

THE TEMPORAL MAZE AND KINAESTHETIC SENSORY PROCESSES IN THE WHITE RAT

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In spite of the generally conceded fact that kinaesthetic processes are of fundamental importance in animal behavior, almost nothing is known that bears specifically upon these processes. All motor responses involve them, and maze studies have particularly emphasized them. In addition scattered observations abound in the literature describing position habits which have interfered with work directed primarily toward the analysis of other forms of sensitivity. In some cases these position habits have been merely the tendency to go to a definite side of the discrimination box at each trial. In other instances tendencies to alternate from one side of the apparatus to the other have been observed; and at least in one series of experimentation (dealing with audition in the rat) this simple alternation has been complicated by the addition of a sensory complex accompanying success. In this case the rat would go to one side of the apparatus trial after trial until escape was possible, whereupon it would go to the other side until escape was possible there. This was a case of simple alternation after success. It could not be termed a purely kinaesthetic automatism because of its modification by the factor of success. Success meant a free passage; failure meant running into the end-stop of the apparatus (1).

Except for Carr's recent extended study of simple alternation (2) no attempt has been made to disentangle the kinaesthetic processes incident to all studies of discrimination from the matrix of other sensory processes in which they are obscured. The present study, first reported in 1918 (3), attempts to determine how much a rat can do in terms of kinaesthesia using the following problems: simple alternation; double alternation (twice to

the right side of the apparatus, twice to the left side, etc.); and a problem termed the "temporal maze," to be described below. Kinaesthesia may be the fundamental sensory process for animals, and still the animals may be able to do very little with it. Such a study as the present will aid in the solution of this problem.

Problem 1. The acquisition of a habit of simple alternation. In this problem seven rats were used, each approximately four months old. All were untrained in previous problems. The apparatus was the T-shaped discrimination box of figure 1. Punishment (electric shocks) and reward were used. As a pre-

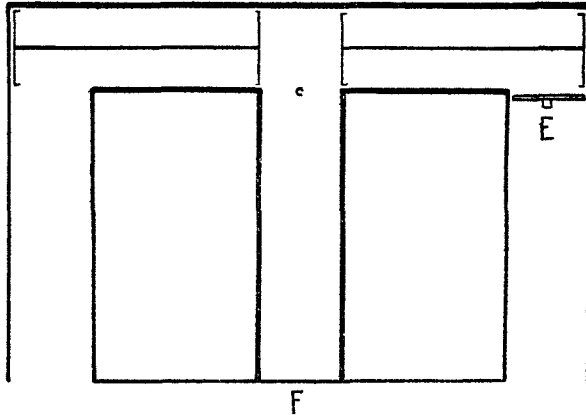


FIG. 1. T-SHAPED DISCRIMINATION BOX

E is the end-stop; *F*, the feeding place; *c*, the point of choice for right or left turns. The extent of the electric grills is shown by the brackets in the upper alley.

liminary, each rat was given the run of the box for two days prior to the beginning of the regular test. During this initial period, no end-stops were used and no food was given until the animal was taken out for the day. In the regular tests the end-stop was shifted so that the rat was forced at one trial to run to the left in order to secure food and avoid punishment and at the next trial to run to the right for the same purpose. The rat was fed and the end-stop was shifted between trials. Ten trials were given daily in the order *lrlrlrlr*. (No external stimuli of light, sound, or odor were present to guide the animal.) The amount of time consumed between each trial was about twelve seconds.

Table 1 indicates the number of trials required by each rat to master the series of alternate runs. The criterion of mastery was an average of 87.5 per cent correct for four days, with no day's record below 80 per cent. The data indicate that the simple alternation habit is acquired in from one to eighteen days, under the conditions of the present experiment. No explanation in terms of external causes is available for the great variation in ability displayed by the animals.

