesting technique to test the backward order of learning the maze. He used a box (see Fig. 89) divided into two halves. Each half presented the rats with four forward-leading paths (alleys 1, 2, 3, 4 and *A*, *B*, *C*, *D*). Each of these alleys had removable ends, but only one was open at any time; the others

served as blind alleys. There were also a number of permanent blinds. The two halves were identical except for the fact that the food box was at the end of the second half in a position corresponding to the end of the first half. If learning is backward from the food box, a change of the pattern in the second half should interfere with the establishment of the habit more than a change of the pattern in the first half. To test this, 83 rats were divided into three groups. One group learned the route to food without any modifications. A second group learned the maze with the first part of the maze changed (a different path open) daily. This group was therefore prevented from learning a specific route through the first half of the maze. The third group was treated as the second, except that the changes from day to day were made in the second half of the maze instead of the first.

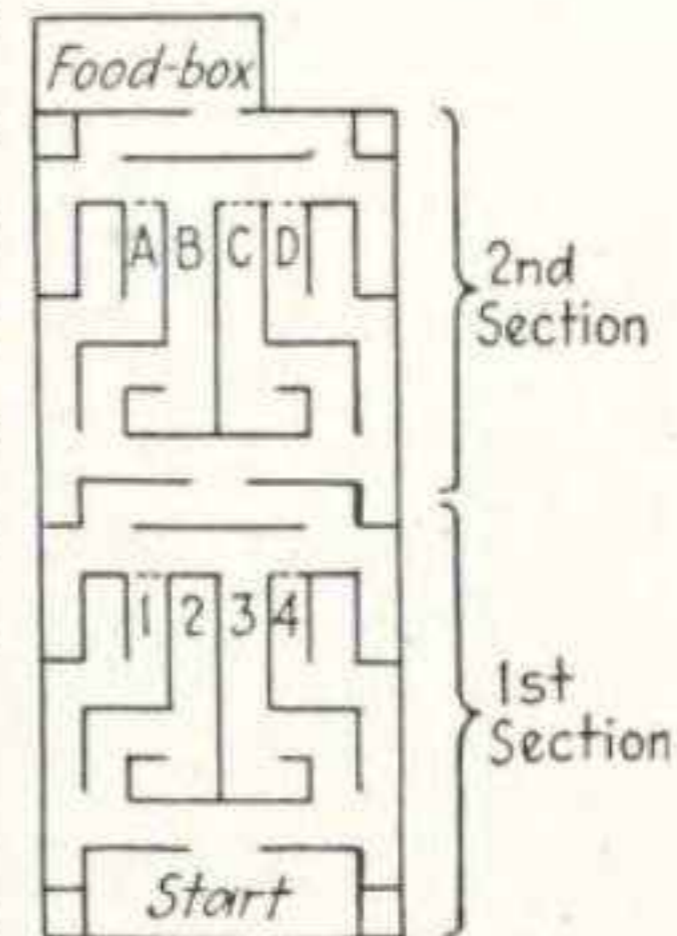


FIG. 89.—Plan of Borovski's maze. The two halves of the maze are alike in pattern. The route through each half may be altered by removing or inserting sections in alleys 1, 2, 3, 4, and A, B, C, D. (Modified from Borovski, 1927, p. 493.)

The results may be summarized as follows: (1) the first group of rats learned the second half of the maze before the first part; (2) after the first group learned the maze, changes in the second half of the maze caused more confusion than changes in the first half; and (3) the third group of rats made many more errors during the learning period than did the second group. The results show that the learning is largely built up backward from the food box. However it must be noted that the first part of the maze was learned even though the second part was changed.

