THE EFFECT OF FLOOR CUES UPON THE MASTERY OF THE UNIT-ALIKE MAZE

by Quin F. Curtis

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the University of Michigan

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Abstract

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The maze used in the experiments reported in this dissertation is referred to as a "unit-alike" maze. This means that the layouts ("units") of alleys from the beginning to the first choice-point (junction), and from each choice-point to the next, are all alike. Also the layouts at all choice-points are alike. In the form used, to avoid the blind, a left choice is required at all junctions except the last (referred to as the exceptional choice-point), where the rat must turn right to reach the food box. By dropping in an appropriate wall section, any junction before the last can be made the starting point.

In most of the experiments, the rat was started each day the same number of times from each of three entrance points, such that he must run through 2, 3, or 4 units before reaching the exceptional choice-point. The order of using these different entrance points was varied according to a systematic schedule. Each experiment was concerned with a specific sort of floor over which the rat ran. In each experiment, the intent was to continue practice until no rat could show further progress.

The results showed that the level of performance to which the rats could attain depended upon the type of floor used. No floor was found on which there was no evidence of learning. The lowest level found was with a floor of suspended wire screen with the walls carried from a superstructure and not resting on the floor; but a floor made of a nine-inch deep bed of fine sand gave results which were not much higher. The highest level was obtained with a floor of smooth concrete. Floors made of one and one-half and three and one-half inches of sand gave intermediate results. Various tests indicated that the cue was not olfactory.

One experiment was designed to show kinaesthetic influence even in the situation where the rat is started in varied order but equally often each day from the three entrance points 2, 3, and 4 units before the exceptional junction. In the first part of the experiment for 10 days, each rat ran 2 trials per day from each of the above three entrance points. In the second part, for a like period, each rat ran the same schedule of trials, except that 2 trials from the entrance point only 1 unit from the exceptional choice-point were interspersed each day among the standard set of runs. In tabulating results, those trials from the 1-unit-distant entrance-point were omitted from the calculations. Such tabulations showed clearly that the added trials in the second part changed the performance on the standard trials to give more errors in the earlier blinds with less errors in the later blinds and less correct runs.

I wish to make grateful acknowledgement of my indebtedness to Dr. John F. Shepard, who suggested this problem and gave unfailing advice and assistance in carrying it out.

TABLE OF CONTENTS

HISTORICAL SURVEY

THE SENSORY CONTROL OF THE MAZE

The question of the sensory cues used by the rat in maze learning has not yet been settled. That the problem is an important one will be denied by no one who desires the highest possible precision in this valuable instrument for the analysis of animal and human behavior. Many of the discrepancies in the earlier work with the maze performed at different laboratories can be reduced to discrepancies in the degree and kind of sensory control used in the experiments. Certainly a common criticism still offered of a new piece of work with animals is that the control of the maze situation was inadequate.

Experiments Emphasizing Kinaesthesis as the Primary Cue in Maze Learning

The problem of sensory control in the maze situation has been sporadically attacked since the work of Small (1901). Small attempted to determine what senses were used by the rat in learning a rectangular form of the Hampton Court maze. Olfaction was controlled by changing the sawdust on the floor occasionally. The use of vision was tested by offering the rats a visual cue in the form of small red pegs at each junction of pathways, on the side towards the true path. Since the rats were not disturbed by removal of these pegs after the maze was learned, Small concluded that vision plays no part in the habit. The fact that blind rats could also learn the maze supported this view. Rats whose vibrissae had been removed could also learn the maze. Since only kinaesthetic and tactile cues seemed to be left, Small concluded that they were the primary cues used by the rat in maze learning.

Watson (1907) provided more convincing evidence that kinaesthesis is the primary cue in maze learning. His method was to compare the learning of the Hampton Court maze by a normal group of rats with the learning of the maze by other groups which had been deprived of one or more senses by extirpation. One group was run in total darkness, after having learned the illuminated maze. The runs were not appreciably slower than normal. Another group was blinded by enucleation of the eye. They were able to run as well after this operation as before. Since no appreciable reduction in score occurs when rats are deprived of the use of vision, Watson concludes that vision is not an essential cue in the maze situation, and probably not even an important secondary cue.

The use of audition was tested by partially deafening a group of rats. The tympanic membrane was ruptured, the ossicles removed, and the cavity of the middle ear filled with paraffin, resulting in a great reduction, but not complete elimination, of auditory sensitivity. However, these animals were able to learn the maze with the same perfection as normal animals. Extirpation of the olfactory bulbs in a third group of rats indicated that olfaction was apparently not a necessary cue. The vibrissae were removed from still another group without serious reduction in score.

One animal was subjected to three operations, rendering him blind, vibrissaeless, and anosmic. This rat learned the maze with difficulty, but finally was capable of perfect performance. These results indicated to Watson that neither visual, auditory, nor olfactory cues play an essential part in the rat's learning.

Another group of experiments was designed to test the place of kinaesthesis, by determining whether it is necessary for the rat to run through a part of the kinaesthetic pattern of the maze in order to orientate himself when dropped into the maze at points other than his regular beginning point. After learning the maze, rats were inserted into it at points other than the regular entrance, sometimes facing in the proper direction, sometimes not. In 60% of the cases, the animal was able to orientate himself immediately, and to proceed correctly to the food box. 39% of the rats gained their orientation only after they had turned a corner, while 7% went back to the beginning before finding their orientation. The fact that more than half the rats were able to "pick themselves up" without turning any corners cannot be explained on the basis of kinaesthesis alone, since one straight alley cannot differ kinaesthetically from another except in length. Supplementary cues of some sort must have been used by the rats. But blind and anosmic animals were able to orientate themselves when dropped in as well as normal animals, showing that vision and olfaction were not the supplementary cues on which the rats depended.

What these supplementary cues were, Watson could not satisfactorily explain.

Rotation of the maze with respect to the cardinal directions brought results equally difficult of interpretation in terms of kinaesthesis alone. Although the pattern was unaltered, rotation of the maze through 180° resulted in such confusion that the rats had to relearn the maze completely. Anosmic and deaf rats were also badly disturbed by rotation through 180° of a previously learned maze pattern. Blind rats were not badly thrown off by a 180° turn. However a 90° rotation affected all classes of animals, indicating either that the first result with blind rats may have been due to chance, or that they were not confused, as were the others, by a conflict between visual and other cues.

Following out the problems suggested by this experiment, Carr and Watson (1908) worked further on the question of orientation in the maze. They built a maze having very long cross alleys running parallel to each other, and having all junctions at the two ends of the maze. The central section was therefore only a series of straight parallel alleys. By removing this central section and pushing the ends together, a shorter version of the same pattern was obtained, in which each alley was shortened, yet the succession of turns remained the same. When the rats had learned the maze in its long form, the central section was removed. Now the rats showed great disturbance, and had a strong tendency to run too far in each alley, resulting in collisions with the end walls. Carr and Watson found this to be evidence that the rat's learning is primarily kinaesthetic.

These rats, like Watson's, were able to orientate themselves immediately in the maze, no matter where they were dropped in. Rotation of the maze caused both blind and normal animals to be confused. Neither of these points is explicable on the basis of learning by kinaesthesis alone.

Experiments Suggesting Cues Supplementary to Kinaesthesis

Bogardus and Henke (1911) attempted to show that maze learning is effected in terms of tactile sensations gained from the walls of the maze, combined with kinaesthesis. They used rats whose vibrissae had been cut off close to the head. These rats were tamed by feeding for several days in the maze food-box, then were run through the maze. The experimenters counted the number of head contacts with the corners and side-walls. It was found that these contacts were numerous at first, but decreased and almost disappeared in the final stages of learning. The contacts were mainly at the junctions and corners, but the rats also hugged the wall on the straightaways. Bogardus and Henke conclude that contacts with the walls furnish the primary cue in early stages of learning, being replaced later by kinaesthetic cues. The same phenomenon held for blind rats, which the workers took to mean that vision plays a minimal part in maze-learning. In criticism, it may be remarked that trained rats make almost no contacts with the walls even in learning a new maze pattern, and it would seem reasonable that the contacts made by the green rat mean only that the vibrissae assist in remaining in the middle of the alley.

Vincent (1915a, 1915b, 1915c) performed a series of careful experiments on the sensory control of the maze habit which indicate that sense modes other than kinaesthesis can provide cues effective for maze-learning, if they are given adequate opportunity to do so. In her work on the introduction of a visual control (1915a) she used a dead-end blind maze in which the true paths and the blind alleys were made to differ from each other as much as possible in brightness value. Black paper lined and covered one, while the other was lined with white paper and open above. One group of rats was trained on white true-paths and black blind alleys, while another group had the opposite arrangement. A control group learned the maze with all alleys uniform in color. Miss Vincent found that both groups of rats which were afforded these distinctive visual cues excelled the control group in both speed and accuracy. To meet the criticism that the rats were responding to some factor other than brightness (possibly an auditory or tactual difference arising from the black covering over the dark alleys) the rats were tested further in a problem box having two exits. These exits were cardboard tubes, one black and one white, bent so that no light rays from the end were visible. It was found that rats which had learned to react to the white true-path in the maze tended to take the white exit-tube from the problem box, while rats which had learned the black true-path in the maze tended to choose the black tube. This strongly indicates that the rats had really been responding to a brightness difference in the maze.

To test whether olfaction can be a cue in maze-learning, Vincent (1915b) laid strips of paper along all the alleys of her maze. The true paths and blind alleys were differentiated from each other by saturating one with the odor of beef extract or cream cheese, while the other had no scent. One group of rats learned to follow the odor along the true path, another learned to avoid it in the blind alleys. In either case, learning scores were higher than those of control animals who were not allowed the olfactory cue.[1] In this test also, the animals showed their preference for (or avoidance of) the scent when tested in the problem box having two exits. Vincent concludes that rats can utilize an olfactory cue if it is made obvious enough, and cannot agree with Watson that "olfactory sensations have no role in the selection of the proper turns in the maze". (Op. cit., p. 83). She does not contend, however, that one rat can follow the olfactory trail of another, or smell food at a distance.

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[1] The learning of the positive group (which followed the odor) was greatly facilitated over the control group, but the negative group (which avoided the odor) was only slightly better.

Average errors per rat: Control, 66.6; Positive, 20.5; Negative, 52. In the later trials, the odor seemed to distract this group rather than to aid them.

Vincent (1915c) attacked the problem of tactual control in a slightly different manner. Instead of arranging the situation so that true and false paths should contrast with each other in some way, a maze was built which could be used in two different forms, differing in their tactual qualities. This maze was elevated from the floor and had hinged side walls, so that it could be used either as an alley maze, or as a simple elevated pathway. Rats were allowed to learn this maze with the sides up. When they were let down, there was the greatest possible confusion, and the rats had to relearn the maze as though it were a totally new problem. The elements commonly thought of as making up the kinaesthetic complex, i.e., distance and succession of turns, remained the same; certain cues from other sense departments were certainly modified. Vincent emphasizes that rats in learning a maze cannot be thought of as learning a simple proprioceptive pattern. Cues from other senses, though perhaps not dominant, make up a part of the total sensory complex, and their disturbance will break down the whole learned pattern. A maze may be learned in terms of senses other than kinaesthesis if these are given a chance to operate.

Following the contention of Vincent that the maze-habit is in part dependent upon the larger sensory environment and is not a mere kinaesthetic-motor chain, Carr (1917) proposed a group of experiments to test how far this wider sensory environment could be altered without breaking down the maze habit. The method consisted in varying the experimental conditions while the maze was being learned and after it had been mastered. Carr used a small glass-covered maze, over which was suspended a square canvas top with flaps which could completely screen off all four sides. With this top down, the maze could be illuminated by means of a centrally located electric lamp within.