After the mastery of the problem, the end-stop was no longer used. No confusion of the animals' responses was produced. Undoubtedly the stimulus for turning in one direction, let us say to the left, was the complex of kinaesthetic, organic, cutaneous,

TABLE 1
Number of trials prior to mastery of simple alternation

RAT	NUMBER OF TRIALS
30	100
• 31	80
33	60
34	50
35	180
36	100
37	10

and olfactory processes involved in a run through the opposite side of the box and terminating in the securing of food.

Problem 2. The acquisition of a habit of double alternation. Using the same apparatus as before, with punishment and reward, tests were made upon the ability of rats to master a double alternation, *llrrllrrll*. After the preliminary acquaintance with the apparatus, the rat was inserted with the end-stop in such a position as to force it through the left side of the apparatus. It was then fed and re-inserted and forced to come through the same side of the apparatus in order to escape. The next two trials were through the right side of the box.

To the great surprise of the experimenter, this apparently simple problem was never mastered by any one of nineteen rats who were tested on it under various conditions. The details of

these abortive attempts at learning and the conditions under which they were made are as follows.

Rats 30, 33, 34 and 35 of the previous problem, simple alternation, were each tested on double alternation for 550 trials, ten trials daily. An interval of twelve seconds between each trial was consumed in feeding and re-inserting the rat. None of the rats made any progress toward the mastery of the problem during these fifty-five days.

Rats 5, 6, 7, 8, 16, and 18, untrained rats two months old, were trained on the problem of double alternation, under the above conditions. Rat 18 received 464 trials. The other received between 600 and 650 trials. At the conclusion of the training period, no rat had made significant progress toward mastery of the problem.

Rats 5, 6 and 16 were now tested on the same problem under slightly different conditions. The end-stop was placed, not in the side alley as indicated in the figure, but just beside the point of choice (*c*) so that the animals were forced to run in double alternation without the possibility of error. Each rat was given 400 trials under these conditions. At the close of this period, the end-stop was placed as usual in the side alley. Twenty trials were now given each rat with the possibility of choice again present. No rat made better than 60 per cent of correct reactions.

In the tests so far described in this section, failure may have been caused either by the length of time interval between trials or by the fact that in the series of ten trials six were to the left and only four to the right. In order to test this, three new rats (51, 52, 53) were tested on double alternation giving eight trials daily, *llrrllrr*. Punishment was used, but food was only given at the close of the day's work. As soon as a rat ran to the exit, he was immediately re-inserted for another trial. There was thus practically no interval between trials. Rats 51 and 53 received 512 trials. Rat 52 received 488 trials. At the close of these tests, no rat had made significant progress toward mastery.

Rats 2, 3, 4, 100, and 101, untrained and two months old, were tested on this problem with four trials daily, *llrr*. There was an

interval of twelve seconds between each trial. Punishment and reward were used. All were given 200 trials, 50 days' work. At the close of this period no rat had made significant progress toward mastery. (Throughout the description of these experiments the phrase "no progress toward mastery" means that there was no evidence of improvement to justify the assumption that if the tests were long continued learning would be completed.)

Problem 3. The double alternation "temporal maze." Following this series of failures to set up the double alternation habit above described, an entirely new method was attempted. Alternating behavior, whether it be simple, double, or more complicated, is analogous to the running of a maze where the response is interrupted from point to point and food given. Might it not be if the rats were trained in a maze where the choices were arranged in an *lrrllrrll* manner that, when transferred to the T-box, they would be able to learn the double alternation problem? In the first test we should have established a double alternation habit in a conventional maze, and in the second test we should be looking for a transfer of this kinaesthetic automatism to the new conditions. It is true that if this transfer did not take place, one could not conclude that the animals could not form the double alternation habit, for there would be many novel conditions that would work against a transfer. However, having failed by the direct method of approach, the indirect method was worth a trial. In order to make the T-box test more comparable with the maze, it was converted into a *temporal maze* as shown in figure 2. The conventional maze is termed by way of contrast a *spatial maze* and is shown in figure 3. A further word of description of each of these mazes is necessary.

