MAZE LEARNING IN RATS IN THE ABSENCE OF SPECIFIC INTRA-AND EXTRA-MAZE STIMULI

BY C. H. HONZIK Univ. of California

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UNIVERSITY OF CALIFORNIA GRADUATE DIVISION

PROGRAMME OF THE FINAL EXAMINATION FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

OF

CHARLES H. HONZIK

A.B. (University of California) 1922

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BIOGRAPHICAL

1901 —Born in Chicago, Illinois.
1922 — Born in Chicago, Illinois.
1925–1927 — Teacher, Weed High School, California.
1929–1933 — Hesearch Assistant in Psychology, University of California.



DISSERTATION

MAZE LEARNING IN RATS IN THE ABSENCE OF SPECIFIC INTRA- AND EXTRA-MAZE STIMULI

In an investigation of the sensory cues used by rats in the learning of a maze, Professor R. C. Tryon discovered that rats, after a slight initial disturbance, could run with their usual accuracy through the maze after being short cut, that is, forced by means of blocks and a new short cut path to leave out a part of the maze. This the rats could do in spite of the fact that all parts of the maze were interchanged and the rats were run in complete darkness. A repetition of this experiment by the writer showed that, with blind rats on an elevated maze, some short cuts were well executed while others were not. The primary object of the present investigation was to discover the conditions under which short cuts could be accurately executed.

In Experiment II an elevated fourteen-blind maze, all of whose parts could be interchanged one with another, was used. The maze was rectangular in general shape, with different arrangements of blinds in three corners. During the first eleven days of learning (two trials a day) the maze parts were not interchanged, the object being to see what effect a sudden change of maze parts would have on maze performance after the maze had been learned. Later, after the rats had learned the maze under constant shifting of maze parts, nine different short cuts were tried. The results of the sudden changing of parts and of the various short cuts may be summarized as follows:

1. When the maze parts were suddenly interchanged maze performance was greatly disturbed, as indicated by the large increase in errors. The cause of the performance disturbance—whether it was due to the changing of specific stimuli that had become directive or to distraction—was not determined by this part of the experiment.

2. Short cuts which greatly distorted the general rectangular shape of the maze were not executed accurately. These short cuts were made by long diagonal paths placed between the adjacent sides of the rectangle.

3. Short cuts which did not greatly distort the rectangularity of the maze were correctly executed. These short cuts were made by short diagonal paths between adjacent sides and by short paths in place of the blind arrangements in the corners of the maze.

4. "Put on" runs corresponding to each of the short cuts, made by placing the rats by hand at a point on the maze which they reached after taking a short cut, showed that the run from the habitual starting place and over the short cut path was essential to accurate performance on the maze beyond the short cut.

5. It was concluded that response in the maze is made, not to individual specific stimuli, but to groups of stimuli, and perhaps to wider patterns of groups of stimuli. Therefore, large disruptions of stimulus patterns, as by the long diagonal short cuts, produced inaccurate performance while lesser disruptions

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had no significant effect. If individual specific stimuli had been directive in the sense that each evoked a definite response, no short cuts could have been correctly performed.

Finally, it was suggested that the essential nature of intelligent behavior is the capacity to respond adequately, that is, with a minimum of effort and without error, under conditions of changing stimuli.

GRADUATE STUDIES

Field of Study: PSYCHOLOGY.

Clinical Psychology. Professor O. L. Bridgman. Experimental Psychology. Professor Warner Brown. Animal Psychology. Professor E. C. Tolman. Psychology of Individual Differences. Professor R. C. Tryon. History of Psychology. Professor G. M. Stratton. Psychological Tests and Measurements. Professor C. W. Brown. Research. Professor E. C. Tolman.

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General Vertebrate Zoology. Professor Joseph Grinnell.

PUBLICATIONS

- Introduction and Removal of Reward and Maze Performance in Rats (with E. C. Tolman). Univ. Calif. Publ. Psychol. 4, 215-232, 1930.
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MAZE LEARNING IN RATS IN THE ABSENCE OF SPECIFIC INTRA-AND EXTRA-MAZE STIMULI

BY

C. H. HONZIK

INTRODUCTION

On the basis of results of a previous experiment⁽¹⁾ it was concluded (1) that maze learning in rats is not necessarily dependent on the formation of simple stimulus-response connections and (2) that accurate maze running is not a purely kinaesthetic chainreflex phenomenon. The suggestion was made that maze learning in rats, even under the ordinary conditions of an unchanging maze, contains elements of what in human beings we call rational learning.

The present investigation is a continuation of the previous study, although a maze of a different pattern is used for two of the three groups of rats utilized. It will not, however, be amiss to repeat in general terms the procedure and argument that hold for both studies:

If blind rats can learn a fairly difficult elevated multiple T-maze when the units of the maze are constantly interchanged and shifted about (the pattern being kept constant), and if, further, the rats are not disturbed in their performance when the maze is rotated in the room, it may safely be said that learning was accomplished independently of *specific* visual, tactual, olfactory, and auditor'y cues or stimuli. When these four types of stimuli are excluded as directive cues in the running of the maze, the rats may still be said to have learned the maze kinaesthetically; that is, they have learned a kinaesthetic pattern which unrolls itself, as it were, when the rats are placed on the maze. If, then, the running of the maze is purely kinaesthetic, a disruption of the kinaesthetic pattern should perceptibly upset and confuse the rats, increasing significantly their error scores. Such a disruption can be simply accomplished by inserting in the maze at desired points a block and a short new path which will force the rats to leave out a part of the maze and cause them to jump, figuratively speaking, from an earlier to a later part of the maze. If now

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the rate are able to make this so-called "short cut" without confusion-if they run the later part of the maze immediately after the short cut* with no significant increase in errors-we are compelled to conclude that they are not running the maze purely kinaesthetically, or, in other words, that kinaesthesis is not operating as a factor necessary to correct running. This conclusion is made certain when we consider that exploration of the maze after the short cut, to pick up kinaesthetic cues, would inevitably lead to blind entrances and cause a significant increase in the number of errors. Visual stimuli and specific tactual, olfactory, and auditory stimuli being now eliminated as necessary factors in the running of the normal pattern of the maze, and pure kinaesthetic running being excluded by the performance on the "short cuts," we conclude that the rats somehow, independently of specific sensory cues, "know" where they are after making the short cut; or, to express the matter in Lashley's words, we conclude that "the maze habit cannot be interpreted as a series of kinaesthetic-motor reflexes [nor as a series of stimulus-response connections] but must be referred to some intraneural mechanism capable of producing an integrated sequence of movements in the absence of directive sensory cues."

EXPERIMENT I

THE MAZE FOR GROUP III

A group of 17 rats (Group III) was trained on the maze used in the previous study. This maze was of the elevated type (fig. 1); the rails or pathways were of finished pine 2 inches wide and stood 30 inches above the floor, being supported by $1\frac{3}{4}$ inch $\times 1\frac{3}{4}$ inch uprights. At points indicated in figure 1, gates were inserted to prevent retracing. These gates were of $\frac{1}{4}$ inch wire mesh. By means of stout wire pivots at the top, they were made to swing between two uprights fastened to the rails. The gates were thus parts of the units to which they were fastened; and they were moved about with the units, as will be explained later. A short nail in one of the gate uprights prevented a gate from swinging backward, and, according as the gate was placed on one or the other side of the nail, the gate could be made to swing in either direction. The gate could also be easily removed, leaving only the two uprights in place.