Carr's first group of tests consisted of various attempts to disturb the maze-running of rats by altering the environmental conditions previous to running the maze. The rats were carried by a variable route to the maze, the living cage was at different times covered, shifted to a new location while preserving its cardinal directions, and rotated. Aside from a few brief disturbances which may have been due to mere shock, orientation in the maze was not affected by what went on outside it.

The next group of tests consisted of alteration of environmental conditions within the maze itself. Cleaning the floor of its accumulated deposits, covering the maze when it was learned uncovered, and uncovering it when it was learned covered produced only mild effects which may well have been due to shock rather than to the alteration of a cue on which the animal was depending. Somewhat more disturbance was exhibited when the constant position of the experimenter was changed, and when the direction of the dominant light was shifted.

Most serious disturbances attended the various tests in which the position of the maze was altered. Changing the location of the maze in the room without disorienting it with respect to the cardinal directions produced an upset in the rats' behavior which lasted for several trials. More serious was the reaction attendant upon rotation of the maze. When the maze was rotated through 90, 180, and 270 degrees on successive days, the rats were badly thrown off. Repetition of these tests brought about gradual adaptation to the various positions. However, rats which were adapted perfectly to the above four positions were once more thrown off when the shifts were to 45, 135, 225, and 315 degree positions. Adaptation therefore did not mean the relinquishing of the cues which caused the disorientation, but merely a relearning each time under the new conditions.

A suggestion that confusion during rotation might be due to a conflict between cues from the outer environment and those from within the maze is indicated by the facts that (1) there was a greater confusion during rotation of the maze in a well-lighted environment than in a darkened one, and (2) there was greater confusion during rotation of a sideless maze (offering more contact with the outside) than during rotation of an enclosed alley maze.

Directly contradicting this is the fact that rotation of the environment (the canvas top) <u>without</u> rotation of the maze caused no disturbance, while rotating maze and environment together <u>did cause disturbance</u>. Nothing in the concept of maze-learning as a proprioceptive function, aided perhaps by contact, can be used to explain this behavior. Carr does not pretend to know "through what sense avenues these disturbances were mediated." (p. 275) Yet he still claims that while visual, auditory, and olfactory data may be present in the maze situation, "organization of these data as compared with those of contact and kinaesthesis are inadequate for the solution of this particular problem". (p. 259).

Groups of blind (Carr, 1917a) and anosmic (Carr, 1917b) rats were now tested under those conditions which had disturbed the normal animals. None of the results were radically at variance with the results from the normal rats. In general, the blind and anosmic rats were slower in learning the mazes and in adapting to changes. Carr is inclined to relate this to the apparent lowered tonicity which follows the extirpation operation.

Hunter (1920), in studying the alternation problem, found results bearing upon the sensory control of the maze. Using a two-choice problem box, he trained rats to run a pattern of simple alternation, where success would lie to the right and left alternately. This was learned very easily. Then he tried a double alternation, in which the succession of correct choices was left, left, right, right, etc. To his surprise, the rats were unable to master this sequence. This led to the construction of a "temporal" maze, in which the rat could be made to run over the same pathway time after time, making his choices of right or left always at the same junction. In running a simple alternation on such a maze, the path of the rat would be a figure eight. This habit was readily acquired.

Hunter then attempted to force the rats to learn a double alternation on the temporal maze. The results were like those in the double alternation problem box: complete failure. At the end of 42 trials they had all set up position habits which rendered further work useless. On the other hand, a double alternation spatial maze was mastered in 5-10 trials. Hunter describes the differences between these mazes as follows: "In the spatial maze, the cues are distributed in new segments of space as well as in new moments of time; while in the temporal maze the cues must arise in the same space..... but will succeed each other as a temporal sequence." (p. 7). Hunter thinks of his "spatial" maze as being the equivalent of the temporal maze except for the spatial arrangement of the turns. As a matter of fact, although the sequence of choices at the junctions was a double alternation, the turns between the junctions were unique and irregular. Unless Hunter thinks that the only points which determine the choices in a maze are the junctions themselves, the two mazes are not comparable. Certainly they differed widely in the kinaesthetic pattern offered to the rat.

Of a group of rats tested on a simple alternation in the temporal maze, one succeeded in learning it. To explain why the rat is able to learn a simple but not a double alternation, Hunter says that in a simple alternation, the kinaesthetic feeling of a left turn may produce a right turn next time around, and vice-versa. But in a double alternation, the kinaesthesis of going left must lead to another left turn the first time around, and to a right turn the second time around. He says this would be requiring two different reactions to the same stimulus, and is impossible. "A given kinaesthetic complex may mean either of several responses, but it cannot mean now one and now another without the addition of some selective element." (p. 16). In the spatial maze, this element is provided by cues which have space location, as well as temporal position. Hunter regards this experiment as showing that rats have no capacity to set up habits where the sensory complexes have only temporal sequence, and that the learning of a sequence such as a double alternation cannot be reduced to chain-reflex terms.

In a later work, Hunter (1929) continued the investigation of sensory control. Double alternation spatial mazes were used in this experiment which do not merit the criticism offered of the 1920 spatial mazes. Here, the length of alley and the sequence of turns between the alternations was kept constant, so that the kinaesthesis from the various parts should have been about the same. The maze was an elevated one, with a pathway of heavy brass strips, carefully machined and joined. Hunter thinks that kinaesthetic and tactile stimuli are adequately controlled by these measures, and that the maze is equivalent to the temporal maze except that the cues are arranged spatially as well as temporally. Rats were able to learn this spatial maze, however. Hunter can find no adequate explanation for their ability to do this, while they remained unable to learn the double alternation temporal maze.

He feels that the difference between the two cannot lie in the kinaesthetic pattern allowed the rat, nor in tactual differences. He suggests that a direction tendency may operate in the spatial maze, since the blind alleys which are easiest to eliminate are those which run at right angles to the direction of the food-box. A "neural supplementing", by which Hunter means that responses made at one part of the maze would help to determine reactions made later in the series, might explain why the rats could run the double alternation, but this factor should operate as well in the temporal maze as in the spatial.

In an attempt to combine the qualities of both temporal and spatial mazes, Hunter built a tridimensional maze. In this maze, the rat ran over the same pathway only once in each trial, as in the spatial maze, but the pathway was built on an incline, and coiled around upon itself as in the temporal maze. Each junction in the maze was directly above the other, with the inclined pathway leading from one level to another. Hunter thought that this arrangement should minimize the effect of environmental cues on the learning process, since the rat is running through a vertical section of his environment rather than through a horizontal one, and any direction cues present would have to be arranged in an up-and-down direction.

He found that rats were able to learn a simple alternation tridimensional maze just about as they would the same pattern in a horizontal spatial maze. In a double alternation pattern, the rats had much more difficulty, but some succeeded in learning the double alternation. After thorough drill, these rats were placed in an elevated temporal maze which was exactly like the tridimensional maze except that of course there was no slope to the pathways. However, the rats did not carry over their ability to run a double alternation pattern to the other maze. This indicates that the tridimensional maze must have afforded a spatial cue of some sort.

In interpreting his results, Hunter assumes *a priori* that proprioceptive cues alone cannot have been responsible for the learning of the double alternation mazes, because the same stimulus cannot call out now one response, now another. If the stimulus situation seems the same in two cases, differential response is given, then other sensory cues must have been present, or else there is the "neural supplementing" of the present response by what has gone before. Hunter indicates that there may have been additional sensory cues supplementing kinaesthesis in the case of the spatial and tridimensional mazes, coming either from the visual environment or from the elevated pathways of the maze.

Dennis (1929) tried to determine whether it was possible for rats to learn a simple maze by means of kinaesthesis alone. His maze consisted of a wide box with a $4\frac{1}{2}$" opening at one corner leading into the food-box alley. The starting point was diagonally across the box from this opening. Only one turn was required. Dennis found that young rats which had been blinded and deprived of vibrissae were not able to find their way from the starting point across the box and into the food-box alley without making contact with the side walls, even when they received electric shocks for so doing. Rats with normal vision were able to run the maze without contacting the walls. Dennis concludes that kinaesthesis alone cannot direct the running of a simple maze, but must be supplemented by tactile or visual cues. Kinaesthesis may determine the direction of a turn, but other cues are necessary to release the turning reaction at the proper time.

Experiments Questioning the Importance of Kinaesthesis

Lashley and McCarthy (1926), investigating the effects of cerebellar lesions on the retention of the maze habit, found results which oppose the view that kinaesthesis is an essential cue in maze learning. They trained seven rats to run the Lashley 8-blind maze, to a criterion of 10 consecutive perfect runs. Retention of the habit was tested by the savings method both before and after the cerebellar injuries had been inflicted. After cerebellar lesions, the normal gait of most of the animals was seriously impeded, and there were marked changes from the normal condition in the motor pattern of progression through the maze. However, 6 of these animals showed almost perfect retention of the maze habit, after allowances are made for the post-operative delay. One animal, in which the cerebellum was totally destroyed, had lost the habit, but was capable of relearning. Two animals were blinded, but showed perfect retention nevertheless. Olfaction was controlled by washing the maze. Lashley believes that "after cerebellar lesions the animals did not fall back upon exteroceptive cues, but continued to react on the basis either of kinaesthetic stimuli, or of some centrally organized mechanism" (p. 431). He inclines toward the latter interpretation.

Lashley and Ball (1929) attempted to throw further light upon the necessity of kinaesthetic cues in maze running by a more direct interference with kinaesthetic sensitivity. Rats were trained in the 8-blind maze until they had reached the criterion of 10 consecutive perfect trials, then were given 50 trials of overtraining. After a rest of 10 days, a pre-operative retention score was obtained by the savings method. The rats were then subjected to various lesions of the spinal cord, some involving section of the dorsal funiculus, others the lateral funiculi, and in one case the ventral funiculus. In one case or another, every part of the cord was severed except the ventro-median bundles. Ten days after operation, they were given post-operative retention tests on the maze.

Most of the rats showed marked motor difficulties after recovery from the operation, yet showed more or less perfect retention of the maze pattern, even when run in darkness. Lashley offers four alternative interpretations of this data:

(1) The kinaesthetic cues may have been eliminated by the lesions, and the animals shifted to other sensory cues for direction in the maze. This interpretation is ruled out, he thinks, by his control of olfaction and vision, and the unlikeliness of the use of auditory cues in the form of echoes from the blinds.

(2) Since the section of the cord took place at the level of the third cervical segment, kinaesthetic impulses from cervical nerves 1 and 2 might still direct the animal.

(3) The proprioceptive paths of the rat's cord may be so diffusely scattered, that afferent impulses may pass through to higher centers in spite of the partial lesions to which the cord was subjected. This possibility is weakened by both anatomical and behavioral evidence to the contrary. The proprioceptive paths in other mammals are known to be confined to fasciculi _gracilis, cuneatus_, the _spino-cerebellar_ systems, etc., and the behavior syndromes of the injured animals suggested a sensory deficiency rather than direct motor paralysis.

(4) "The engram of the maze habit consists of some central organization in which the general direction and succession of turns are so recorded that, once the series is initiated, the essential sequence of movements may be performed in the absence of sensory control and with considerable variation in the actual movements produced." (p. 97). This latter interpretation, admittedly vague, is Lashley's own opinion. It is needless to point out that this interpretation runs contrary

to the notion that kinaesthetic control is imposed by anything like serial reflexes evoked during the running of the habitual pattern.