The temporal maze was manipulated as follows: With the entrance-stop as indicated in figure 2 and the end-stop on the right, the animal was placed at *E*. When in the course of its explorations, the animal came down the side alley to about the point *L*, the entrance-stop was shifted to the dotted position on the right. This left a circular path, with the one off-shoot to the right, through which the rat might trace and retrace. After the rat had made its second trip around the left side of the ap-

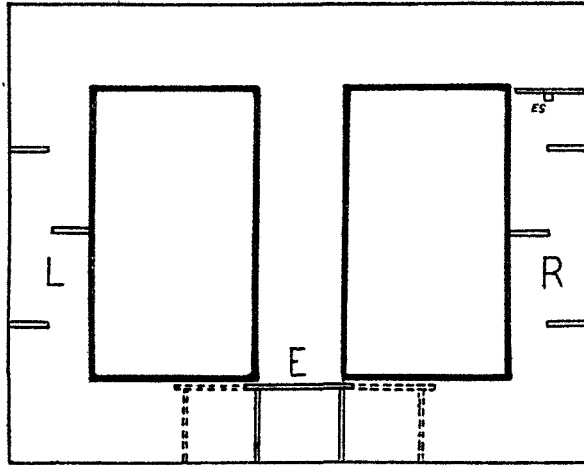
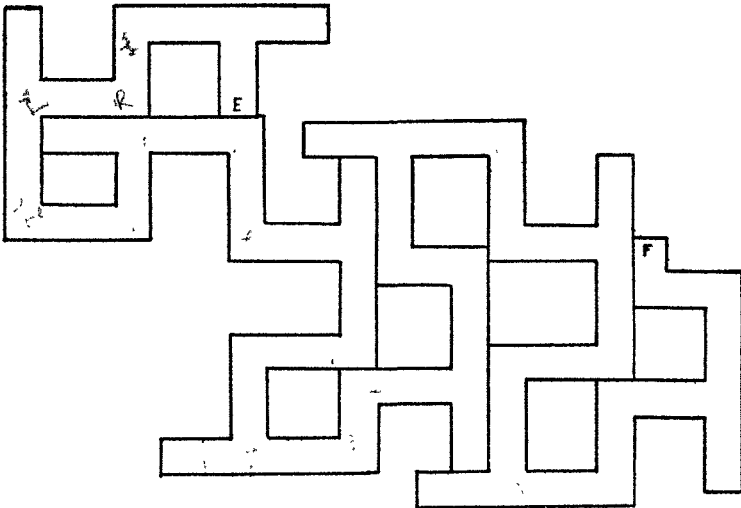


FIG. 2. THE TEMPORAL MAZE

E is the entrance-stop which can be shifted right or left as indicated by the dotted lines; *es*, the end-stop; *L* and *R*, points referred to in the paper. The three partitions in each of the side alleys were present in only one control test with rat 110. They were present in no other test.

FIG. 3. A SPATIAL MAZE COMPOSED OF SUCCESSIVE T-SHAPED UNITS WHERE THE CHOICES ALTERNATE AS *lrrllrrll*

E is the entrance, and *F* the food-box.

paratus and reached the point *E*, the end-stop was shifted to the left alley (dotted position) and the entrance-stop was again shifted to its central position. When the rat had run through the right alley and reached about the point *R*, the entrance stop was shifted to the dotted position on the left. It remained in this position, until the rat was ready for two trials to the left again. This method was followed until the rat had been forced to run *lrrllrrll*, i.e., the regular ten trials. It should now be clear why this problem is termed a temporal maze. The rat is compelled to run through the *same* pathway in varying combination during *successive* moments of time. In the spatial maze not only new moments of time are involved but also new portions of space. Or to put the situation differently, 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 during the ten trials, but will succeed each other as a temporal sequence. The rat has demonstrated his ability* to master almost every degree of complexity in a spatial maze. What are the limits of his ability in a temporal one? The shifting of the end-stops was not noticed by the animals. It is possible that at times the shifting of the entrance-stop was noticed and thus served to distract the animals. No punishment was used and the animals were fed only at the close of the day's test.