The maze contained 19 blinds and these varied in length from 11 to 14 inches. The true path measured 59 feet. The units of the

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^{*} To Dr. R. C. Tryon belongs the credit of first suggesting and trying the method of "short cutting" to disrupt a kinaesthetic sequence, if such exists.⁽⁷⁾ Instead of using blind rats, Tryon ran his rats in complete darkness. His startling results suggested this further research.

maze were numbered consecutively, beginning at the starting platform, from 1 to 26. Of these 26 units ten, namely, units 1, 2, 4, 9; 10, 11, 12, 14, 16, and 22, were 42 inches in length; units 6, 13, 24, and 26, 36 inches; units 3, 20, and 25, 16 inches; units 7, 21, and 23, 30 inches; units 15 and 19, 28 inches; and units 5, 8, 17, and 18 were of odd lengths, 22, 63, 65, and 55 inches, respectively. Units



Fig. 1. Diagram of elevated maze used in Experiment I. Arabic numerals indicate blinds; roman numerals, units. Short cuts are indicated by broken lines.

of the same length could be interchanged easily by lifting a unit out of the maze and inserting another from another part of the maze in its place. The pattern of the maze, of course, remained unchanged. Units of odd lengths could not be interchanged without changing the pattern, but these units could be turned end for end or replaced by others of the same length that had been lying idle. Ten units, besides the ones just mentioned, were constructed and these were inserted at various times in appropriate places in the maze while the original units lay idle.

It is obvious that, with the maze so constructed, it was possible to change the maze completely, so far as its component parts were 102 University of California Publications in Psychology [Vol. 6

concerned, without changing the pattern. If there were directive timuli, taxinel or olfactory, specifically located at the various choice points in the rat's path, interchanging the units would inevitably disturb these stimuli and make dependence on them of no avail. Since the floor on which the maze was set was rather uneven, the junction of any two units varied from one interchange of units to another, and this had the effect of further increasing the confusion of tactual stimuli with the shifting of units. It should be mentioned also that besides being shifted from place to place the units were often turned end for end so that what had been a blind was now a part of the true path, and vice versa. In such shifts units with gates would have the gates in the blind, and this necessitated removal of the wire mesh or removal of the nail to let the gate swing both ways so as to make possible a return in the event of an error. It is clear that with this procedure the effect was to confuse tactual and olfactory stimuli completely and probably to add new distracting stimuli because of the unevenness of the floor and the presence in many units of gates in blinds, these gates being in such positions that they could be felt by the vibrissae of the rats when they stood at the choice points.

METHODS AND ANIMALS

The rats were blinded by removal of the eyeballs, a simple operation that had no perceptible bad effect on the rats' health or vigor. Preliminary training was begun five days after the operation. This preliminary training required six days and consisted of three runs over a straightaway on the first day and then from four to seven runs daily on longer set-ups with corners and gates. The rats were then started on the maze proper (fig. 1).

Two runs daily were given on the maze up to the twenty-first day, and thereafter three runs daily. The animals were fed only in the food box at the end of the maze and the food was so apportioned that they were always hungry and eager for food. Frequent weighing was used as a check against too great a loss in weight.

An entrance into a blind to within four inches of the end of the blind was counted an error. This means that in the longer blinds (blinds varied from 11 to 14 inches) the rat could enter a blind to its full body length, but if its vibrissae did not reach the end of the blind—and this could not occur unless the rat came within less than four inches of the end—such an entrance was not counted an error. Ignoring in this way partial blind entrances may be thought a low criterion for error scoring. Reasons for the procedure are as follows. If a blind rat turns before it has reached the end of the blind, we may fairly say that without direct sensory evidence of having entered a blind it has checked an error. Visual evidence was precluded, since the rats were blind; tactual and olfactory evidence could not be depended on, because units were shifted and turned end for end. In the short cut trials, when the rats came to choice points immediately after making the short cut, hesitation and uncertainty in behavior was frequently observed. Often an entrance into a blind was begun but quickly checked. Since units were interchanged in all short cut trials, specific sensory stimuli could not be causes for this checking of false turns, and we may say that in such entrances a complete error was not made. Some danger lay in the possibility of inaccurate observation of the rat's distance from the end of the blind, and it should be said that if there was any doubt the entrance was scored an error. Full errors, as just defined, were indicated by the numbers of the blinds in which they were made; thus not only the number of errors but also the exact location of each error was recorded for every run.

RESULTS FOR GROUP III

Group III consisted of 13 males and 4 females, ranging in age from 2 to 4 months at the beginning of training. For the first two days of training (two runs daily) the maze was unchanged. On the third day, 13 of the 26 units in the maze were interchanged and turned end for end. Figure 2 gives the error curve for the group. A rapid drop in the curve for the first two days will be noticed. It is certain from results of the previous study and from other maze studies that this descent of the curve would have continued on the third, fourth, and perhaps the fifth day, if the maze had been left unchanged. The sudden shifting of 13 maze units on the third day checked this drop of the curve. Thereafter, because no less than 10 (usually more) units were shifted for each and every run, the curve is jagged and its descent extremely slow. Shifting of units was so arranged that each day all the units changed place, about one-half for the first run, the other half for

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the second. To reach what looked like a plateau required 25 days of running, or 55 runs. It was thought that increasing the number of daily runs might hasten learning, so from the twenty-first day on three runs daily were given.

The checking of the initial drop in the curve due to interchange of units and the subsequent slow descent of the curve raise an important question. W. S. Hunter,⁽²⁾ from similar results on his own mazes, has argued that the stimuli from the maze are directive; they become cues in the true sense because they call forth definite behaviors. Confusion of the stimuli by shifting of units causes disruption of maze performance, or, as in our experiment, a retardation in learning, because, with constant shifting, stimuli cannot become directive. But it is possible to argue, perhaps less plausibly, that shifting of units (and of stimuli) is merely distractive. Thus, disruption of maze performance could be said to result from distraction ensuing from a change in the habitual arrangement of stimuli. Against this view may be advanced the argument that negative adaptation to this sort of distraction should be acquired and that our curves, after the initial slowing down, should drop more rapidly than they have done. It is clear, from these opposing interpretations, that the question of the function of intra-maze stimuli in maze performance is not conclusively answered by our results or by Hunter's. It is also guite clear that we have here a question of fundamental importance in the general problem of maze learning.

But whatever the true function of intra-maze stimuli may be, the rats undoubtedly learned the maze to a fair degree of accuracy. Thus on the twenty-third and twenty-fourth days the error records (3 runs daily) were, for the six trials, 11, 12, 38, 23, 24, and 18 errors respectively; or, expressed as average scores per rat: 0.65, 0.71, 2.24, 1.35, 1.41, and 1.10 errors respectively. Since there were 19 blinds in the maze, even the highest average score (2.24 errors) indicates a high degree of accuracy of performance. We may conclude that the rats learned the maze independently of specific tactual and olfactory stimuli from the maze, or, in other words, that accurate running was not a matter of simple stimulus-response connections, so far, at any rate, as intra-maze stimuli were concerned.