Experiments Emphasizing the Importance of Floor Cues

The experimental work which first definitely showed the existence of cues originating from the floor of the maze was performed by Shepard (1928). The maze was of the Shepard Universal type, described elsewhere (Shepard, 1921, Cameron, 1928). The platform is of wood, 2 inches thick, covered with asphalt linoleum 3/16 inch thick, cut in 12 inch squares. The maze pattern was built up from standard sections of beaverboard fitting into grooved posts, making alleys about 6 inches wide and 7 inches high. The alleys are roofed over with heavy wire mesh. Illumination is from 100 small shaded lamps, arranged 24 inches center-to-center each way. The maze pattern consisted of two groups of like-units similar to those used in the present experiment (see p.26a). The first group had five standard units followed by one exceptional unit in which the reaction necessary to avoid the blind was opposite to that required in the standard units. The second group had four standard units followed by the exceptional unit.

When the rats were run in this maze, it became quickly evident that they were not learning on the basis of kinaesthetic cues. One rat learned the reaction which would carry him through the standard units, but which caused him to make an error in the exceptional unit. This reaction became automatized. The other rats quickly learned to give the correct reaction to the standard units and the opposite reaction to the exceptional unit. That they were not doing this kinaesthetically became obvious when they were "dropped in" to the maze at other units than that which was the regular beginning point. The rats were not disoriented, as they would have been on the basis of kinaesthesis, but quickly picked themselves up and gave the correct reaction when they arrived at the exceptional unit. This behavior would have been impossible had the exceptional unit been distinguishable only by its position in the series. The units were plainly not alike for the rats, but the exceptional one was recognized by them through some local cue resident in that unit.

Shepard then performed a series of experiments to locate this cue. These tests are briefly restated here to show the evidence upon which the existence of a floor cue was based.

Vision. To destroy any general orientation in the experimental room, the alley walls of the maze were made much higher than they had been during the learning period. This had the effect of sharply reducing the visual field about the animal, but no disturbance appeared in the maze habit as a result of the change. Negative results also followed the shifting of the maze platform to new locations in the room.

Various tests in darkness were now carried out. Sometimes the rats were brought to the experimental room in darkness and inserted into the maze in the dark, but allowed to make their run with lights turned on. At other times they were carried about the room in darkness before being put into the maze, lest they get a cue from the experimenter's route to the maze. All these tests had negative results. Finally they were forced to make their runs in darkness also. After a few hesitant trials the rats were able to run as well as before. We must conclude that vision was not an essential cue in enabling the rats to run the unit-alike maze correctly no matter where dropped in.

Tests for cues from the walls. To test the possibility that local cues arose from slight curvatures in the maze walls of the various units, drawings were made of these imperfections, and then the walls were trued up with a straight-edge. Still the rats were not disturbed. Crooks and turns were thrown into the walls in an opposite direction, but the rats appeared not to notice the change. In a final test for cues of any sort from the walls, the maze was torn down, the panels comprising the walls were thoroughly shuffled, and the pattern rebuilt. There was still no change in the rats' performance. These tests seemed to eliminate the possibility of a cue of any description from the walls of the maze.

Olfaction. In one test, the surface of the alleys was wiped off with water after each run. In another, olfactory trails, if present, were falsified by rotating the squares of linoleum floor-covering at the junctions through 180°, so that the trail which formerly led to the true path would now lead into the blind alley. After both tests the rats continued to run without error. This would seem to eliminate olfaction.

Floor cues. Slight slopes and sags in the floor which might have acted as cues were radically altered by elevating the center of the maze with building jacks. The rats were not thrown off.

The floor-pieces which lay in the alley immediately preceding the junction were now taken up and interchanged, so that the piece lying in the alley of the exceptional unit was laid down in the corresponding alley of the preceding unit. Now for the first time the rats showed strong signs of disturbance. When they arrived at the spot where the interchange had occurred, all seemed confused, and many gave the exceptional reaction at the unit preceding the accustomed one.

This indicated that the cue used by the rats in locating the exceptional unit lay in the floor of the maze. Subsequent tests abundantly verified this. For example, rats which had been running the maze without error on the linoleum floor, when changed to a floor composed of ½ inch hair-felt covered with rubber sheeting and black percale, behaved as if in an entirely new situation. They not only were unable to run the pattern, but could not even relearn to do so, indicating that for them the cue had been eliminated. When the pattern was shortened, however, they were able to learn one (or at most, two) standard units followed by the exceptional unit, and were unable to regain their orientation if the routine were departed from. Rats which were trained on this floor of felt, however, were able to get the cue from it, and were able to orient themselves to the exceptional unit no matter where dropped into the maze.

Due to the uniform nature of the floor-coverings used, and to the fact that changes in the sub-floor produced more serious disturbances in the performance of the rats than changes of the surface covering, Shepard believed that the floor-cue was of auditory character rather than tactual, and was produced by the resonances set up in the floor by the foot-beats of the running animal. Attempts were made to find a flooring which would be of such uniform character that no differential sounds would be given off in different parts. Among other materials tried were rubberized nainsook, hair felt, cotton batting, 1/16 inch lead strips, and Masonite "pressed wood". Sooner or later, the animals were able to get a differential cue from each of these, and to run any number of like-units without error. This evidence as to the nature of the floor-cue, together with the failure to find any floor which would be uniform for the rats, was the background of the present experiment.

Curtis (1931) attempted to bring the floor cue under control, and to study the learning of the unit-alike maze when kinaesthesis was the only cue allowed the rat. He used a unit-alike maze similar in plan to that used in the present study (see p.26a). The floor of this maze was composed of sand,

$1\frac{1}{2}$ inches deep, over which was spread black oil-cloth. Six rats were given a long period of training on two standard units, followed by one exceptional unit. When this three-unit combination was mastered to the extent of the rats' ability, a series of test runs was given, in which the rats were dropped into the maze at points other than their regular starting point. Results showed that the rats tended to run off a kinaesthetic pattern of three units, no matter where started in the maze, rather than to pick out the exceptional unit by means of some local cue. Curtis concluded therefore that the rats were not receiving any cues from the floor or elsewhere which would distinguish the exceptional unit from the others in the series.

However, the result of this experiment was not as clear-cut as could be desired, because the rats had never mastered the three-unit pattern with great accuracy, even after long training. A second experiment was therefore performed, in which the rats were trained to run a pattern of only two units, one standard unit followed by the exceptional unit. This combination was readily learned to a high performance level. Then a test series was given as before, with the rats being dropped into the maze at points preceding and following the entrance point used during training. Now, even more certainly than before, the rats ran off a pattern of two units no matter where started in the maze, and without apparent regard for the old exceptional unit to which they had formerly reacted.

Curtis concluded from these experiments that:

(1) "It is possible to construct a maze which will afford the rat no environmental cues, and in which his learning may be shown by positive test to be kinaesthetic in character.

(2) "The control of floor cues may be effected by use of a floor composed of a deep layer of sand, covered with some uniform material such as oilcloth.

(3) "On a simple unit-alike maze, rats can learn to give a different reaction to one of the units on the basis of its ordinal position in the series, provided that not more than one standard unit precedes the exceptional one." (p. 68)

STATEMENT OF PROBLEM

The experiments of Shepard and Curtis have emphasized the following facts concerning the sensory control of the maze:

(1) On many types of floor, rats are able to distinguish a cue which the majority of them use as the primary cue in maze learning.

(2) On the sand floor, kinaesthesis apparently dominates over local cues in learning the unit-alike maze.

The question arises: Do rats learn kinaesthetically on sand floor mazes because cues from the floor and other parts of the environment are lacking, or simply because such cues are reduced enough so that kinaesthesis is easiest? In other words, can rats be forced to learn the unit-alike maze in terms of local cues, when kinaesthetic cues are made unreliable? The present experiment seeks to answer this question; specifically, it proposes:

(1) To subject the sand-floor maze to a more rigorous test, by determining whether rats can learn this maze in the absence of reliable kinaesthetic cues.

(2) To study the influence of various degrees of floor control upon the learning of the unit-alike maze.

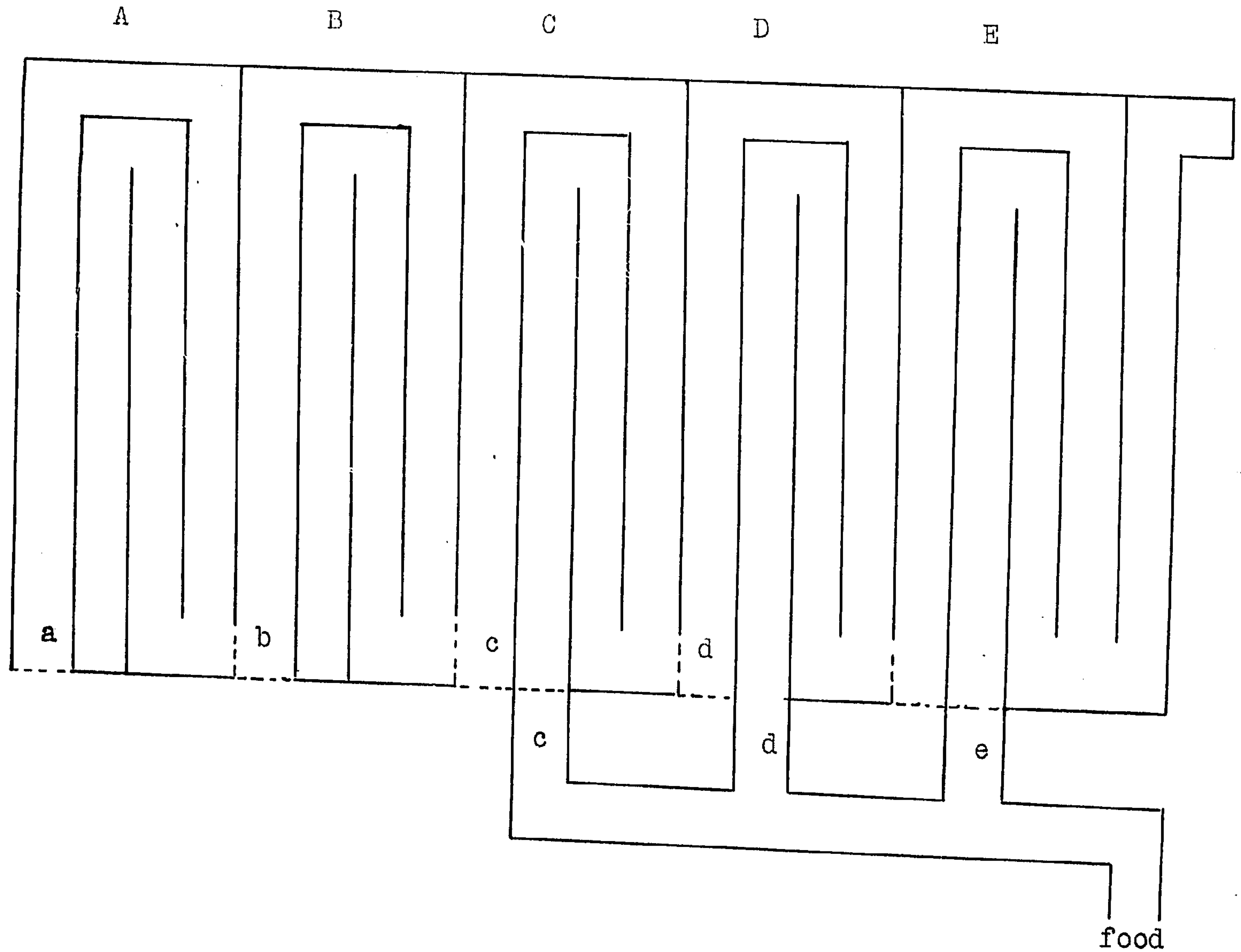

Figure I

Diagram of the Unit-Alike Maze

APPARATUS

The various experiments of this investigation were carried on in two rooms, both located on the ground floor of the science building. The floors were of concrete, and there were no large objects of furniture in the room except the maze.