The spatial maze illustrated in figure 3 was constructed in order to present ten points of choice for the rat when running forward along the true pathway. The correct choices were arranged in the sequence *lrrllrrll*. The maze was uncovered and painted black, with alleys 8 inches deep. The T-shaped units of this maze were arranged in series as is necessary in the conventional maze. Therefore in addition to the qualitative cues which arise as the animal runs, there will be either spatial characteristics attaching to these cues or else special space cues conditioned by the extended nature of the pathway. As contrasted with this, the temporal maze has but one unit, and the space cues are eliminated.

Six untrained rats, nos. 102, 103, 104, 105, 106, 107, two months old, were trained on the space maze of figure 3. One trial per day was given (equivalent to ten trials in the T-box). The criterion of learning was a perfect run on each of three successive days, a very much higher criterion than was used with the discrimination box. Table 2 indicates the number of days used by each rat prior to the perfect runs. The table indicates that the rats acquired the association very readily. There was nothing in their learning curves to mark this maze as peculiar.

TABLE 2

Number of trials prior to three perfect runs in the spatial maze

RAT	NUMBER OF TRIALS
102	5
103	8
104	10
105	10
106	12
107	6

TABLE 3

Number of trials in temporal maze

RAT	NUMBER OF TRIALS
102	28
103	43
104	46
105	43
106	42
107	42

The six rats trained on the spatial maze were now transferred to the temporal maze using the method described above. One trial per day was given. Table 3 indicates the total number of trials given each rat. At the close of these periods, no rat had mastered the problem. All had fallen into position habits which made the continuation of the test useless. During the progress of the training improvements took place in the following particulars: (1) the tendency to retrace or run through the maze in the reverse direction was practically eliminated; (2) the time was

decreased from an average of eighteen minutes (m.v. 3.5 minutes) on the first trial to an average of three minutes (m.v. 35 seconds) on the last trial.

During the training the following tendencies and characteristics of behavior were manifested: a tendency toward simple alternation; a tendency to run a loop of the maze in the reverse direction as though continued activity of this type might bring the final reward of food; a tendency to alternate after success, as described at the first of the paper; and finally a tendency toward greater variability in the first four choices than in the last six constituting the day's test. Of these the tendency toward simple alternation and the tendency to alternate after success

TABLE 4
Behavior in temporal maze

RAT	SERIES OF CHOICES				
	ll	rr	ll	rr	ll
103	rw	rw	rr	rw	rr
	rr	ww	rr	ww	rr
	rw	ww	rr	ww	rr
	rw	ww	rr	ww	rr
104	wr	ww	rr	ww	rr
	wr	ww	rr	ww	rr
	rw	ww	rr	ww	rr
	ww	ww	rr	ww	rr

have appeared so constantly in all difficult problems with the T-box, that it seems almost safe to affirm that these are innate reaction tendencies of the rat.

In illustration of the last of the four mentioned behavior tendencies, the series of choices made by two typical rats on four successive days at the close of the experimentation can be indicated in table 4. *W* indicates a wrong choice. *R* indicates a correct choice. In each case the reference is to a choice occurring at the point where the right and left paths diverge at the top of the T. An inspection of this table will show that the first four responses are not identical from day to day. The last six responses indicate a position habit of going to the left. Alterna-

tion after each successful discovery of a free passage gives a record of this type, selected from the data for rat 106, *rwrrwrwrw*. Simple alternation is illustrated by this sample behavior from rat 102, *rwrrrwrrw*. Here the animal ran first to the left and alternated regularly thereafter, giving the record just quoted.