There remained extra-maze auditory and possibly olfactory stimuli. To check on the possible influence of these, (1) the maze was rotated first 180° from its original position, then back to its original position, and (2) the food box and food were moved to a position near blinds 7 and 9 (see fig. 1). The curve of figure 2 shows the results of these changes. Correlated with removal of food box and food, there were no significant increases in errors. Upon rotation of the maze there is an upward jump, in the error curve, from 13 to 29 errors. It is, however, very doubtful that this increase in errors was entirely due to a change in the direction of auditory stimuli. Because the maze was not on a platform, rotation could only be effected by taking the maze completely apart and setting it up again in a new place; and, because of the extreme unevenness of the floor, this procedure undoubtedly caused unusually large tactual differences at the junctions of units, i.e., the choice points. The upward jump in the error curve was most probably due to this fact. Nevertheless, the highest error score when the maze was rotated was only 4 errors greater than the highest score in the four days before rotation. It is to be noted also that there are in the error curve other upward jumps as large as and some larger than this rise of 16 errors (an average increase of 1 error per rat) which seems to be due to maze rotation. For example, on day 55 there is an upward jump of 18 errors; on day 23, 26 errors; on day 20, 18 errors. We may safely conclude that extra-maze auditory and olfactory cues did not play an appreciably significant rôle in the maze performance.

So far, we had excluded visual stimuli, prevented the operation of specific intra-maze tactual and olfactory stimuli, and shown the lack of influence of extra-maze auditory and olfactory stimuli. The possibility remained that the rats were running the maze kinaesthetically. In kinaesthetic behavior, as, for example, the playing of a very well known piece on the piano, it is generally supposed that each movement is the stimulus for a definite succeeding movement. The essence of kinaesthetic behavior is the definite, unvarying order in the sequence of movements. Disruption of the order, or any forced changed in the fixed sequence, must inevitably disrupt the organism's smooth performance, and presumably the animal is compelled to fall back on external stimuli to set itself right, to recover the habitual order of movements. In our rats such a forced disruption was effected by short cutting, that is, by forcing the rats, by means of a block and a short new path, to leave out a part of the maze. The habitual order of movements was definitely changed. But when the order of movements of the rats was thus changed there was no possibility of falling back on specific stimuli, for these were changed with the shifting of the units, and auditory and olfactory stimuli from outside the maze were found to be without influence.

Training for Group III extended over 60 days. From the twentyfirst day on, as mentioned above, three runs daily were given, and on the twenty-sixth day the various short cutting trials were begun. Eleven different short cuts, as indicated in figure 1, were tried, and eight of these were given twice on widely separated days. The first run each day was always over the whole maze (such runs will hereafter be called normal pattern runs) and frequently the first two runs were of this type, followed by short cut or "put on" trials. It was necessary to give at least one, preferably two, runs each day over the complete maze, because the true path in the maze as a whole had to be maintained as a basis on which to try short cuts. A succession of short cut trials without normal pattern runs would probably have led to confusion, since this would have meant the running of changing maze patterns.

The procedure being in all essentials the same for all short cuts, one short cut trial may be described in some detail. Short cut 2-7 (see fig. 1) was given on the twenty-sixth day (fig. 2). On this day ten units of the maze were interchanged and a normal pattern run was given. A short path was then inserted between units IV and X, and two tin blocks were placed, one at a point six inches from the turn into unit V, the other six inches from the turn into blind 6. All the units from unit IX on were interchanged with other units. The rats were started from the platform and all entered unit V, as was to be expected. Encounter of the block here naturally caused some confusion; most of the rats wandered back over unit IV to the gate on unit III. It may be mentioned that this confused behavior diminished with succeeding short cut trials, as if the rats had learned to look for a short cut path whenever a block was encountered. Sooner or later, the new path to unit X was

found and taken. All the rats, on this trial, approached the block on unit IX. Our chief interest was to record the rats' behavior from this point on. Hesitations at the choice points were frequent, but no complete record was made of these; only errors as defined above were recorded. The units were again shifted and the rats run a second time on this short cut. The number of errors made in the part of the maze from blinds 7 to 19, inclusive, is to be compared with the number of errors made in the same portion on normal pattern runs, that is, when the rats ran the entire maze. Although error curves furnish easier and clearer comparisons, we present, to conserve space, a table instead. Table I gives scores for each trial of the various short cuts, and, to compare with these, eight scores on the same part of the maze when the rats ran the full normal pattern. Table 1 is to be read as follows. Short cut 2-7 (blinds 7-19) was given three times, twice on the twenty-sixth day and once on the forty-ninth day (right-hand column). Error scores made on these trials are, in the same order, 15, 22, and 13 (third column). Error scores made on the same part of the maze, namely, blinds 7-19, when the rats ran the normal pattern, are 29, 17, 18, 28, 11, 6, 12, and 11 (second column). These eight scores are taken from the eight normal pattern runs preceding the first 2-7 short cut trial, and are therefore only sample scores, since there were many more normal pattern runs, but these scores are representative of normal pattern performance on blinds 7 to 19. It will be noted that the highest score for short cut 2-7 (22 errors) is well below the highest normal pattern score (29 errors). We may therefore say that this short cut was executed within the criterion of correct performance. Whatever confusion the short cut may have caused, it was certainly not sufficient to increase the errors above the usual records when the rats ran the whole maze. The data of table 2 indicate that the rats did not explore more than usual; dependence on specific tactual and olfactory stimuli from the maze was impossible, because the units had been shifted; extra-maze auditory and olfactory stimuli had been found without effect. We may conclude tentatively that the rats in some sense "knew" where they were after taking the short cut path, and that by virtue of this "knowledge" they ran the rest of the maze with their usual accuracy.

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	Normal pattern scores	Short cut scores	Days when short cuts were given
Short cut 2-7 (Blinds 7-19)	29, 17, 18, 28, 11, 6, 12, 11	15, 22, 13	26, 26, 49
Short cut 8-12 (Blinds 12-19)	5, 13, 9, 5, 4, 2, 5, 9	18, 6, 20, 4, 14	27, 27, 50, 51, 51
Short cut 2-5 (Blinds 5-19)	22, 26, 15, 14, 19, 12, 19, 21	24, 18, 21	28, 28, 52
Short cut 6-14 (Blinds 14-19)	2, 1, 0, 1, 0, 5, 0, 4	18, 13, 5, 8, 5	29, 29, 30, 30, 57
Short cut 8-14 (Blinds 14-19)	0, 1, 0, 5, 0, 4, 2, 5	3, 2	31, 31
Short cut 3-6 (Blinds 6-19)	23, 19, 34, 26, 23, 18, 14, 24	29, 15, 16	32, 32, 54
Short cut 2-15 (Blinds 15-19)	0, 5, 0, 2, 1, 5, 0, 1	10, 5, 6	33, 33, 59
Short cut end 6-15 (Blinds 15-19)	5, 0, 2, 1, 5, 0, 1, 1	0, 2	37 , 37
Short cut 3-mid 8 (Blinds 6-19)	19, 21, 23, 18, 14, 24, 17, 19	20, 20, 7	34, 34, 55
Short cut 1-15 (Blinds 15-19)	0, 2, 1, 5, 0, 1, 1, 0	10, 2, 1	35, 35, 57
Short cut mid 17-15 (Blinds 15-19)	2, 0, 1, 5, 0, 6, 1, 0	6, 2	36, 36