The unit-alike maze pattern was essentially that devised and used by Shepard (1928) and used by Curtis (1931). It is the simplest unit-alike pattern which brings both entrance and exit points on the same side of the maze, and allows easy modification of these points from outside the maze. The pattern is shown in Figure 1. It will be seen that there are five identical units and part of a sixth. The junctions are all alike, the right-hand turn leading into a blind alley and the left-hand turn leading into the next unit. Any one of the units can be converted into the "exceptional" unit by lifting out the partition at the end of the blind alley, transforming it into the food-box alley, and by blocking off the next unit at the upper turn to form a cul-de-sac. These changes make it necessary for the rat to turn right for the true path, while a left turn leads into the blind.

Any one of the units may be converted into the starting point of the maze by blocking off the unit which precedes it. The partitions which block off one unit from another, form the ends of blind alleys and starting gates at entrances to all units, are made of thin sheet metal, the gates sliding up and down in grooves cut into the maze wall.

In some of the experiments, the maze walls were fashioned of pine boards, 7 inches high and $\frac{1}{2}$ inch thick. In others, the maze was built up from universal sections like those used by Shepard. These sections were made of beaverboard panels $4\frac{1}{2}$ inches by 7 inches, which fitted into $1\frac{1}{4}$-inch square posts grooved on all four sides to receive the panels. The maze was covered with $\frac{1}{2}$-inch wire mesh, to prevent the rats from climbing out or looking over the alley walls.

A rectangular wooden frame was constructed to straddle the maze, being supported by four short legs at the corners. A row of 6-volt lamps with square cardboard shades was strung longitudinally on this frame, spaced so that lights occurred above corresponding points in each of the units of the maze pattern. Lights also extended out beyond the end units of the maze, spaced in the same manner, for a distance of one unit. The frame also supported panels of beaverboard which extended from the level of the lights down to the maze itself, and which served to separate each unit of the maze from its neighbor on either side. In this way, the units were rendered indistinguishable from one another in the degree and arrangement of illumination.

Just over the lights, and supported by the wooden frame, was spread a cheesecloth cover. The thin cloth was large enough to cover the frame and drape to the floor on each side. Since the lights were inside this cover and the room outside was darkened, it was easy for the experimenter to see through the cloth to observe the rats in the maze, while it would be difficult for the rat inside to see out. The rat was thus given an apparently uniform visual environment in each unit, and visual cues from the experimenter or the maze room were as far as possible eliminated.

The food-box at the end of the maze was located outside of this gauze cover. A special alley, also outside the cover, connected the end of each blind alley with the food-box, so that by lifting the gate at the end of the blind, it could be converted into a true path leading to the food-box.

PROCEDURE

Subjects: The rats used in this investigation were tame white animals about eight months old when the experiments began. With the exception of one group, which will be discussed later, they had had no previous experience in the maze. In all, 30 rats were used.

Methods: Every effort was made to maintain a regular routine in the handling and running of the rats. The number of runs given each day was six in some of the experiments and nine in others. The rat was brought from the animal room, placed in the maze at the proper starting point, and allowed to make his run. As he approached the end, the experimenter pulled a string opening the door to the food-box and shutting it after the rat had passed through. This prevented retracings after the rat was in the box. During the run, the experimenter remained in the room, but stood quiet to prevent auditory cues, and was of course screened from the sight of the animal by the gauze curtain across the top of the maze.

Throughout any one phase of the experiment, the exceptional unit containing the exit to the food-box remained the same, so that the rats could learn to locate this unit by means of any environmental cues they could obtain, from the floor or elsewhere. But the starting point of the maze was varied from trial to trial, according to a pre-arranged schedule, so that kinaesthetic cues would never furnish a reliable guide to the location of this exceptional unit. In other words, the number of units of the maze which the rat must traverse to reach the food-box was varied continually. In most of the experiments, the number of units through which the rat was required to run was two, three, or four.

The schedules of entrance points for both 6 and 9 runs daily are given below. It is assumed that the exit point is located in unit D. (See Fig. 1.)

Table 1

STARTING POINTS FOR 6 OR 9 RUNS DAILY

(read down)

Trial												
1	A	B	C	A	B	C	A	B	C	A	B	C
2	B	A	A	B	A	A	C	C	B	C	C	B
3	C	C	B	C	C	B	B	A	A	B	A	A
4	C	B	B	A	C	C	A	A	C	B	B	A
5	B	C	A	C	A	B	B	C	A	C	A	B
6	A	A	C	B	B	A	C	B	B	A	C	C
7	B	A	A	B	A	A	C	C	B	C	C	B
8	C	C	B	C	C	B	B	A	A	B	A	A
9	A	B	C	A	B	C	A	B	C	A	B	C

It will be seen that there are 12 different combinations in which the day's work of 6 or 9 runs might be given, and these 12 combinations were used in rotation. Unless this complicated order of entrance points was memorized by the rat, he could obtain no reliable kinaesthetic cue to tell him how far he must run before arriving at the exceptional unit of the maze. Another feature of the running schedule which should be noted is that each day's work contains the same number of runs from entrances A, B, and C. Only in this way can one day's work be compared with another, since results show that the runs from the various starting points are not equal in difficulty. Rats have more chances for error when they are started at entrances farther away from the food-box.

Since this experiment is not concerned with the rate of learning of the maze, but only with the degree of final proficiency and the sensory cues used in the completed maze habit, the rats were permitted to obtain their first familiarity with the maze by free exploration. They were placed in the maze for about 2 hours daily during the first week and allowed to explore at random. Then they were removed from the maze and fed in the food-box. In this way, the food association was established, initial timidity in the maze situation was overcome, and a certain amount of learning of the maze pattern had occurred before records were begun.

It may be readily seen that if the rat runs off any sort of consistent kinaesthetic pattern in this maze, his score of errorless runs cannot be greater than $33\frac{1}{3}\%$. If he should adopt the habit of turning left at each junction, or right at each junction, his score would be zero. If he should run 2, 3, or 4 units before giving the exceptional reaction, one-third of his runs will be correct. A rat which consistently makes more than 1/3 of his runs correctly may be assumed to be receiving some exteroceptive cue which assists him in locating the exceptional unit.

When the rats had learned the maze to the point where no further improvement was shown in their scores, as measured by the number of errorless runs in each day's work, a series of tests was begun. These tests were alterations of various features of the maze environment, to find out the nature of the sensory cues being used by the rat.

RESULTS

Throughout the results, our criterion of performance in the maze is based on the error record rather than on time or number of trials required. This is because we are particularly interested in the *kind* of mistake made in learning the maze and in adapting to the various changed situations which we presented to the rat. An "error" in this experiment is defined as any entrance into a cul-de-sac in which the rat gets at least his head and shoulders into the blind. Mere hesitations at the blind without turning into it were not considered errors.

In recording, the errors made at the various blind alleys were kept separate, so that a complete analysis of the behavior at each blind could be made. However, in tabulating the results, only the *first* error made by the rat in any one trial was counted. This procedure was adopted for the following reasons: (1) the first error seems more significant than the others in the information it gives as to the kinaesthetic or exteroceptive cues the rat may have been using; (2) since the rat tended to enter all the blinds along the route, after having made one error, counting all errors would have the effect of "weighting" unduly the trials made from entrances farther removed from the food-box, where there were more errors to be made. By counting only the first error, we treat the problem as though the rat were "aiming" at the exceptional unit, and we score his success by the distance his first shot lands from the mark.

In each of the experiments to be reported, the rats were given equal numbers of runs each day from 3 different entrance points, A, B, and C. The distance of the exit (where the exceptional turn had to be made) was 4, 3, and 2 units respectively from these starting points. Since this method of running the rats prevented accurate localization of the exceptional unit in terms of kinaesthesis, we wished to discover whether or not there were local sensory differences between the units which would enable the rats to make better than a chance score.

We must inquire here just what a "chance score" would be in this maze situation. When started from entrance C, the rat arrives at two junctions, at both of which he may turn either left or right. Since only one combination of turns is correct, namely, a left turn at the first junction and a right turn at the second, the chances are 1 out of 4, or 25%, that he will choose correctly on the basis of chance. When started from entrance B, there are three junctions or choice-points, and only one combination of correct turns, L L R. The chances, then, are 1 out of 8, or 12½%, that this combination will be run off. When started from entrance A, there are 4 choice-points, requiring the reaction L L L R. Here the likelihood is 6¼% that the combination will be given by chance. Since equal numbers of runs are given from each of these starting points, the <u>mathematical</u> chance score for the whole combination is the average of these chance scores, or 14.58% of correct runs.

However, rats placed in a problem situation of this kind never make their responses completely at random, as Krechevsky (1932) has well shown. In the unit-alike maze, even after 1 or 2 trials, they begin to make responses in an orderly manner, seemingly dictated by kinaesthesis. A common response in early learning is to make right turns at all choice points, or left turns at all choice points. As training progresses, most of the animals begin to run patterns like L R R R, L L R R, or L L L R. In other words, the rat learns that the right turn, which is correct for the exceptional unit but incorrect for the standard units, is to be held in abeyance until at least one unit has been traversed. After the right turn is released, it is usually given at every junction until the critical (exceptional) turn is reached. Reactions like these, in which the animal turns left at the first junction, and gives the right turn some time after that, will result in scores of about 33⅓%.

In this experiment, therefore, a score of more than 1 out of 3 correct runs will be taken as evidence that the rat is detecting some sensory difference in the units of the maze which serves to locate the exceptional unit for him with greater accuracy than kinaesthesis is able to provide.

EXPERIMENT 1

THE RUBBER-COVERED SAND FLOOR

The first experiment sought to duplicate the maze of Curtis' (1931) study. To this end, the floor of the unit-alike maze was composed of a bed of sifted lake sand, $1\frac{1}{2}$ inches deep, laid down directly on the concrete floor of the maze room. Over the bed of sand was spread double-coated red rubber sheeting. The maze pattern was built up from small universal sections already described, and rested directly on this floor. A group of 10 rats was given a long period of training on this maze, and 7 completed it. They were given 6 trials a day according to the 6-run schedule (p. 31). They had 2 runs each from entrances A, B, and C, and the exceptional turn was located in unit D, so that the rats had to run through 2, 3, or 4 units to reach it.

Table 2 shows the final proficiency of 7 rats in running this pattern, being based on the last 30 trials of each rat. It shows the percent of times that the exceptional reaction (the right turn) was given in each unit of the maze. The reaction is correct in unit D, but incorrect in all the others. When the exceptional reaction is given in units A, B, or C, the error is one of anticipation; when given in unit E, of perseveration.