In case an animal fell into an automatism which repeated itself from day to day without essential variation, one would have a temporal maze habit, although not the particular one which was sought. Rat 105, e.g., was the one rat who acquired such an invariable form of response. This rat always alternated after each success for the first four choices and then ran a position habit to the left for the last six choices. His record therefore day after day was *rwrrrwrrr*. Here was an automatic chain of unit responses which involved running through the same space in succeeding intervals of time. What were the cues involved? Was the cue a kinaesthetic one derived from turning to the left or right, or was it a combination cue involving a contact-kinaesthetic experience with the end-stop? Was the behavior controlled essentially by cues from within the organism or from cues that depended upon specific phases of the external environment? Controls were now introduced with several of the animals that approximated this automatic behavior in an effort to answer the question. It will be possible to follow through the records for three of the animals, and then to state in general what the result has been.

Rat 105, as stated, had an invariable form of response in the order *lrrlrlllll*. A control was now introduced with this rat where all the choices were to the left. The entrance-stop was shifted after the first trial but not thereafter. The end-stop remained on the right side continually. The rat ran *lrrlrrrlrr*. The tendency to run to the right to secure food, being checked by the end-stop, overcame the normal tendency to run all of the last trials to the left, so that the left position habit appears only in choices 4 and 8. The second control used required the rat to run a series of choices five of which were to the left and five to the right, *lllllrrrrr*. Entrance- and end-stops were shifted in the middle of the series. The rat chose in the order *lrrrlllll*. In

other words, the animal first turned to the left, then alternated to the right as usual. Failing to receive the sensory complex associated with success, he ran one more trial to the right than usual. The impulse to run to the left now asserted itself, and the remainder of the runs were made to that side. The next day the same control was used and the rat ran *lrrlrlllll*. Here the interference of the reaction tendencies peculiar to the first and last halves of the normal reaction comes in the fourth and fifth trials. The tendency to run to the right until success was encountered was so strong that after the fourth choice was made the rat retraced his steps and investigated the end-stop on the right. He went again on the following trial to the right side, and only then did the turn-left tendency predominate. This same type of behavior was repeated when the series of choices was changed to *lllllrrrr*. When a series composed wholly of rights was used, the animal happened to go to the right on the first trial whereupon he went left for the rest of the series. As a final test the rat was inserted without either entrance- or end-stop. It was thus possible for the animal to run in any direction. If the end- and entrance-stops were not serving as partial cues, the kinaesthetic tendencies should unroll in the normal manner. The result of the control was for the rat to make all of its choices to the left with a great deal of retracing in a clockwise direction, due apparently to the absence of the entrance-stop.

These controls indicate that the normal integration of the two reaction tendencies of rat 105 depended upon sensory complexes from outside the animal's body. The impulses for running right and left, undoubtedly carried in proprio-ceptive terms, depended for their normal functioning upon extero-ceptive data.

Rat 106 also had the tendency to alternate after each success in the first of the series, although the total series was never automatized as with rat 105. Controls were used where the series of choices in place of being double alternation were *llllrrrrr* and *lllllrrrr*. This rat always ran to the left the first trial, then to the right until successful and then to the left, thereby alternating after each success. The sensory complex from running against the end-stop (failure) produced a return to the same side until

the complex was absent, whereupon the rat ran to the other side. The securing of food between trials was not necessary in order to produce the alternation. It was not the kinaesthetic complex involved at the point of choice (at the top of the T) which determined the direction of the subsequent choice, but the sensory complex at the end of the alley underlying a free or an obstructed passage.

Normally rat 104 behaved in the manner described in table 4, running all to the left with the possible exception of the first one or two choices. When tested with *Ulllrrrrr*, the rat responded *rrlrrrlll*, showing the tendency to alternate after success conflicting at random with the position habit to the left. With the series composed entirely of choices to the right, the animal made the first choice to the right and all others to the left.

We shall attempt later in the paper to explain why the rats could not learn the temporal maze where the demand was for double alternation through a continuous pathway.

Problem 4. The simple alternation "temporal maze." We come now to the experiments upon the temporal maze with simple alternation. Here the apparatus and method described above on pages 5-7 were used, except that the entrance- and end-stops were shifted to require a simple alternation. The rat was thus forced to run a continuous figure 8, once around the left of the box and then once around the right, continued for ten choices.