TABLE 1

				Sho	rt cut	2-7					
B	linds*	7	8	9	10	11	13	14		Totals	Number of rats making errors
Trial 1	Errors	5	3		2		5			15	10
Trial 2		1	3	1	4	1	11	1		22	15
Trial 3		1	5	2	5					13	10
	Totals	7	11	3	11	1	16	1		50	
				Shor	t cut 8	-12	.			I	
В	lin ds	12	13	14	17						
Trial 1	Errors	3	12		3					18	12
Trial 2		2	3		1					6	6
Trial 3		6	13	1						20	14
Trial 4		1	3							4	4
Trial 5		2	12							14	12
	Totals	14	43	1	4					62	
				Sho	rt cut	2-5	·				
Bl	inds	5	6	7	8	9	10	11	13		
Trial 1	Errors	8			7	1	4		4	24	14
Trial 2			1	1	9	1	2	1	3	18	13
Trial 3	••••••	6	2		5		5	1	2	21	12
	Totals	14	3	1	21	2	11	2	9	63	
				Shor	t cut 6	-14					
B	lin ds	14	16	17							
Trial 1	Errors	12	4	2						18	12
Trial 2		8	2	3						13	11
Trial 3		2	3							5	5
Trial 4		7	1							8	8
Trial 5		3		2						5	4
	Totals	32	10	7						49	

TABLE 2

* Blinds containing no errors, for example, blinds 18 and 19, are not indicated in the table.

				Shor	t cut i	8-14			
B	linds	14	16	17			 	 Totals	Number of rats making errors
Trial 1 Trial 2	Errors	1	2 1	 1			 	 3 2	3 2
	Totals	1	3	1			 	 5	

TABLE 2-(Continued)

Short cut 3-6

Bli	inds	6	7	8	9	10	11	18	16	х. 	
Trial 1 Trial 2 Trial 3	Errors	4 1	2 1 3	8 5 5	2 1 1	5 3 5	1	6 5 1	1 	29 15 16	15 11 12
	Totals	5	6	18	4	13	1	12	1	60	

Short cut 2-15

Bli	nds	16	17	18	 	 			
Trial 1 Trial 2 Trial 3	Errors	7 1 4	1 3 2	2 1 	 	 ·····	····· ····	10 5 6	10 5 6
	Totals	12	6	3	 	 		21	

Short cut 3-mid 8

Bli	nds	6	7	8	9	10	12	13	17		
Trial 1 Trial 2 Trial 3	Errors 	3 2 	1 2	7 5 2	 1 3	3 7 	2 2 	3 2 	1 1 	20 20 7	12 12 6
	Totals	5	3	14	4	10	4	5	2	47	

				Shor	t cut 1	-15					
Bl	inde	16	17							Totals	Number of rats making errors
Trial 1	Errors	6	4							10	8
Trial 2		1	1							2	2
Trial 3		1								1	1
		-		-	—	—	-	-	—	-	
	Totals	8	5							13	

TABLE 2—(Concluded)

			8	hort c	ut mid	17-15			
В	linds	15	17				 		
Trial 1 Trial 2	Errors	4 1	2 1				 	 6 2	
	Totals	5	3				 	 8	

5 1

_										
Bli	nds	17					 			
Trial 1 Trial 2	Errors						 		 4	 4
		-	-		-	—	 -		-	-
	Totals	4					 		4	

Short cut and 6-15

It is also of interest to know in what blinds the errors were made on short cut trials, and how many rats of the seventeen made errors. This information is contained in table 2, which is to be read as follows: On the first trial of short cut 2–7, blind 7 had 5 errors, blind 8, 3 errors, blind 10, 2 errors, blind 13, 5 errors; and 10 rats made a total of 15 errors, which means that some of these 10 rats made more than one error while the remaining 7 rats made no errors. On the second trial, blind 7 had one error, blind 8, 3 errors, etc., and 15 rats made a total of 22 errors. The totals indicate that blind 13 was entered most frequently (16 errors), and blinds 8 and 10 next (11 errors each). If the rats had explored the maze immediately after taking the short cut, in an effort to "pick up" the kinaes-

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thetic sequence, we should expect blinds 7 and 8 to account for most of the errors. Actually they account for 18 errors as against 27 errors in blinds 10 and 13. Blinds 10 and 13 were, incidentally, also difficult in the normal pattern runs.

At this point two possible arguments may be considered. The possibility that the rats might have run correctly the part of the maze following the short cut path by chance, was mentioned above. In the previous experiment,⁽¹⁾ in order to obtain objective evidence on this point the maze pattern following short cut 2–7 (and other short cuts) was completely changed, but the new pattern had the same number of blinds. The argument was that, if the rats were running corectly merely by chance, then they should perform equally well on any pattern. The enormous increases in errors when the maze pattern was changed demonstrated conclusively that chance could not account for the rats' performance. Because of this clear demonstration it was deemed unnecessary to repeat the procedure in the present study.

The other argument is that, in spite of the constant shifting of units, some intra- or extra-maze stimuli by which the rats could be guided, still remained. If there were such directive stimuli, it is reasonable to suppose that the rats could be guided by them from any point within the maze to the end of the maze. This was tested by the following procedure: The rats were placed by hand on the end of blind 6, which is the place they reach after going through the short cut path, and allowed to run to the end. A block was placed, as in short cut 2-7, on unit IX six inches from the turn into blind 6. Units were changed as for short cut runs. The starting platform was not used. Table 3 gives the results for two such "put on" runs; the error scores are 32 and 44 as against scores of 15, 22, and 13 for the corresponding short cut 2-7. This excess of "put on" scores over short cut scores indicates considerable confusion, or, we may say, lack of "knowledge" of whereabouts in the maze. (Similar "put on" runs, corresponding to each of the other ten short cuts, were tried, and in all the runs there were significant increases in errors—see below.) We may safely conclude that if any directive stimuli remained after unit-shifting (for both "put on" and short cut runs), they were insufficient for the correct guidance of the rats.

	Day on which given	Errors	Errors on corresponding short cuts
Put on end of blind 6, correspond- ing to short cut 2-7	38 38	32 44	15, 22, 13
Put on end of blind 11, correspond- ing to 8-12	39 39	28 20	18, 6, 20, 4, 14
Put on end of blind 4, correspond- ing to 2-5	40	49	24, 18, 21
Put on far end of unit 18, corre- sponding to 6-14	41	18	18, 13, 5, 8, 5
Put on mid unit 17, corresponding to 8-14	42	11	3, 2
Put on mid unit 9, corresponding to 3-6	43	27	29, 15, 16
Put on food end of unit 18, corre- sponding to 2-15	44	10	10, 5, 6
Put on mid unit 18, corresponding to end 6-15	48	8	0, 2
Put on mid unit 8, corresponding to 3-mid 8	45	27	20, 20, 7
Put on end of unit 19, correspond- ing to 1-15	46	15	10, 2, 1
Put on mid unit 21, corresponding to mid 17-15	47	13	6, 2

TABLE 3

When we ask why the large difference in error scores between the short cut and the corresponding "put on" runs, the importance of the run from the starting platform to the short cut path, plus the run along this path, becomes evident. The run from the starting platform to the short cut path was obviously essential to good performance beyond the short cut. The reason for this will become clear from the results of Experiment II. The remaining ten short cuts (and the corresponding "put on" runs) will be briefly discussed in the order in which they were given. (For the exact location of each short cut, fig. 1 should be consulted.) Short cut 8–12 was not executed with the required accuracy in four of the five trials on which it was given. This was surprising, since on casual inspection of the maze one would judge this short cut to be easy. Of the 62 errors made in the five trials of this short cut, 43 (70 per cent) were made in blind 13 (see table 2). The error scores of the two "put on" runs, however, are higher than the short cut scores; this would indicate that confusion after the short cut was not so great as on the "put on" runs.