The most salient feature of Table 2 is the large percent of correct responses made in the exceptional unit, D. The

Table 2

MASTERY OF THE RUBBER-COVERED SAND FLOOR

		Units				
Rat	Entrance	A	B	C	correct D	E
10	a	0	0	10	90	0
	b	-	0	20	80	0
	c	-	-	0	100	0
					av. 90	
20	a	0	0	30	60	10
	b	-	10	20	60	10
	c	-	-	0	80	20
					av. 66	
22	a	0	10	10	80	0
	b	-	0	0	100	0
	c	-	-	0	80	20
					av. 86	
23	a	0	10	20	70	0
	b	-	10	0	90	0
	c	-	-	0	100	0
					av. 86	
24	a	10	10	30	50	0
	b	-	10	10	80	0
	c	-	-	0	90	10
					av. 73	
25	a	10	0	20	70	0
	b	-	0	10	90	0
	c	-	-	0	100	0
					av. 86	
26	a	0	10	10	80	0
	b	-	10	10	80	0
	c	-	-	0	90	10
					av. 83	
Average	a	2.8	7.1	18.6	71.4	1.3
	b	-	5.7	10.0	82.8	1.3
	c	-	0	0	91.4	8.6
					av. 81.9	

Percent of right turns made in each unit. N = 30 trials.

exceptional reaction is given more frequently in unit D than in any other unit, no matter whether D comes second, third, or fourth in the series of units through which the rat runs. This means that the preponderance of correct responses in unit D cannot be attributed to kinaesthesis, but must be due to some sensory differences between the units which the rat is able to discriminate.

The next step is to determine the nature of this cue upon which the rats are relying, and attempt to eliminate it. With this in mind a series of tests was undertaken, in which various features of the maze environment were altered, one at a time, to see which changes would cause the animals to be disturbed in their performance. Summaries of these tests follow.

Vision. The possibility that visual cues from the maze environment may have enabled the rat to pick out the exceptional unit was tested by running the animals in total darkness. Table 3 shows the number of times the exceptional reaction was given in each unit of the maze on the day of the test, as compared with the three days preceding and one day following the tests. The numbers shown on the table are the total of 7 rats x 6 trials (N equals 42).

Table 3

EFFECT OF RUNNING RATS IN DARKNESS

		Units				
		A	B	C	correct D	E
Days preceding	3	0	0	7	34	1
	2	0	1	2	39	0
	1	3	4	11	22	2
	Test	3	6	12	18	3
	Test	1	1	8	32	0
Day following	1	2	0	12	27	1

Number of right turns given in each unit, out of a possible 42 (7 rats times 6 trials).

The table shows that on the first night of running in darkness, the rats made fewer correct responses in unit D than they had on any of the 3 preceding nights. We may take this as a rough indication that the test produced an effect on the rats' behavior. They also tended to give the exceptional reaction too early in the series, at units B and C. However, on the second night of the test the rats made a normal score and even showed improvement over the first night preceding the tests. We may conclude that running in darkness disturbs the rats slightly at first, but that this effect disappears within 6 trials. Vision therefore is probably not a primary cue in this maze situation.

Olfactory and tactual cues. To test the use of olfactory or tactual cues arising from the concretions on the rubber floor, the portions of the maze near the junctions were torn down and the floor washed with soap and four changes of clear water. The pattern was then rebuilt on the same location as before. Table 4 shows the results of this test, in terms of the number of right turns given at each of the units, out of a possible 42 (7 rats times 6 trials).

Table 4

EFFECT OF WASHING FLOOR AT JUNCTIONS

		Units				
		A	B	C	correct D	E
Days preceding	3	1	0	4	34	3
	2	1	1	6	31	3
	1	0	1	10	30	1
	Test	0	0	10	25	7
Day following	1	0	0	8	32	2

Number of right turns given in each unit, out of a possible 42 (7 rats times 6 trials).

It will be seen that the rats make fewer correct right turns in unit D on the test day than they did on the three days preceding the test. There was a slight tendency for them to delay the right turn until unit E was reached. Apparently some disturbance resulted from washing the floor of the maze, but it was very slight and had disappeared by the next day.

Floor cues. A more critical test of the use of cues from the floor covering is to alter its position with respect to the rest of the maze. The maze was therefore torn down and the rubber sheeting was moved one unit to the left (toward the beginning of the maze); the portion of the rubber sheet which formerly lay under unit D now lay under unit C. The maze pattern was then rebuilt. Any cues emanating from this floor covering will tend to cause the rats to give the exceptional reaction in unit C rather than in unit D. The blind alley of unit C was now connected with the food-box, as well as that of D, so that whichever the rat chose he would receive his reward. Table 5 shows the result of this test.

Table 5

EFFECT OF MOVING RUBBER CLOTH ONE UNIT TO LEFT

		Units				
		A	B	C	correct D	E
Days preceding	2	0	0	8	33	1
	1	0	1	6	34	1
	Test	0	1	33	6	2
Days following	1	1	4	23	14	0
	2	0	3	19	16	4

Number of right turns given in each unit, out of a possible 42 (7 rats times 6 trials).

Here for the first time we see a profound reaction to the changed maze. On the 2 days preceding the test the rats correctly gave the exceptional reaction in unit D about 34 times out of a possible 42. When the floor covering was moved, however, the exceptional reaction was given in D only 6 times, while it was given 33 times in unit C. Moreover, this effect persisted for several days after the test. It seems likely, therefore, that the primary cue which differentiated unit D from the rest of the series was derived from the rubber cloth floor of the maze.

The next step was to remove the rubber cloth from the floor entirely, and to see whether the rats' ability to give the exceptional turn at the correct point in the maze disappeared. The rats were drilled on the rubber cloth floor until the effects of displacing it had worn off, then the maze was torn down once more and the cloth was removed entirely. Now the rats were running on bare sand. Effects of this change are shown in Table 6.

Table 6

EFFECT OF REMOVING RUBBER CLOTH

		Units				
		A	B	C	correct D	E
Days preceding	3	0	0	11	29	2
	2	2	1	4	33	2
	1	0	7	4	30	1
	Test	5	2	13	17	5
Days following	1	1	9	12	20	0
	2	1	6	8	25	2

Number of right turns given in each unit, out of a possible 42 (7 rats times 6 trials).

As would be expected, if our hypothesis that they were deriving their primary cue from the rubber cloth were correct, the rats broke down entirely when the rubber cloth was removed and they were forced to run on bare sand. Table 6 shows that for 3 days before the test, the right turns were concentrated in unit D, where they were correct. But when the rubber cloth was removed, this discrimination broke down, and the exceptional reactions were given almost equally in units C and D, and to a lesser extent in B and E. This degree of accuracy is little more than kinaesthesis can provide. A second experiment was therefore undertaken to test the learning of the unit-alike maze on a floor of bare sand.

EXPERIMENT 2

THE $1\frac{1}{2}$-INCH BARE SAND FLOOR

Since Experiment 1 showed that rats obtained a cue from the rubber cloth cover of the sand floor maze, a floor of bare sand offered the possibility of controlling the floor cue. The 7 rats which had completed Experiment 1 were given 6 trials a day on the bare sand floor unit-alike maze. They were started from units A, B, and C, according to the 6-run schedule, and were required to turn left at all junctions except in unit D, where the exceptional (right) turn was correct.

Table 7 shows the degree of mastery attained by the rats on the bare sand floor. The table is based on 99 consecutive trials of each rat, taken after their scores showed no further improvement. It shows that the unit-alike maze is not learned to such perfection on the bare sand floor as on the rubber cloth floor. The exceptional reaction is given in unit D only 66.6% of the time, as compared with 81.9% on the former material. The success of the rats when started at entrance C is not much different in the two cases, but the trials from entrances A and B are much less successful on the bare sand floor than on the rubber cloth.

However, the rats do not run an invariable kinaesthetic pattern, no matter where dropped in the maze. When started at entrance a, they give the exceptional reaction mostly in unit C or unit D, 3 or 4 units away. When started at b, they give the reaction 71% of the time in D, a distance of 3 units. But

Table 7

MASTERY OF THE 1½-INCH BARE SAND FLOOR

Rat	Entrance	A	B	C	D (correct)	E
		Units				
10	a	5.	5.	37.2	52.	0.8
	b	-	4.8	11.4	83.8	0.
	c	-	-	1.1	97.8	1.1
					av. 77.8	
20	a	5.2	5.2	29.6	58.5	1.7
	b	-	5.8	22.1	71.1	1.0
	c	-	-	6.2	73.2	20.6
					av. 70.7	
22	a	0.85	10.0	35.8	52.5	0.85
	b	-	6.5	18.7	70.1	4.7
	c	-	-	6.9	77.4	15.7
					av. 66.7	
23	a	3.3	2.5	39.3	53.3	1.6
	b	-	1.9	14.1	82.1	1.9
	c	-	-	3.9	88.3	7.8
					av. 63.3	
24	a	5.0	10.1	40.8	43.2	0.9
	b	-	7.6	24.5	63.2	4.7
	c	-	-	9.3	74.2	16.5
					av. 60.2	
25	a	7.4	18.0	54.9	18.9	0.8
	b	-	6.3	33.3	58.6	1.8
	c	-	-	7.6	84.8	7.6
					av. 54.1	
26	a	1.6	8.0	48.0	42.4	0.
	b	-	4.6	24.1	70.4	0.9
	c	-	-	2.0	83.2	14.8
					av. 65.3	
Average	a	4.05	8.40	40.8	45.80	0.95
	b	-	5.36	21.17	71.33	2.14
	c	-	-	5.29	82.70	12.01
					av. 66.6	

Percent of right turns made in each unit. N = 99 trials.

when started at c, they turn right in D 83% of the time, a pattern of only 2 units. There must be some sensory differences between the units which enable the rats to react differently when started from the different entrance points. To discover what these differences were, another series of tests was undertaken.

Visual cues. The rats were run for 2 days in total darkness. The results of this test are given in Table 8.

Table 8

EFFECT OF RUNNING RATS IN DARKNESS

		Units				
		A	B	C	correct D	E
Days preceding	3	1	3	12	26	0
	2	1	8	7	25	1
	1	1	1	4	36	0
	Test	3	8	4	27	0
	Test	0	8	4	30	0
Day following	1	0	2	10	30	0

Number of right turns given in each unit, out of a possible 42 (7 rats times 6 trials).

On the first night of running in darkness there was some decrease in the number of correct responses at D, as compared with the previous night, and a slight tendency to make the exceptional response too early in the series. On the second night of running in darkness the runs seem perfectly normal. We must conclude that vision is at least not an essential cue in determining the behavior of the animals in this maze situation.

Floor cues. The next tests were designed to show whether the floor was again furnishing the cue by means of which the exceptional unit was differentiated. The scores made by the rats on 3 test days are given in Table 9. On the first test the sand floor was stirred and leveled by means of a blast of compressed air. On the second day, a layer of fresh sand was sprinkled about ½ inch deep around the junction in each unit. On the third day, the sand was mechanically stirred at the junction and down the length of the alley preceding the junction. Table 9 shows that the effect of these changes was to decrease the maze score progressively from day to day, so that recovery did not begin until the second day following the tests.

Table 9

EFFECT OF ALTERING SAND AT JUNCTION AND PRECEDING ALLEY

		Units				
		A	B	C	correct D	E
Day preceding	1	0	2	9	31	0
	Test	0	5	7	27	3
	Test	2	5	15	20	0
	Test	2	4	16	19	1
Days following	1	0	2	23	17	0
	2	0	4	13	25	0

Number of right turns given in each unit, out of a possible 42 (7 rats times 6 trials).