The Goal-gradient Hypothesis and the Serial Position of Blind Alleys.—Hull (1932) approaches the problem from a study of motivation. He postulates an excitatory gradient increasing in intensity from the beginning of the maze to the food box. Hull was led to this conclusion by his observation that rats ran more rapidly in the latter part than in the first part of the maze. From this postulation of a goal gradient it follows that deviations from the true path are more critical and effective when the gradient is high. We should therefore expect the part of the maze near the food box to be learned first. We should also expect the gradient to be higher at the beginning of a short maze than at the beginning of a long one. If a maze contains both a short and a long route to food, the short

route should be learned first. As the gradient differences would exist at the junctions, the true path being nearer the goal, should be preferred. But if this line of reasoning is correct, all blinds should be eliminated at the junctions. Partial entrances into blinds are, however, very common before they are completely dropped out. Further, long blinds, because they carry the rat farther from the food than do the short, should be eliminated more quickly than short blinds. This also seems to be contrary to the actual facts.

Assuming the importance of the goal-gradient hypothesis and the tendency of rats to turn in the general direction of the food location, Spence (1932) examined some maze data obtained by Tolman and Honzik on a 14-junction maze in which all junctions were alike in that each presented the rat with a choice between a right-going and a left-going path. By assigning certain relative values to the pathways at each junction, the value depending on the nearness of the pathway to the goal and on the direction of the pathway with reference to the position of the goal, he arranged the blinds in their theoretical order of difficulty. On comparing this theoretical order of difficulty with the actual order of elimination Spence found a high degree of correspondence (a correlation of 0.9 or more). He concluded that the difficulty of blind-alley elimination depends on (1) the distance of the blind from the goal; (2) the direction in which the blind leads with reference to the position of the food box; and (3) the tendency of the rat to anticipate the goal reaction.

Spence and Shipley (1934) found the order of blind-alley elimination to be backward during the first few trials, but as learning progressed, the order of elimination changed to a forward one. The forward order appears attributable to a tendency to anticipate the final turn in the maze, since most of the errors were made in blinds which turned from the true path in the same direction as the final turn which led to food. Thus the forward order of blind-alley elimination was not due to a more rapid elimination of the blinds in the first part of the maze but to an increase in errors in the latter part of the maze. If the goal-gradient hypothesis is applied to the results of this experiment, it would have to be used to explain the increased intensity of the anticipatory tendency and the consequent increase in errors in the latter part of the maze. This being the case, it is difficult to understand how the same goal gradient can, at the same time, account for the backward elimination of blinds.

It seems to the present authors that the results can be satisfactorily explained by assuming (1) the establishment of a food association in the first few trials, and (2) the inadequacy of the kinesthetic process for making differentiations between the similar junctions. As a consequence, the learned goal reaction is made at the wrong junction. This accounts for the persistent errors in the latter part of the maze, on the basis of inadequate sensory discrimination and not on the basis of motivation.

If this is the case, one might assume that anticipatory reactions would be independent of the position of the goal. A study by Spragg (1934) actually bears this out. He used a unit maze in which the turns required were *rrrrlrrr*. In this experiment a left turn is the exceptional turn and it does not lead to food. Nevertheless, errors were concentrated at the junction preceding the exceptional turn as is shown in Table 27. However, the concentration of errors was not so great as when the exceptional turn was the last and led to food. This is to be expected since the problem required is a discrimination between running four and five units, rather than seven and eight. As the difference between four and five is relatively

TABLE 27.—ANTICIPATORY RESPONSES TO THE EXCEPTIONAL TURN IN A UNIT MAZE (FROM SPRAGG, 1934)

Unit	1	2	3	4	5	6	7	8	Total
Response required	<i>r</i>	<i>r</i>	<i>r</i>	<i>r</i>	<i>l</i>	<i>r</i>	<i>r</i>	<i>r</i>	
Errors in 1st 25 trials	27	26	18	57	41	8	8	14	199
Errors in 2nd 25 trials	10	13	30	45	48	6	1	5	158
Total errors	37	39	48	102	89	14	9	19	357

greater than the difference between seven and eight, fewer errors would be expected. Furthermore, a right turn followed the exceptional left turn, hence a discrimination between the fifth and sixth units was also required. This should cause errors at the fifth unit and that is actually what Spragg found.