Short cut 2-5 was performed with the required accuracy on its three trials. The very high score of the corresponding "put on" run confirmed the fact that the run from the starting platform to the short cut path was essential to good performance thereafter.

Of the five trials of short cut 6-14, only one (the last) may be considered as done correctly. This short cut was probably so difficult because of the presence of blind 14 at the end of the short cut path. Of the total of 49 errors made on the five trials, 65 per cent were made in blind 14. Of the errors made in the "put on" run which was started on the short cut path, 77 per cent were in blind 14. That there were relatively few errors in the blinds beyond 14, namely, blinds 15 to 19, may be explained by saying that the long run over unit XVIII plus the two turns without blinds at the ends of unit XIX acted as a triple cue by which the rats "recognized" their position in the maze. The recognition, however, could not have been by means of stimuli from the units themselves, since these were changed. It is, however, possible that the long run and the turns acted as kinaesthetic cues, that is, that these re-aroused the kinaesthetic pattern. The possibility that some short cuts could be explained in this way will be considered in connection with short cuts that have such factors in their favor.

The two trials of short cut 8–14 come easily within our criterion of good performance. The long run on unit XVIII plus the two turns cannot be advanced as an explanation, since these come after blind 14. Of a total of 5 errors this blind accounted for only one. The "put on" run had a high score, again demonstrating the necessity of the run from the platform to the short cut. But further, of the 11 errors made on the "put on" run, 82 per cent were in blinds 16 and 17. Thus, in this run at least, the run over long unit XVIII plus the two turns did not act as an effective cue. This conclusion is strengthened by the results of poorly executed short cut 2–15, which had the two turns but not the long run in its favor, and nevertheless had too many errors, chiefly in blind 16.

The first trial of short cut 3-6 may be considered doubtful, since its score is as high as that of the "put on" run. The remaining two trials, however, are well within the criterion. The three scores made on short cut 3-mid 8 were well below the highest normal pattern score; the corresponding "put on" run had a high score. The first trial of short cut 1-15 had too high a score; the other two trials yielded low scores. The corresponding "put on" score was high. The scores of short cuts mid 17-15 and end 6-15 were all good, the first trial of short cut end 6-15 having no errors at all. The corresponding "put on" scores were high.

Aside from the long run on unit XVIII and the two turns at either end of unit XIX mentioned above, correct performance on short cut runs might possibly take place simply as a result of the following out of an acquired kinaesthetic pattern. If the sequence of turns following close after a short cut is exactly the same as the sequence of turns in the part of the maze that has been left out, the rats could run a short cut trial correctly by simply following a habitual kinaesthetic sequence. For example, the sequence of turns following short cut 2-7 is LRLLRL, etc.; the sequence in the left-out portion is RRLLLR. Here, obviously, the two sequences are different, and a following out of the habitual one would not give a correct performance in the short cut trial. The two analogous sequences for short cut 2-5 are LLRLRL, etc., and LRRLLL; for short cut 6-14 they are LRRLLRLLR and RLRLLRLLR. Even though the two sequences of turns were the same, a correct performance on a short cut trial would involve a disregard of the differing length of runs between turns, and this is unlikely. Inspection of the maze in figure 1 will show, however, that in no short cut are the two sequences alike, and consequently it cannot be said that the following of a learned, stereotyped sequence accounts for any correct performance on a short cut trial.

SUMMARY AND CONCLUSIONS

We may summarize the results of short cutting as follows: On two of the eleven different short cuts (8-12 and 6-14), error scores were too high to meet the required accuracy. On three short cuts (3-6, 2-15, and 1-15) scores of first trials were doubtful or definitely too high, but the scores of remaining trials for each short cut were good. On six of the eleven short cuts (2-7, 2-5, 8-14, 3mid 8, mid 17-15, and end 6-15), scores on all trials were well within the criterion. The six corresponding "put on" run scores were high, that is, above the criterion used for short cut trials. It is evident from this that the run from the starting platform to the short cut path was essential to accurate performance beyond the short cut.

Why some short cuts should be performed correctly and others not is not at all clear from the maze used in this experiment. We may hazard the guess that the spatial characteristics of a short cut, that is, its position in the maze, have something to do with it. The character of the maze pattern following a short cut does not seem to be a determining factor, for the patterns following the six correct short cuts differ greatly one from another. Since six of the eleven short cuts were executed with the required accuracy, we conclude that rats possess in some degree the ability in question. This ability we should describe as a capacity to react effectively and with a minimum of effort, not on the basis of specific stimuli, but by the apprehending of spatial relations.

EXPERIMENT II

THE MAZE FOR GROUPS I AND II

In order to discover if possible what the spatial characteristics of a short cut may be that make it difficult or easy, an elevated maze of a simpler general outline was constructed. It was thought that a maze rectangular in outline with different arrangements of blinds in three corners might reveal something of the factors operating. Accordingly, the maze shown in figure 3 was set up. As in the other maze, the rails were of pine 2 inches wide, set on uprights 30 inches from the floor. The three long paths (units I, VIII, and XV) each measured 8 feet, and were therefore interchangeable. Two gates on each of these long rails prevented retracing. The maze contained 14 blinds, all 12 inches in length except blind 9, which was 16 inches. The units in the corners were of two different lengths, 16 and 30 inches. Besides the units in the maze, two 8-foot rails, four 16-inch units, and six 30-inch units were constructed, and these were inserted in the maze at appropriate places when interchanging of units began. It is clear that, as in the other maze, a complete change of component parts was possible without change of maze pattern.

In a maze of this sort it was comparatively easy to make the arrangements of the blinds in the three corners differ one from another sufficiently to preclude the possibility of a rat's running correctly through one corner arrangement under the mistaken notion that it was in some other corner. Inspection of figure 3 will show that the true path at the three corners describes quite different patterns. The succession of turns in the corners is as follows: first corner, R(L)LRRL(L); second corner, (L)LRRR(L)(L); third corner, L(R)RLRL. (Letters in parentheses refer to forced turns, that is, turns without blinds.)

Specifically, the questions asked were these: (1) If the rats are short cut diagonally from one side of the rectangle to the adjacent side, thus cutting out one corner arrangement of blinds, will they react correctly in the rest of the maze? (2) If two corners are cut out by short cutting from one side to the opposite side, will the rats perform correctly? (3) Will performance after the rat has run a diagonal short cut differ from the performance after the rat has run a short cut made by removing the units in a corner and extending one side to make it join the adjacent side at right angles? In more general terms, the question was whether the rats were aware that the maze pattern formed a rectangle, and whether, by virtue of this awareness, they could execute correctly the various short cuts.