After the rats had recovered from the effects of these alterations of the maze floor, the tests were repeated. Table 10 shows an attempt to disturb the rats once more by covering all the alleys of the maze with $\frac{1}{4}$-inch of fresh sand. To the surprise of the experimenter, this time there was no observable effect upon the animals' score. The sand of the whole maze was then leveled and stirred thoroughly with the air-blast on 2 successive days. Still there was no effect; the rats ran as though they did not notice the change. These tests are shown in tables 10 and 11.

Table 10

EFFECT OF COVERING MAZE WITH FRESH SAND

		Units			correct	
		A	B	C	D	E
Days preceding	3	0	4	15	22	1
	2	1	3	12	26	0
	1	0	6	11	25	0
	Test	0	4	13	22	3
Day following	1	2	5	7	26	2

Number of right turns given in each unit, out of a possible 42 (7 rats times 6 trials).

Table 11

EFFECT OF STIRRING SAND

		Units				
		A	B	C	correct D	E
Days preceding	3	0	0	7	35	0
	2	1	1	6	33	1
	1	1	0	9	30	2
	Test	1	1	8	30	2
	Test	0	2	4	33	3
Days following	1	0	0	10	28	4

Number of right turns given in each unit, out of a possible 42 (7 rats times 6 trials).

Two theories were suggested to account for the consistent performance of the rats in spite of these alterations of the floor. (1) The animals may have been capable of extremely rapid adaptation to changes in the floor cue, so that, even when the cue was altered by stirring the sand, they could relearn in terms of a new floor cue in a few trials. (2) The animals may have been responding to a sensory difference derived from the deepest layers of the floor, which cue was not destroyed by shifting the sand or placing fresh layers on top of the old.

To test the first hypothesis, that of extremely rapid adaptation to changes, the exceptional unit was moved from D to E. The rats were now started from units B, C, and D. Thus the exceptional unit was still 2, 3, or 4 units from the starting points, and all features remained the same except that a persistent floor cue would tend to make the rats give the exceptional turn at D. Rapid adaptation to changes, on the other hand, would cause the rats quickly to adopt the habit of giving the exceptional reaction at E.

Table 12

EFFECT OF CHANGING EXIT POINT OF MAZE

		Units					
		A	B	C	correct D	E	F
Days preceding	3	0	0	11	31	0	
	2	0	0	12	29	1	
	1	0	1	15	25	1	
Test	I		0	0	27	13*	2
Test	I		0	2	26	12*	2
Test	I		0	0	26	10*	6
Test	II	0	1	5	31	5	
Test	II	2	3	5	32	0	

Number of right turns given in each unit, out of a possible 42 (7 rats times 6 trials).

* Correct exit.

Test I. Entrances at B, C, D. Exit at E.

Test II. Entrances at A, B, C. Exit at D.

Table 12 shows the result of this test. It is apparent that the rats did not adapt quickly to the change. At the end of three days of this test they are still giving the exceptional reaction in unit D as frequently as before, although this is now incorrect. The only adaptation comes in the increased frequency with which the exceptional reaction is given in Unit E. These cases occur mostly when the rats are started in unit D, when E is only 2 units away.

EXPERIMENT 3

THE $3\frac{1}{2}$-INCH SAND FLOOR

To test the second hypothesis mentioned above, that rats gain a cue from some sub-stratum of the floor which is not affected by disturbance of the surface, a completely new maze was built. A heavy wooden platform supported by steel rollers was constructed, large enough to support the whole maze. A bed of sand $3\frac{1}{2}$ inches deep covered with a thin black cloth was laid over this platform, and the unit-alike maze was built on top of all. This maze had the advantage of being moveable in the maze room so as to test the effect of general environmental cues as opposed to cues within the maze.

A group of 11 rats was given an extensive period of training in this maze. They were started from entrances in units A, B, and C, according to the 6-run schedule, while the exceptional unit was located in D.

Table 13 shows the final proficiency of the rats in running this maze. It is based on the last 99 trials which they ran, and gives the percent of right turns made in each unit of the maze. Two of the rats, #32 and #36, quickly adopted a kinaesthetic rhythm which they ran no matter where started in the maze. #32 gives the right turn in the first junction he arrives at about 80% of the time, while #36 gives the right turn at the first junction about 67% of the time. Neither of these rats shows any evidence of responding differently when

Table 13

MASTERY OF THE $3\frac{1}{2}$-INCH SAND FLOOR

		Units				
Rat	Entrance	A	B	C	correct D	E
20	a	6.	3.	57.7	33.3	0.
	b	-	0.	30.3	66.7	3.
	c	-	-	3.0	81.8	15.2
					av. 60.6	
25	a	0.	27.3	48.5	24.2	0.
	b	-	6.0	36.3	57.6	0.
	c	-	-	3.1	63.6	33.3
					av. 48.4	
31	a	12.2	0.	33.3	54.5	0.
	b	-	3.	36.4	60.6	0.
	c	-	-	6.0	93.9	0.
					av. 69.3	
32	a	81.8	18.1	0.	0.	0.
	b	-	78.7	15.2	6.1	0.
	c	-	-	87.8	12.1	0.
					av. 6.0	
33	a	0.	3.1	42.4	54.5	0.
	b	-	0.	21.3	78.7	0.
	c	-	-	0.0	93.9	6.1
					av. 75.7	
34	a	0.	6.1	42.4	48.4	3.
	b	-	0.	9.1	87.8	3.1
	c	-	-	0.	84.8	15.2
					av. 73.7	
35	a	21.3	39.3	27.3	12.1	0.
	b	-	15.1	39.4	36.4	9.
	c	-	-	12.1	81.9	6.
					av. 43.4	
36	a	66.7	30.3	3.	0.	0.
	b	-	66.7	27.2	6.1	0.
	c	-	-	72.7	24.2	3.
					av. 10.1	

Table continued

Table 13 - continued

Rat	Entrance	Units A	B	C	correct D	E
37	a	0.	3.	30.3	63.7	3.
	b	-	0.	6.	93.9	0.
	c	-	-	3.	87.8	9.1
					av. 81.8	
38	a	3.	3.	15.1	78.8	0.
	b	-	0.	0.	100.0	0.
	c	-	-	0.	100.0	0.
					av. 92.9	
39	a	12.1	3.0	33.3	51.6	0.
	b	-	3.0	24.3	72.9	0.
	c	-	-	6.0	90.9	3.
					av. 71.8	
Average omitting #32 and #36	a	13.4	9.7	35.6	46.8	0.6
	b	-	3.3	22.6	69.4	0.5
	c	-	-	3.2	79.5	8.0
					av. 65.2	

Percent of right turns made in each unit. N = 99 trials.

started at the different starting points, so they probably were guided by kinaesthetic cues alone. The other 9 rats all respond differentially to the different starting points, and make an average success at the exceptional unit of 65.2%. They must have been detecting local cues of some sort to make this score.

Some feature of the floor was thought to be the most likely source of these cues. The black cloth covering the sand floor was first suspected. Its influence was tested by tearing the maze down and moving the cloth 1 unit to the left. Table 14 shows that no effect of any kind on the rats' behavior was to be observed as a result of this change.

Table 14

EFFECT OF MOVING FLOOR COVERING ONE UNIT TO LEFT

		Units				
					correct	
		A	B	C	D	E
Days preceding	3	1	3	2	47	1
	2	0	2	4	44	4
	1	0	2	8	41	3
	Test	2	1	4	46	1
Day following	1	0	2	8	42	2

Number of right turns given in each unit, out of a possible 54 (9 rats times 6 trials).

Environmental cues. The use of cues from the larger environment of the maze room was next tested. The detection of such cues by the rat was thought to be unlikely in view of the precautions taken with lighting, screening the maze with gauze, etc. However, the platform supporting the maze-floor and maze was moved 1 unit to the left in the maze room, and the superstructure of lights, separators between units, and gauze cover, was moved with it. Cues from within the maze should now cause the rats to give the exceptional turn at the usual point, unit D. Cues from the larger environment outside should cause the rats to run too far before giving the right turn, entering unit E. Table 15 shows the results of this test.

Table 15

EFFECT OF MOVING ENTIRE MAZE ONE UNIT TO LEFT

		Units				
		A	B	C	correct D	E
Days preceding	3	1	4	7	41	1
	2	2	6	5	39	2
	1	1	5	2	45	1
	Test	1	2	11	37	3
Day following	1	0	4	8	42	0

Number of right turns given in each unit, out of a possible 54 (9 rats times 6 trials).

There is indeed a disturbance attendant upon moving the maze in the larger environment, but the effect is one of generalized disturbance rather than of causing the rats to make the expected specific response to the cue.

This test was repeated a little later, when cues from the outer and inner maze environments were made to oppose each other in a different way. After the rats had recovered from the former test, the floor, maze, and superstructure were once more moved one unit to the left. This time, however, the starting points and exit points of the maze were displaced one unit to the right at the same time. Thus the rats ran through the same segments of the outer environment as before, but cues within the maze would tend to make them give the exceptional reaction 1 unit too early in the series. Table 16 gives the result of this test.

Table 16

EFFECT OF MOVING MAZE AND FLOOR ONE UNIT TO LEFT

		Units correct					
		A	B	C	D	E	F
Days preceding	3	2	6	4	35	1	
	2	0	7	6	35	0	
	1	1	1	1	45	0	
	Test	0	2	10	20	11*	5
Days following	1	0	1	7	26	12*	2
	2	0	1	2	29	14*	2

Number of right turns given in each unit, out of a possible 48 (8 rats times 6 trials).

* Correct exit.

Cues from within the maze or its floor will throw the rats into unit D. Cues from the outer environment or a kinaesthetic habit will throw them into E. Since unit E is chosen more often for the exceptional reaction during the test than on days preceding, there is an indication that the outer environment or kinaesthesis has some effect on the performance. Still more striking, however, is the fact that unit D continues to attract as many exceptional reactions as it does, in spite of the fact that responses in this unit are not rewarded, that it would be opposed by cues from the general environment and by any kinaesthetic component. It is evident from this test that the maze responses are primarily dominated by cues arising from within the maze itself.

The influence of cues arising from the sand of the floor was now studied. Tables 17 and 18 show the results of 2 tests made more than a week apart, in which the exceptional unit and the one preceding it (C and D) were torn down, the sand beneath them thoroughly stirred and interchanged, and the walls then replaced. On both tests there is a decided disturbance, as indicated by the decrease in right turns at unit D and the increase in these turns in adjacent units.

Table 17

EFFECT OF DISTURBING FLOOR IN UNITS C AND D

		Units				
		A	B	C	correct D	E
Days preceding	3	2	1	4	46	1
	2	0	2	8	42	2
	1	3	1	11	39	0
	Test	2	4	17	29	2
Day following	1	1	0	16	31	6

Number of right turns given in each unit, out of a possible 54 (9 rats times 6 trials).

Table 18

EFFECT OF STIRRING SAND IN UNITS C AND D

		Units				
		A	B	C	correct D	E
Days preceding	3	2	3	15	31	3
	2	2	0	16	34	2
	1	2	0	6	46	1
	Test	1	2	22	26	3
Day following	1	1	1	21	31	0

Number of right turns given in each unit, out of a possible 54 (9 rats times 6 trials).

Ten days after these tests, the same procedure was repeated, except that the test was made more rigorous by tearing down the whole maze instead of only two units, and thoroughly stirring up the whole sand floor. Some of the sand was removed from the bed and mixed in buckets; the remainder was raked from one end of the bed to the other. Finally the sand was levelled off and the maze rebuilt. Table 19 shows the result of this test. The rats showed no disturbance at all!