Thus by assuming that the exceptional turns are the first to be learned and that they must be differentiated from the others, the results of the serial order of blind-alley elimination can be explained

without recourse to goal reactions as such. Goal reactions are likely to appear important, not because they are goal reactions, but because *the turn into the food alley is an exceptional one*, being characteristic in the sense that *this turn leads to something different from all the other turns*. The goal-gradient hypothesis assumes that the speed of learning is a function of the motivating situation, whereas the above explanation makes no such assumption.

CONCLUSIONS

From the foregoing analysis of maze learning we may regard the maze habit as the establishment of a unified pattern of responses which depend upon a variety of stimuli. The rat must set up preferences for alternate alleys and in order to do this, various points in the maze must differ for it. Traversing a learned maze is not merely the running of a rhythm of movements, because the rat can, when placed in any part of the maze, find its way successfully to the next point. We may greatly interfere with the animal's rhythm of running without causing it to become lost. As long as various parts of the maze can be *differentiated* by the rat, it is capable of responding correctly to any particular part of the maze pattern without first experiencing the preceding parts of the maze. As such, the maze pattern is not an indivisible unity. The kinesthetic sensations alone are not a sufficient sensory basis for the learning of large mazes, since the differential experiences between them are not reliable and consistent enough to be useful. The junctions in the maze usually are the critical points, and it is there that characteristic differences must be found by the animal.

To make a correct run an animal must not only integrate certain parts of the maze, but it must first *select* that which must be integrated. The problem of selection is increased in difficulty by increasing the number of items. This is what happens when we increase the number of junctions or complicate them by adding to the number of paths leading from them. Selection is also made more difficult by using blinds which are difficult to isolate in that they have no definite point of termination.

The actual *learning* part of maze behavior is one of *integration*. Certain factors increase the difficulty of this process. The number of units to be integrated is, of course, one of the factors. Other factors are less obvious.

The swings or turns in the maze in relation to the length of alleys influence the mechanics of running and cause certain alleys to be more obvious and more easily entered than others. This causes difficulty because it introduces certain natural tendencies which must be overcome in learning. Junctions which are preceded by the centrifugal swing, therefore, not only require the formation of the proper association, but also the inhibition of certain mechanical tendencies in running. Hence this factor increases or decreases the difficulty of the formation of the proper associations, depending on whether the mechanics of the swing favors the entrance into the blind or into the true path.

Another factor which must be considered in maze learning is the *interference of partial learning with a more complete learning*. The experience of receiving food in a certain place is an important event, and the characteristic experience which accompanies it is the last choice which leads to the food. The contiguity of these two experiences results in their combination. As soon as this association is formed, the response to food tends to be repeated at the earliest opportunity. The animal therefore applies the characteristic turn which it has learned to other junctions in the maze and tends strongly to enter certain blinds. Not until the rat makes further distinctions between the last turn to food and other turns in the maze can it overcome this tendency to apply an act already learned to wrong parts of the maze. After the animal has learned to apply the characteristic response to the correct junction, it learns to associate the preceding contiguous experience with this junction. In this manner the maze responses are built up backward.

In this connection it is perhaps important to recognize that the mammal is not merely a learning creature, but is also capable of *reorganizing* its experiences. If a rat has explored a region, such as a simple maze, and is then fed at any point in the maze, it is capable of going directly to the food when placed at any other point in the maze. (This problem will be treated at length in Chap. XX.) In such a case the associations have not been built up gradually, rather the path to food has been simultaneously integrated. If a rat is capable of reorganizing and integrating such random experiences as are obtained during free exploration, it must have an ability which will be useful in building up the maze pattern. It seems that this ability to reorganize and to spontaneously integrate experiences plays an important part in the integration of the maze habit.

When we realize the number of qualitative factors which are at play in the process of learning and consider that abilities other than learning may also be involved during the process of building up the maze pattern, it becomes clear why the behavior of animals in the maze had been so difficult to analyze. The animal's responses may not only be the resultant of an involved learning process, but of other processes as well. This being the case, the maze is not a measure of pure learning ability. It is perhaps more accurately described when termed an *intelligence* test—with intelligence regarded as a composite of these abilities which are concerned with adaptation through experience.

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