METHOD AND ANIMALS

Two groups of male rats (Groups I and II), each group composed of 13 rats, were trained over a period of 102 days. The rats ranged from 2 to 4 months in age at the beginning of training. Blinding was effected by removal of the eyeballs. Preliminary training extended over four days with 3 to 6 runs daily, first over



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a straightaway, then over longer paths with turns and gates. On the maze proper two runs daily were given, and, even when short cutting was begun, the number of daily runs was never more than two. Food was always given in the food box at the end of the maze,



Fig. 3. Diagram of elevated maze used in Experiment II. Arabic numerals indicate blinds; roman numerals, units. Short cuts are indicated by broken lines and capital letters.

and frequent weighing served to prevent too great a loss in weight, besides indicating roughly the degree of hunger.

As in Experiment I, an entrance into a blind to within four inches of the end of the blind was counted an error. The reasons for this scoring criterion given in Experiment I hold here also. If the rat's distance from the end of a blind was in doubt, the entrance was scored as an error. Errors were indicated by the numbers of the blinds in which they were made.

RESULTS FOR GROUPS I AND II

Results for Groups I and II up to the point when short cutting began will be treated separately. This is because Group II was started on the maze two days after Group I, and thus Group I was four runs ahead of Group II. But before short cutting began, the two groups were equalized by running Group I only once a day for four days so that this group then had the same number of runs as Group II. Thereafter, all short cuts and other runs were given the two groups on the same days, and results on short cuts and other runs for the two groups have accordingly been lumped.

Because of the long paths between the corners of the maze, that is, between the parts that required learning, it was thought that learning would be somewhat retarded. It was therefore surprising to find a very steep descent in the error curves of both groups (fig. 4). By the end of the third day (six runs) the rats had apparently learned the maze; from that day on both curves are plateaued, the only noticeable deviations being the two runs on day 7 of Group II. It is perhaps unnecessary to remark that during this period the maze was not changed in any way. We wished to see what effect the sudden interchanging of all maze units would have on the rats' performance and thereby possibly to gain some light on the rôle of intra-maze stimuli.

On the thirteenth day for Group I and the eleventh day for Group II (because Group II was two days behind Group I) every unit of the maze was interchanged with some other appropriate unit. This change was made for the second daily run, that is, between the first and second runs of the day. The effect on both groups was startling. Group I made more errors than it had on the first trial; Group II made almost as many (fig. 4). It was as if a new maze had been suddenly presented. Whatever the exact rôle of intra-maze stimuli may be in respect to blind rats, it was obvious that the changing of these stimuli by shifting of units had a great disruptive effect on maze performance.

Other interesting facts appeared. As was mentioned above, the interchange of units was made for the second daily run of days 11 and 13. The maze was then left untouched for the first run of the succeeding day. But for the second run of the succeeding day the units were again completely interchanged. Thus the shifting of units took place between the two runs of each day up to day 21 (day 19 for Group II). Considering for the moment only the curve of Group I, we note a very regular up and down zigzagging from days 13 to 21. It will be noticed that all the points marked "2" are above the points marked "1"; the second run of each day, that is, the run immediately following an interchange of units, always had more errors than the first daily run, which was made on the maze unchanged from the previous day. One may interpret this by saying that on the first run of each day (and the last run of the preceding day) the rats had experienced groups of stimuli (tactual, kinaesthetic, and olfactory) in definite spatial relations and that the disturbance of the general stimulus-pattern resulting from the unit-shifting for the second daily run was the cause of the increase in errors. The question whether the increase in number of blind entrances was due to distraction or to the fact that the stimuli had taken on some directive value during the two previous runs, is not answered by the results just described, and we shall presently show that this question is probably beside the point.

On the above interpretation as a basis, a prediction might be made that interchanging units between days instead of between the two daily runs should cause the following changes in the error curves: (1) the first runs of each day should have more errors than the second runs, and (2) the up and down zigzags should be of smaller magnitude, since the rats had a longer period (24 hours) in which to "forget" how the stimuli were arranged on the preceding day. Actually, the curve bears out these predictions. The points marked "1" are all higher than the points marked "2." (The reversal in the relative positions of the 1's and the 2's caused by the change in time of unit-shifting is easily seen by following the broken line in fig. 4, Group I). And the up and down excursions of the curve are in general smaller.

The facts, then, are that, when unit-shifting occurred between the two daily trials, the second trial always showed more errors

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than the first, and that when the shifting occurred between days, the first trial showed more errors than the second. We must add, however, that although the same facts also hold substantially for Group II, there are two differences between the two curves: (1) the up and down excursions of the curve of Group II are not so regular as those of the curve of Group I, and (2) on day 24 (Group II) the positions of "1" and "2" are reversed. Probably these differences are not serious, since the spatial relations of the "1" and the "2" points are, with the one exception noted, constant.

We return once more and briefly to the questions of distraction and the possible directive rôle of stimuli. It has been argued that, if the maze had been left unchanged after the first unit-shifting, the curves would have descended to their former low levels in a few runs, as is evidenced by the sharp drops on days 14 (Group I) and 12 (Group II), and that it was the continual distractions caused by interchanging of units that prevented this. On the contrary, it is equally plausible to argue that constant interchanging prevented stimuli from becoming directive. And against the distraction theory it may be further urged that habituation or negative adaptation to continual distraction, if it were really distraction, would have been acquired, and the curves would have reached plateaus much sooner than they actually did.

We have returned to this discussion, first, because of the obvious importance of the question of the rôle of stimuli in maze learning, and, secondly, because one of the theories, namely, that the stimuli are directive, has been accepted⁽²⁾ on what we believe to be entirely insufficient evidence. It appears, however, from the significant results of Lashley's researches, that the question whether or not individual stimuli are directive, in the sense that each response is connected in some way with a specific stimulus, is beside the point, that it is an unreal question. Nor, it seems, can we attribute the great disturbance in maze performance following the disturbance of stimuli to distraction in the usual meaning of the term. Lashley writes :

We may state as a general principle that the stimulus to any reaction above the level of a spinal reflex involves, not the excitation of certain definite sensory cells, but the excitation of any cells of a system in certain ratios, and that response may be given to the ratio, even though the particular cells involved have not previously been excited in the same way during the formation of the habitual reaction.⁽⁴⁾

Though this was written specifically of visual-perceptual habits, the principle applies to all types of habits. In another place⁽⁸⁾ Lashley writes:

... I believe that in every reaction, above the level of a spinal reflex to protopathic stimulation, the adequate stimulus is a pattern which is effective when applied anywhere upon the sensory surface and the motor response involves an equally variable grouping of motor neurons.... We have seen that the adequate stimulus in such cases [habits based on vision, kinaesthesis, and touch] is not the specific cells activated, but the pattern of excitation which may shift over the sensory surface and likewise over the cortical field. In such a pattern the relative intensity, distance of separation, and frequency of excitations seem to be the only constant factors.

It seems clear that a reaction is made not to individual and specific stimuli but to patterns of stimuli. We cannot then speak of directive stimuli in the sense that each stimulus calls out a particular response. The integrated response of running the maze is made to a stimulus pattern or perhaps to groups of stimuli that are patterned in definite ways. It is probable that, as the rat learns a maze, complex integrations of visual, tactual, olfactory, and kinaesthetic stimuli are formed. Visual stimuli being excluded for our rats, integrations were probably established through tactual, kinaesthetic, and olfactory stimuli. The sudden disturbance of tactual and olfactory stimuli by unit-shifting had the effect of disrupting completely the stimulus groups that formed the basis for correct response. Kinaesthetic stimuli alone were not sufficient after such a disruption, and the maze habit had to be re-formed on the basis of new integrations. If this interpretation is true, it is clear that we cannot speak of distraction as the cause of maze-habit disturbance following unit-shifting.