Table 19

EFFECT OF STIRRING AND INTERCHANGING SAND IN ALL UNITS

		Units				
		A	B	C	correct D	E
Days preceding	3	0	1	9	40	4
	2	0	3	16	33	2
	1	1	1	19	31	2
	Test	0	7	12	31	4
Days following	1	1	3	20	27	3
	2	0	3	16	31	4

Number of right turns given in each unit, out of a possible 54 (9 rats times 6 trials).

The fact that various alterations of the sand floor of the maze rapidly lost their power to disturb the maze-habit led to further experimentation.

EXPERIMENT 4

THE 9-INCH SAND FLOOR MAZE

The previous experiments with sand floor mazes seemed to show that: (1) most serious detriment to the maze habit was produced by disturbing the sand floor; (2) the effect of these disturbances rapidly diminished when repeated. To explain this fact, one theory was that the rats began using cues derived from the deep layers of the floor when cues from the surface layers were made unreliable by being frequently altered. To test this theory and to make one last attempt at constructing a sand floor which would not give differential cues, a unit-alike maze was built which had a sand floor 9 inches deep. The bed for this floor was made by elevating the walls of the platform used to support the maze in experiment three. The set-up of the maze was identical in every respect with that of the preceding experiment except that the sand floor is nearly 3 times as deep.

Eight of the eleven rats used in the preceding experiment were trained on this floor, #20 having died, and #32 and #36 having failed in the earlier experiment. They were given 9 runs a day from entrances A, B, and C. The exceptional unit was located at D.

Table 20 shows the degree of final mastery of this maze, based on the last 99 trials of each rat. In general, the scores of the rats are considerably reduced over those made on the

Table 20

MASTERY OF THE 9-INCH SAND FLOOR

		Units				
					correct	
Rat	Entrance	A	B	C	D	E
25	a	6.	36.	43.	12.	3.
	b	-	0.	60.7	39.3	0.
	c	-	-	9.1	90.9	0.
					av. 47.3	
31	a	9.1	36.7	39.8	15.0	0.
	b	-	3.0	63.7	33.3	0.
	c	-	-	9.0	78.8	12.2
					av. 42.3	
33	a	3.	18.1	54.7	24.2	0.
	b	-	0.	39.3	60.7	0.
	c	-	-	6.1	90.8	3.0
					av. 58.5	
34	a	3.	21.2	48.5	27.2	0.
	b	-	9.1	36.4	54.5	0.
	c	-	-	0.	72.7	27.3
					av. 51.1	
35	a	9.1	81.8	9.1	0.	0.
	b	-	21.2	69.7	6.1	3.0
	c	-	-	21.3	75.7	3.0
					av. 27.2	
37	a	0.	15.2	36.4	48.4	0.
	b	-	3.0	15.1	81.9	0.
	c	-	-	3.0	90.9	6.1
					av. 73.4	
38	a	0.	6.	33.3	60.6	0.
	b	-	0.	24.3	72.7	3.
	c	-	-	6.1	84.8	9.1
					av. 72.7	
39	a	15.0	24.2	27.3	33.4	0.
	b	-	9.1	48.4	39.4	3.
	c	-	-	3.0	93.9	3.
					av. 55.5	
Average	a	5.7	29.9	38.1	27.6	0.3
	b	-	5.7	44.5	48.4	1.5
	c	-	-	4.7	84.1	8.0
					av. 53.4	

Percent of right turns made in each unit. N = 99 trials.

$3\frac{1}{2}$-inch sand floor. One rat, #35, who scored better than chance on the shallower sand floor, is reduced to 27% correct responses in this maze, and seems to be running a kinaesthetic pattern of 2 units most of the time.

The average success on the 9-inch sand floor is 53.4% of correct responses to the exceptional unit, while on the 3-inch floor it was 65.2% and on the $1\frac{1}{2}$-inch floor 66.6%. The decrease in score is about 12%. Moreover, the drop is not due to the total failure of a few rats; every animal made a lower score on the 9-inch sand floor than on the 3-inch floor.

No tests were made to determine what cues were used in solving this maze. However, since the maze, environment, and subjects were all the same as in the preceding experiment, it seems fair to assume that the dominant cues used by the animals were also the same, and that the reduction in score on this maze was caused by the fact that cues from the 9-inch floor were more difficult to detect.

EXPERIMENT 5

THE CONCRETE FLOOR

A floor of solid concrete was next to be tested. The floor of a small room on the ground level was chosen for the purpose. The concrete was smoothed off with a carborundum brick, and a unit-alike maze was set up from universal sections, directly on this floor. The method of lighting and screening the maze was like that used in the sand floor mazes.

A group of 8 rats which had been previously used by Shepard in various maze problems was given a period of training on this maze. At the end of 50 trials, all but one of the rats were making scores far in excess of those made on the sand floor mazes. The training was continued for about 100 trials, with no further improvement in score.

Table 21 shows the scores made by 8 rats in their last 45 trials. Rat #116 is shown to be running a kinaesthetic pattern, since his scores are essentially the same regardless of where he is started in the maze. He gives the exceptional reaction at either the first or second junction. All the other rats discriminate the exceptional unit from the standard units with great success, averaging 87.3% correct responses in this unit.

No positive test was made of the factors influencing the running of this maze. There is a strong probability, however, that the dominant cue used by the rats came from the floor,

<u>Table 21</u>

MASTERY OF THE CONCRETE FLOOR

					correct	
Rat	Entrance	2	4	6	8	10
120	a	0.	6.66	20.	66.66	6.66
	b	0.	0.	0.	93.33	6.66
	c		0.	0.	93.33	6.66
					av. 84.44	
122	a	0.	26.66	13.33	60.	0.
	b	0.	0.	20.	73.33	6.66
	c		0.	0.	100.	0.
					av. 77.77	
123	a	0.	6.66	6.66	86.66	0.
	b	0.	0.	6.66	93.33	0.
	c		0.	0.	100.00	0.
					av. 93.33	
125	a	6.66	0.	33.33	60.00	0.
	b	0.	0.	0.	100.00	0.
	c		0.	6.66	86.66	6.66
					av. 82.22	
126	a	0.	0.	13.33	80.00	6.66
	b	0.	0.	13.33	86.66	0.
	c		0.	6.66	93.33	0.
					av. 86.66	
127	a	0.	0.	6.66	93.33	0.
	b	0.	0.	6.66	86.66	6.66
	c		0.	0.	100.00	0.
					av. 93.33	
128	a	0.	0.	6.66	93.33	0.
	b	0.	0.	6.66	93.33	0.
	c		0.	0.	93.33	6.66
					av. 93.33	
116	a	33.33	46.66	6.66	13.33	0.
	b		33.33	46.66	13.33	6.66
	c			33.33	60.00	6.66
					av. 28.88	
<u>Average</u>	for all rats except #116				87.29	

Percent of right turns given in each unit. N = 45 trials.

for the following reasons: (1) The set-up of the concrete floor maze was identical, as far as the experimenter could discern, with that of the sand floor mazes where the rats were found to be using the floor; (2) The only rat which failed to learn the concrete floor maze, #116, had previously failed to learn a unit-alike pattern on the maze platform used by Shepard, where the rats were shown to be using floor cues. This rat, then, probably failed on the concrete floor because he was not able to abstract a cue from either the floor of Shepard or the concrete floor.

EXPERIMENT 6

THE WIRE-MESH FLOOR

The final type of floor used in this investigation was composed of a strip of ordinary galvanized window screen, suspended at its two ends and stretched tightly across a frame which held it about 3 inches from the floor of the maze room. The screen was thus subjected to constant tension along the long axis of the maze. Beneath the screen, supporting sticks ran cross-wise of the maze, spaced exactly 1 maze-unit apart. The maze walls did not rest on this screen floor, but were suspended about ½ inch above it. The walls were made of pine boards, ½ inch x 7 inches, screwed to two long strips of pine, 1 inch x 4 inches, which supported them. The maze superstructure was the same as that used in all the unit-alike patterns already discussed.

Eleven rats were trained in this maze. Five of them had been used previously in the sand floor mazes, while the other 6 had had no previous maze experience. They were allowed to explore the maze 2 hours a day for 2 weeks before records were begun. The usual method was employed: 9 trials a day from entrances A, B, and C, with the exceptional unit located at D. Training was continued for about 500 trials.

Table 22 shows the success achieved by the rats in their last 99 trials in this maze. Their average score as measured by the number of correct responses in unit D was only 46%, as compared with 53% on the 9-inch sand floor, 65% on the 3½-inch sand floor, 66% on the 1½-inch sand floor, and 81% on the rubber cloth floor.

Only 2 out of the group of 11 rats learned this maze to a criterion of 65% errorless runs in the last 99 trials. An Attempt was made to carry out tests of the sensory cues used by these two rats, #38 and #44. However, #38 died before the tests were made. Rat #44 was given extra training to perfect any system of sensory cues he might be using. In one test, the transverse supporting members under the floor were moved one unit toward the beginning of the maze, without any observable effect on the rat's performance. In another, the maze walls were moved one unit to the left with respect to the floor, so that the exceptional unit lay over a different floor segment. Now the rat showed considerable disturbance. After a period of retraining, the test was repeated by moving the walls back to their original position, and again there was a drop in the number of errorless runs.

No emphasis can be laid on these results because only one subject was used, but it is suggested that the floor was again at least partially responsible for the better than chance score made by this rat.

Table 22

MASTERY OF THE WIRE-MESH FLOOR

Rat	Entrance	A	B	C	D (correct)	E
				Units		
31	a	21.2	78.7	0.	0.	-
	b	-	12.1	84.8	3.	-
	c	-	-	9.1	90.9	-
					av. 31.3	
33	a	3.	18.2	45.5	30.3	3.
	b	-	3.	27.3	69.8	0.
	c	-	-	6.	78.	15.
					av. 59.3	
34	a	3.	15.1	51.5	27.3	3.
	b	-	3.	39.4	48.5	9.1
	c	-	-	0.	48.5	51.5
					av. 41.4	
35	a	9.	90.9	0.	0.	0.
	b	-	15.2	78.7	6.	0.
	c	-	-	9.	84.	6.
					av. 30.0	
38	a	18.2	12.1	18.2	45.4	0.
	b	-	6.	30.3	63.6	0.
	c	-	-	6.	93.9	0.
					av. 67.6	
40	a	21.3	78.7	0.	0.	0.
	b	-	45.4	51.5	3.	0.
	c	-	-	39.4	57.6	3.
					av. 20.2	
41	a	15.1	6.	42.4	27.3	9.1
	b	-	18.2	21.3	57.5	3.
	c	-	-	6.1	87.8	6.1
					av. 57.5	
43	a	69.8	9.	9.	12.	0.
	b	-	12.1	21.2	66.7	0.
	c	-	-	12.	87.8	0.
					av. 55.5	

Table continued

Table 22 continued

Rat	Entrance	Units A	B	C	Correct D	E
44	a	15.2	9.	21.2	51.5	3.
	b	-	9.	9.	81.8	0.
	c	-	-	3.	96.9	0.
					av. 76.7	
45	a	33.3	18.	21.2	33.3	0.
	b	-	33.3	30.3	36.4	0.
	c	-	-	12.2	87.8	0.
					av. 52.5	
46	a	66.6	21.3	3.	9.	0.
	b	-	69.7	45.2	12.1	3.0
	c	-	-	57.6	42.4	0.
					av. 21.2	
Average	a	25.1	32.5	19.3	21.3	1.6
	b	-	18.2	39.9	40.5	1.5
	c	-	-	13.5	77.2	7.5
					av. 46.3	

Percent of right turns given in each unit. N = 99 trials.