Seven untrained rats were used, nos. 108-114. Rats 108 and 109 were three months old when the tests began, and the others were five weeks old. The detailed presentation of the records is unnecessary, because they merely repeat what has already been given for the double alternation temporal maze. Only one animal, no. 110, mastered the problem. Table 5 shows the number of trials given each rat. Each trial is equivalent to ten trials in the T-box. Attention should be directed to the tremendous variation in difficulty existing between the simple alternation problem in the T-box and in the temporal maze.

In the course of the training, all rats acquired a position habit to the right. This was uncomplicated by other reaction tendencies as had been the case in the training on the previous tem-

poral maze. Various expedients had to be used in an effort to break up this stereotyped form of response. The rats were forced constantly through the left side of the maze; or they were taken out of the apparatus and fed between each of the ten choices; or they were given several days rest. These methods succeeded only with rat 110, and this animal mastered the problem in the manner to be described below.

The animals who succeeded only in building up a right position habit were tested with the end-stop so arranged that an open pathway existed only around the right side of the apparatus. When this was done the rats either ran all of the ten choices to the right in conformity with their position habit, or once or twice made left turns. So when the apparatus was arranged to per-

TABLE 5
Number of trials given on temporal maze, simple alternation

RAT	NUMBER OF TRIALS
108	20
109	18
110	59 (mastered)
111	60
112	65
113	51
114	64

mit only free runs to the left, the animals made either all wrong choices or occasionally interspersed a turn to the left. The evidence indicates, therefore, that this position habit is practically uninfluenced by entrance- and end-stops. The behavior is undoubtedly a chain of reflexes whose stimuli are internal. This is further supported by the fact that when the rats were inserted with end-stop and entrance-stop removed so that a continuous path was open to the animal, each ran at least 80 per cent of its choices around the right side of the box. Here where no stops were used, there was much retracing about the box, but each time the rat ran through the central alley in the normal direction, it turned to the right. Reliance was therefore placed upon the entrance-stop as a cue for guiding the animal into the central

alley, thus preventing retracing; but once the rat went through this alley, its choices were in accordance with its one kinaesthetic tendency, to turn to the right. In several cases some evidence was found indicating the rôle of the end-stop. Let us take the case of a rat who ran twice to the right meeting failure at the first and success at the second choice. This success, before the position habit was thoroughly established, would lead the animal to run to the left. It was found that if success (a free pathway) and not failure (a blocked pathway) were offered the rat on the first trial, that he would at the next trial go to the left.

We may now turn to a brief description of the behavior of rat 110 who learned to run the simple alternation temporal maze. This rat, as stated above, also developed position habits which required breaking by all three of the methods there described. The process of learning was long and tortuous. At the close of the 59 trials, rat 110 could run the continuous path of *lrlrlrlrlr* without error, save that it usually retraced at least once per trial. This retracing was usually running from some point in the side alleys back along the top of the T to the end-stop of the opposite side. In a space maze, this would probably be counted as two errors. The fastest time made by this animal was 52 seconds. Without apparent cause, the time fluctuated between this and 105 seconds. The response never became so automatic and stable as is customary in a space maze. After the habit was mastered, only the entrance-stop was used regularly. The end-stop was quickly and quietly inserted only when the rat made a wrong choice. It does not seem probable that the lack of stability in the habit was due to distracting influences. The cause of the instability was rather the difficultness of the task.

The following results were secured with controls used with rat 110: (1) When twenty continuous choices per day were given as opposed to ten, no disturbance was apparent. This control doubled the length of the maze. The animal practically continued to run successive figure 8's until removed from the maze. (2) When the entrance-stop was taken out of the maze and not used after the first trial, the rat failed to turn into the central alley. (3) The maze was rotated 180 degrees and the rat was

inserted at the same absolute location in the room, i.e., it was inserted at what had before been the point of choice at the top of the T. The entrance-stop was used at the new entrance. Except for this all cues from within the maze were now in new locations. The external environment, the entrance-stop, and the kinaesthetic relations remained relatively unchanged. The control did not disturb the rat. (4) Obstructions were now placed in the alleys as indicated in figure 2. These were partitions extending one-half way across the alley. They forced the rat to run in a serpentine path and thus varied the general nature of the kinaesthesia. The animal's habit broke down completely in the first trial as soon as it encountered the first obstruction. This was undoubtedly due to distraction from a novel stimulus. When tested again on the second and fourth succeeding days, the rat ran normally with this control.