One further point remains to be mentioned regarding the error curves of Groups I and II. These curves, in spite of their great irregularity, show a steady, although slow, descent. The maze was undoubtedly being learned, albeit slowly. On the three days preceding day 30 (Group I) and day 28 (Group II) the error scores for the groups are: Group I, 29, 18, 24, 23, 27, and 27 errors; Group II, 32, 24, 28, 20, 30, and 18 errors. Expressed as average scores per rat on single runs these are: Group I, 2.23, 1.38, 1.85, 1.77, 2.08,

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and 2.08 errors; Group II, 2.46, 1.85, 2.15, 1.54, 2.31, and 1.38 errors. Thus the average errors per rat ranged from slightly over one to two and one-half errors on a fourteen-blind maze. We may say that the rats learned the maze though not with a high degree of accuracy.

	Scores	Days		Scores	Days
	35	70	Maga rotated 00°	4 0	82
	33	71	Maze fotated 90	37	
	32	72		42	83
	25	73	Maze rotated 180°	41	
Before	31	74	position	42	84
	23	75		37	
rotation	25	76		32	85
	17	77		31	
	31	78	Maze turned back	34	86
-	18	79	position	24	
	21	80		32	87
	27	81		26	

TABLE 4

Beginning with day 30 (Group I) and day 28 (Group II) unitinterchanging was discontinued for eight days, the object being to see if this would hasten learning, that is, the elimination of errors. It did not do so, and the reason was that approximately half the rats had apparently acquired, during the unit-shifting period, stereotyped errors, chiefly in blinds 2, 9, and 10. But the up and down excursions of the curves were noticeably decreased, confirming the fact that such excursions had resulted from interchanging of units.

Before proceeding to the results on short cut trials it will be well to dispose of the matter of maze rotation, which was used as a check on the possible influence of extra-maze olfactory and auditory stimuli. The maze was rotated first 90° counter-clockwise, then another 90° counter-clockwise (180° from original position), and finally back to the original position. Instead of an error curve to show the effects of this rotation, we present table 4, which gives a number of error scores (for the group of 26 rats on the whole maze) before and after rotation.

When the maze was rotated 90° there was an increase of 5 errors over the highest score before rotation (from 35 to 40 errors). With the next rotation the highest score was 42 errors. As with the maze of Experiment I, rotation could be effected only by taking the maze apart and setting it up again in a new position; and, because of the unevenness of the floor, it is certain that discrepancies occurred at the junctions of units, and that these discrepancies were not present when units were interchanged while the maze was in its normal position. The slight increases in error scores may easily be due to these unusual tactual stimuli and not to directional change of extra-maze auditory or olfactory stimuli.

Results on Short Cut Runs

Short cutting was begun on day 47, by which time, as explained above, the two groups were equalized as to number of runs. From now on the two groups will accordingly be treated as one. Eight different short cuts were tried: short cut 1-8, by a long diagonal (marked A in fig. 3, which should be consulted for location of short cuts); short cut 8-15, by a long diagonal (marked B); short cut 1-15, from middle of unit I (C); short cut 1-8, at right angles (D); short cut 8-15, at right angles (E); short cut 1-8, by a short diagonal (F); short cut 8-15, by a short diagonal (G); and short cut 1-15, from unit I extended (H).

One short cut and its results will be described in detail before the others are considered. The first trial of short cut 1-8 by a long diagonal (A) was given on day 47 (fig. 5). All the units of the maze were first interchanged, including the units of corner 1 (the sets of blinds at the three corners of the maze will be designated, for convenience, corners 1, 2, and 3, in the order in which they are encountered from starting platform to food box). One of the 8-foot rails plus a 16-inch rail was placed in a position indicated by the

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broken line (A) in figure 3. Two blocks made of tin were placed, one on unit I, the other on unit VIII, each about six inches from the points where the diagonal short cut path joined units I and VIII. The 26 rats (Groups I and II consolidated) were run, and the errors in blinds 6 to 14, inclusive, were carefully noted. The error score for the group of 26 rats in blinds 6 to 14 is to be compared with the scores made in the *same* part of the maze when the whole maze was run, that is, in normal pattern runs. This comparison is shown in figure 5. As in Experiment I, a short cut is considered correctly performed only when its error score does not exceed the highest normal pattern score for the same part of the maze. It is clear (fig. 5) that the first trial of this short cut was not executed with the required accuracy; the short cut score (46 errors) exceeds the highest normal pattern score (27 errors) by 19 errors.

The error curves of figures 5 to 9, which show performances on short cut trials and on "put on" runs, were constructed in the following way: The blinds following any particular short cut were taken, and the errors made in these blinds when the rats ran the full normal maze pattern were counted. The first part of each curve shows their performance on a particular part of the maze for normal pattern runs. Next after this part, and as a continuation of it, the curve shows the number of errors made in the same part of the maze when the particular short cut under consideration was given. Thus a direct comparison can be made between performances on a specified part of the maze for short cut and for normal pattern runs. Because each short cut was given more than once there are parts of the curves between short cuts that represent performance on normal pattern runs for the appropriate part of the maze. And in the period of time between any two trials of a particular short cut, other short cuts were given, but these are not represented on the same curve, since these other short cuts cover different parts of the maze. Because normal pattern runs following short cut trials may be disturbed (that is, error scores increased) by the preceding short cut runs, and thus there may be produced abnormally high normal-pattern scores with which short cut scores must be compared, each curve contains a part representing normal pattern scores before short cut trials were begun. In-

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spection of the five curves will show that in each curve the highest normal pattern score comes, not in the period during which short cut trials were given, but in the period before day 47, that is, before short cut trials were begun.

Short cut 1-8, by a long diagonal, was repeated on days 55, 67, 79, and 88 (fig. 5), and on all these trials the errors were too high to come within our criterion. Table 5 shows that on the five trials of this short cut. 72 errors were made in blind 6. 69 errors in blind 9, 23 errors in blind 8, and relatively few errors in the remaining blinds. The reason for this distribution of errors is as yet largely a matter of guesswork; one may, however, plausibly assume that the large number of errors in blind 6 occurred because the first correct turn in corner 1 is to the right and the rats were under the mistaken notion that they were at corner 1 instead of corner 2, and accordingly turned right into blind 6. From table 5 we note also that, on the first trial, 22 of the 26 rats made one or more errors. 22 rats made errors on the second trial, 15 rats on the third trial, 19 rats on the fourth, etc. Inspection of individual error scores reveals the fact that two of the 26 rats, namely rats W2 and W18, made perfect scores (no errors) on all five trials of this short cut. This confirms what one would expect, that rats vary in their ability to execute short cuts correctly. On any particular short cut trial, some rats will make many errors, some no errors. This means that when we lump the results of a group of rats, as we do here, (1) the good performances of able rats are obscured, and (2) the performances of the poorest rats determine disproportionately the performance of the group, since able rats can do no better, whereas the error scores of the poor rats are limited only by the number of blinds. Thus the performance on any short cut is largely the performance of the poorest rats. The remedy for this would be consideration of individual scores, individual error curves, etc., but the great practical difficulties of this procedure outweigh its advantages.