DISCUSSION

The primary conclusion to be drawn from the results of the experiments reported here is that mazes of unit-alike pattern differ in difficulty according to the type of floor used in their construction, when other factors are held constant. The difference in difficulty between the various floors used in this investigation is shown by Table 23, which summarizes the scores of each rat on all the problems. The score given is the percent of errorless runs made from each entrance point during the last 99 runs in the maze.

If we take the percentage of perfect runs made on each floor as a criterion, we see that the scores range from 87.29% for the concrete floor maze to 46.3% for the wire screen floor. This means that perfect runs were made almost twice as frequently on the concrete floor as on the wire mesh. The order of difficulty of the various floors according to this criterion is: (1) concrete, (2) rubber-covered sand, (3) 1½-inch sand, (4) 3½-inch sand, (5) 9-inch sand, (6) wire-mesh floor. For a second measure of the relative difficulty, we may take the number of rats who attained a given criterion of success on each floor. One such criterion might well be the score which we estimated was the highest score which could consistently be attained without the aid of local sensory differences between the units -- 33.3%. If we apply this criterion to Table 23, we see that no rats fell

Table 23

PERCENT OF ERRORLESS RUNS DURING LAST 99 TRIALS IN EACH PROBLEM

Rat	Rubber-covered sand	1½-inch sand	3½-inch sand	9-inch sand	Concrete	Wire Mesh
10	90%	77.8%	---	---	---	---
20	66%	70.7%	60.6%	---	---	---
22	86%	66.7%	---	---	---	---
23	86%	63.3%	---	---	---	---
24	73%	60.2%	---	---	---	---
25	86%	54.1%	48.4%	47.3%	---	---
26	83%	65.3%	---	---	---	---
31	---	---	69.3%	42.3%	---	31.3%
32	---	---	6 %	---	---	---
33	---	---	75.7%	58.5%	---	59.3%
34	---	---	73.7%	51.1%	---	41.4%
35	---	---	43.4%	27.2%	---	30.0%
36	---	---	10.1%	---	---	---
37	---	---	81.8%	73.4%	---	---
38	---	---	92.9%	72.7%	---	67.6%
39	---	---	71.8%	55.5%	---	---
40	---	---	---	---	---	20.2%
41	---	---	---	---	---	57.5%
43	---	---	---	---	---	55.5%
44	---	---	---	---	---	76.7%
45	---	---	---	---	---	52.5%
46	---	---	---	---	---	21.2%
116	---	---	---	---	28.8%	---
120	---	---	---	---	84.4%	---
122	---	---	---	---	77.7%	---
123	---	---	---	---	93.3%	---
125	---	---	---	---	82.2%	---
126	---	---	---	---	86.6%	---
127	---	---	---	---	93.3%	---
128	---	---	---	---	93.3%	---
Average Score	81.9%	66.6%	65.2%	53.4%	87.29%	46.3%

below a chance score on the rubber-sand floor or the 1½-inch sand floor. One rat failed the concrete floor; this rat had previously been shown by Shepard to be unable to learn in terms of the floor cue, although able to learn in terms of kinaesthesis. Two rats out of 11 fell below the criterion on the 3½-inch sand floor. Of the same group of animals, one more fell below chance when run on the 9-inch sand floor. (The 2 rats who fell below chance on the 3½-inch floor were not continued on the 9-inch floor, but would almost certainly have failed here too.) On the wire-mesh floor, 4 rats out of 11 fell below the criterion.

A third criterion might be the number of rats making scores better than 65%, a number chosen because it is about twice the "chance" score, and because it is roughly the modal score for all tests. This criterion is attained by 87% of the rats on the concrete floor, 85% of the rats on the rubber-sand floor, 71% of the rats on the 1½-inch sand floor, 64% of the rats on the 3½-inch sand floor, 25% of the rats on the 9-inch sand floor, and 18% of the rats on the wire-mesh floor.

From inspection of the maze performance according to these 3 criteria, a classification of the 6 types of floor in order of increasing difficulty may be attempted. By all criteria, the concrete floor and the rubber-covered sand floor offered the least difficulty for the rats, and by 2 criteria the concrete floor is slightly the easier of the two. There is almost no difference between the average scores made on the 1½-

inch and $3\frac{1}{2}$-inch sand floors, but the percentage of rats attaining the criteria of 33% and 65% is slightly greater on the $1\frac{1}{2}$-inch floor. By all 3 measures the 9-inch sand floor and the wire-mesh floor are the most difficult, with the wire-mesh floor the hardest of all.

To attempt to suggest reasons for the difference in difficulty between these various floors is equivalent to inquiring what the nature of the floor cue is, since the differences in difficulty seem to be a result of floor differences.

However, the problem of the nature of the floor-cue is little advanced by inspection of our data. The fact that the two least difficult floors for the rats, the rubber-covered sand and the concrete floors, were the smoothest, hardest, and least rich in tactual differences to the human, seems evidence that the cue is probably not tactual in nature. Shepard has obtained more conclusive evidence to this same end. He has made the suggestion that the cue may be of resonance character, resulting from vibrations of auditory frequency. These data do not support or oppose the resonance view. It might have been supposed that the wire-screen floor would be rich in such resonances and thus easily learned, which was not the case. On the other hand, the various floors of bare sand might be thought to be lacking in auditory resonance, and to damp resonances from layers below. (This was the opinion which first led to the construction of sand floor mazes.) Some support for the resonance view may perhaps be found in the fact that sand floors are difficult to learn in terms of floor cues, and that the difficulty increases with the depth of the sand.

Shepard (1928) found in his work that alterations of the sub-surface layers of the floor produced more serious deterioration of the unit-alike maze discrimination than changes of the surface floor covering. He has suggested therefore that resonances from below the surface may be used as cues. If this is true for the maze floors used in this investigation, it suggests an explanation for the poor scores made on the wire-screen floor and on the 9-inch sand floor. The very deep sand would be more effective in masking any sort of cue from below than the shallow sand. Likewise, the wire screen floor, suspended as it is from the two ends, would be likely to communicate nothing from below the surface, while the intrinsic vibrations of the screen may have been nearly identical in all parts. In honesty, it must be admitted that such discriminations would require a degree and kind of auditory acuity which is completely incomprehensible to the human. Yet their existence and use in at least one maze situation, that of Shepard, has been demonstrated.

Several pieces of evidence point to the fact that the rats have here been forced to use floor cues which were obscure and difficult to attain, and which would not have been preferred in a situation where the sensory factor was less rigorously controlled. (1) Shepard's work shows that in learning the unit-alike pattern on ordinary floors, floor cues are preferred to kinaesthetic cues. (2) Curtis (1931) showed that on a sand floor covered with oilcloth, kinaesthesis is preferred over floor cues. (3) Experiment 1 of this study showed that when kinaesthesis is made unreliable in a similar situation, the rats can be forced to return to the use of floor cues, apparently derived from the surface material. (4) When even these are destroyed, by removing the surface cloth and stirring the sand, the rats are still able to gain something of a sensory difference which enables them to perform with much reduced accuracy.

There is evidence here that the rats were not depending solely on local cues resident in the several units of the maze, but that kinaesthesis was a part of the sensory complex determining their choices. When the rats were placed in the maze at any one of the three starting points ordinarily used, they had to run 2, 3, or 4 units to the food-box, and the correct response may be said to have been made to a local cue within the kinaesthetic range of 2-4 units. To test whether kinaesthesis did in fact limit the range of units in which the rat might give the exceptional reaction, a series of runs was given in which the range of possibilities was increased by occasionally starting the rats only 1 unit away from the exceptional unit, as well as the usual 2, 3, or 4. The first junction in the series has now become potentially correct as far as kinaesthesis is concerned, and if kinaesthesis is playing an appreciable part in the maze habit, responses to the first unit the rat comes to should be increased and the number of correct runs reduced. Table 24 shows the comparison between a group of 420 standard runs, in which the exceptional unit was always 2-4 units distant from where the rats started in the maze, and a test group of 420 runs in which the exceptional unit was 1-4 units away. The test group is made comparable to the standard group by omitting the runs requiring only 1 unit.

Table 24

INFLUENCE OF KINAESTHESIS UPON MAZE ACCURACY

	Units correct				
	A	B	C	D	E
Standard group	1	6	99	306	8
Test group	9	42	87	277	5

Number of right turns given in each unit. N = 420.

It will be seen that the test group of runs shows fewer cases in which the exceptional reaction was withheld until unit C or D was reached, and more cases in which the exceptional reaction was given in units A or B. We may conclude that kinaesthesis is a part of the complex of cues which determine the responses in our maze situation.

The question now arises, did any other sensory cues play a part in the habit except kinaesthesis and floor cues? The various tests showed that such cues were not essential in locating the exceptional unit of the maze, since the responses did not fall to a chance level when they were temporarily removed or altered, and the effect of these disturbances was quickly lost when the tests were repeated.

We have called the floor cues the primary cues in this maze situation because: (1) alteration of the floor produced greater detriment to maze accuracy than any other environmental changes which we made; (2) mazes which were very poorly learned were identical (so far as we could see) with those which were comparatively well learned, except for the floor.

However, rats were able to adapt themselves to repeated alterations of the floor surfaces, so that these changes no longer caused any lowering of the performance level.

Two explanations suggest themselves to account for this ability to neglect floor changes. One has already been discussed: the possible shift to cues of the same nature coming from deeper levels of the floor. Another interpretation might be that the rats simply learn to depend on other elements of a sensory complex of which the floor was originally the most important part. Our experiments do not provide a positive test as to the correctness of either of these interpretations. It seems logical, however, that if rats were able to run one maze on the basis of a sensory complex which did not include the floor cue, they should have been able to make equally good scores on subsequent mazes regardless of the floor used. This was not the case.

In further experimentation along these lines, it is suggested that a better means of controlling the factor of kinaesthesis would be to use a maze composed of so many units that the exceptional one could not be located accurately on the basis of kinaesthetic cues. This method would avoid any confusion resulting from finding the exceptional unit sometimes earlier, sometimes later in the kinaesthetic series, as in our experiment. Spragg (1933) used such a maze, and found that a unit-alike maze containing 8 units could not be learned kinaesthetically, because with this number of units the rat cannot make fine enough kinaesthetic discriminations to distinguish 7 units from 8.

It is suggested that a positive test of the use of floor cues of an auditory-resonant nature (as distinguished from tactual cues) could be obtained by causing the maze floor to vibrate continuously, at constant or variable rates. Such floor cues could be either masked or emphasized by this means, and the resulting effects upon maze performance analyzed.

SUMMARY AND CONCLUSIONS

Rats were trained to run a maze composed of a number of units identical in pattern, of which one unit required a reaction opposite to the others. The use of kinaesthetic cues was restricted by starting the rats in the maze at 3 different points according to a pre-arranged schedule. Six types of floor construction were at different times used in this maze situation: a sand floor covered with rubber-sheeting; floors of bare sand having depths of $1\frac{1}{2}$ inches, $3\frac{1}{2}$ inches, and 9 inches, a concrete floor, and a floor of suspended wire screen. Tests were made to determine the nature of the sensory cues governing the responses to the various units of the maze. Under these conditions, the following conclusions seem justified:

1. Rats can achieve partial mastery of a unit-alike maze pattern in the absence of reliable kinaesthetic cues.

2. Within the limits of this experiment, cues from the floor of the maze are more important than other sensory factors in determining the rats' responses in the maze.

3. When other factors are held constant, unit-alike mazes vary in difficulty for rats according to the floor on which they are constructed.

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