When the rat was inserted in the apparatus under standard conditions, the entrance-stop was in place across the entrance. The animal turned, "nosed" the stop, and then ran. It was thought, therefore, that the entrance-stop might give the initial cue to the habit. (Control 2, as well as the observation just presented, indicates the control which this stop exercises during the running of the maze.) No test was made of this possibility while the rat was making perfect reactions, but presumably the results now to be described would have been secured had the test been made at that time. Toward the close of the controls the rat developed a habit of going always to the right on the first two choices. The remaining eight choices then alternated perfectly. It was decided to place the entrance-stop across the entrance (in the position occupied on the first trial) at various times during the day's work. When the animal was ready to run through the central alley, the entrance-stop was to be shifted across the entrance thus causing the rat to turn and "nose" the stop before continuing the run. On the first day, this test was used whenever the rat would otherwise have gone to the left. In two out of five times the cue derived from the shift overcame any tendency to go left, and the rat ran to the right. On the second day, the cue forced the rat to run to the right four times out of

five. On the third day the entrance-stop was so shifted six times, and five times the rat ran to the right when normally it would have gone to the left. Choice of the turn to the right was clearly conditioned, therefore, by the presence of the entrance-stop. This response was also aroused normally by running around the left side of the box and being forced into the central alley by the stop as indicated by control 2.

Interpretative comments. We may now comment upon the significance of the data secured on the temporal maze as they throw light upon problems connected with the spatial maze. Why can rats not learn double alternation? The answer seems to be this: The experience of running around the left side of the T (kinaesthetic, tactual, olfactory, etc.) can serve as a cue for going around the right side of the T or for going around the left side of the T again, but it cannot serve at one time for the first response and at another time for the second one. The rat can use the cue either in going constantly around one side of the apparatus or in going alternately from one side to the other. It cannot use the same cue for both responses. This clearly excludes the possibility of mastering a temporal maze where the choices might be arranged *lrlrrrlrrrl*. 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. The experiments have also indicated the great difficulty with which a simple alternating temporal maze is mastered. Here it was possible to set up a chain of responses each link of which was the stimulus for the next, but only one rat mastered the problem and that after prolonged coaching. In addition we have seen reason to attribute a certain indefinite amount of influence to cues derived from the entrance-stop (in certain cases even the end-stop played a rôle).

If the conventional account of the reactions in a spatial maze were correct, the rat should be able to learn a temporal maze of almost any complexity. It is said that in the former maze, the kinaesthetic cue from running one segment controls the running of the succeeding segment, so that a chain of proprioceptive activity results. The work on the temporal maze indicates that

it is all but impossible to set up a mere temporal sequence of kinaesthetic processes with the rat. [Running the spatial maze therefore must require cues which have space location as well as temporal position. In other words the rat must recognize in terms of space where he is in the maze. These spatially located cues may be anything but a kinaesthetic complex. This is not to say that a characteristic kinaesthesia will not arise in certain portions of the maze. It is to point out that the space location of the kinaesthesia is due to non-kinaesthetic processes (contact, e.g.). The present tests have indicated that the rat has practically no capacity to set up habits where the sensory complexes succeed each other merely in time. It is possible that a rat might learn a space maze requiring simple alternation and then run it in terms of kinaesthesia. The animal however easily masters the ordinary maze where the choices may be in any combination. How can it use the kinaesthesia connected with a left turn at one time to initiate a turn to the right and at another moment to initiate a turn to the left? Our tests have indicated that this cannot be done unless spatially arranged cues are available.

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