Finally, we must note the performance on the "put on" run that corresponds to short cut 1-8 by a long diagonal (fig. 5). This type of run, as explained under Experiment I, began at the point where the short cut path of the corresponding short cut ended, in this run at the point where the diagonal path joined unit VIII. The rats were placed by hand on unit VIII at this point. A block was used to prevent their running toward corner 1. The very high score on this run—32 errors above the highest short cut score—indicates that the rats were considerably more confused on the "put on" run than on the corresponding short cut run, even though the performance on the short cut run was not good enough to come within our criterion. It will be recalled from Experiment I that the run from the starting platform to the short cut path and the running of the path were found necessary for accurate performance in the maze beyond the short cut path. This finding was confirmed by all the "put on" runs of the present experiment.

We may now consider the seven remaining short cuts in the order given. Three trials on short cut 8-15 by a long diagonal (B in fig. 3) were given, on days 48, 55, and 70, and for two trials the scores were higher than the highest normal pattern score (fig. 6). Table 3 shows that 31 errors (70 per cent) of the total 45 errors were made in blind 10. The high score on the corresponding "put on" run indicated that confusion was less, or fewer rats were confused, on the short cut run than on the "put on" run.

Short cut 1-15 from the middle of unit I (C) had four trials, on days 49, 57, 79 and 99 (fig. 7), and all the scores were too high. Of a total of 112 errors, 67 (60 per cent) were made in blind 10 (table 5). The corresponding "put on" run had a score of 38 errors, only 6 errors above the highest short cut score.

The next short cut was 1-8, at right angles (D); five trials were given, on days 51, 58, 72, 81, and 91 (fig. 8). The error curve for this short cut shows all five scores well within the criterion. This was surprising, since the part of the maze run through after this short cut is exactly the same as that run through in short cut 1-8 by a *long diagonal*, except that in short cut 1-8 at right angles there are *longer runs on units I and VIII*. It will be recalled that short cut 1-8 by a long diagonal was never correctly executed (fig. 5). Why this difference ? Before considering possible explanations, let us see what occurred on short cut 8-15 at right angles and compare the performance on this short cut with that on short cut 8-15 by a long diagonal.

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Short cut 8-15 at right angles (E) was tried three times, on days 53, 60, and 72 (fig. 9). Again we find all the scores within the criterion. (The "put on" score was very high.) The only difference between this short cut and 8-15 by a long diagonal is that there are longer runs on units VIII and XV. (It cannot be said that the right-angled short cuts were correctly performed because they came later in training when the rats were more familiar with the maze, for, if this were so, the still later, that is, the third, fourth, and fifth trials of the long-diagonal short cuts should have been correctly executed, but they were not-figs. 5 and 6.) It thus appeared that the differences in performance between short cut 1-8 by a long diagonal and short cut 1-8 at right angles, and between short cut 8-15 by a long diagonal and short cut 8-15 at right angles were due to the longer runs on units I, VIII, and XV in the rightangled short cuts. In searching for some reason why these longer runs should cause such obvious differences in performance, it occurred to the writer that the long-diagonal short cuts considerably distort the rectangularity of the general maze pattern. A glance at the diagram of the maze (fig. 3) will show that short cut 1-8 by a long diagonal (A) gives the maze a roughly triangular shape. So also does short cut 8-15 by a long diagonal (B). This distortion of the spatial relations of the long paths in the maze, it seemed, brought about the incorrect performances on the longdiagonal short cuts.

We sought to test this hypothesis in the following ways. A *shorter* diagonal from unit I to unit VIII, it was reasoned, would not greatly distort the rectangularity of the maze, since the normal runs on units I and VIII would not be greatly shortened. Such a short cut would obviously approach short cut 1–8 at right angles in its preservation of the rectangular shape of the maze. For this short cut the units in corner 1 had to be removed to make room for the short diagonal, but otherwise the usual short cut procedure was followed. Two trials were given, on days 62 and 75 (fig. 5). For both trials the scores were within the criterion; inspection of the curve in figure 5 reveals the unmistakable difference in performance on this short cut and the short cut by the long diagonal. Performance thus checked with our theory.

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Blinds*		6	7	8	9	10	11	12	Totals	Number of rats making errors
Trial 1	Errors	15	1	5	18	3	4		46	22
Trial 2		19	1	7	16	4			47	22
Trial 3		11	1	4	9	4	1	1	31	15
Trial 4		14	1	3	14	2	1		35	19
Trial 5		13	1	4	12	1	2	1	34	16
	Totals	72	5	23	69	14	8	2	193	

TABLE 5

Bl	nds	10	11	12	13	 		
Trial 1 Trial 2 Trial 3	Errors Totals	13 8 10 31	4 3 1 8	2 1 3	1 1 1 3	 	 20 12 13 45	16 11 11

Short cut 1-15	from	mid	unit	I ((")
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Bl	nds	10	11	12	13	14				
Trial 1 Trial 2 Trial 3 Trial 4	Errors Totals	18 19 12 18 67	4 2 7 3 16	6 1 1 7 15	3 7 1 11	 3 3	····· ···· ····	····· ·····	31 22 27 32 112	21 19 19 23

Short c	ut 1-8	at rigl	ht angle	s (D)
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В	linds	6	7	8	9	10	11			
Trial 1	Errors	8		3	14	2			27	16
Trial 2		6		3	10	3			22	14
Trial 3		4		2	10	2	2		20	10
Trial 4		3	1	3	6	2	4		19	9
Trial 5		9		2	11	1	3		26	14
	Totals	30	1	13	51	10	9		114	

*Blinds containing no errors, for example, blinds 13 and 14, are not indicated in the table.



Bl	inde	10	11	12	13				Totals	Number of rate making errors
Trial 1 Trial 2	Errors	53			 1				5 7 7	55
Trial 3	Totals	5 13	2 5	····	1	·····	·····	····	7 19	

TABLE 5-(Concluded)

Short cut 8-15 at right angles (E)

Short cut 1-8 by a short diagonal (F)

Bl	inds	6	7	8	9	10	11	 	
Trial 1 Trial 2	Errors	6 5		4 2	10 8	4 1	 2	 24 18	12 11
	Totals	11		6	18	5	2	 42	

Short cut 8-15 by a short diagonal (G)

Bli	nds	10	11	12	 	 		
Trial 1 Trial 2	Errors	6 5		 1	 	 	6 6	6 6
	Totals	11		1	 	 	12	

Short cut 1-15 from unit I extended (H)

Bli	nds	10	11	12	 	 		
Trial 1 Trial 2 Trial 3	Errors 	5 8 8	1 1 2	1 2	 	 	7 9 12	7 9 11
	Totals	21	4	3	 	 	28	



Similarly, short cut 8-15 by a short diagonal (G) was next tried, on days 62 and 76. Again both scores were within the criterion, offering further confirmation of our explanation.

It will be noticed that short cut 1-15 from the middle of unit I (C) also distorts the rectangular shape of the maze by greatly decreasing the height of the rectangle. Performance on this short cut, it will be recalled, was poor. The same short cut, made however from unit I (extended) to the end of unit XV, would not greatly distort the rectangle and a run through it should be executed within the limits of our criterion. Such a short cut (H) was given three times, on days 65, 78, and 100 (fig. 7). All three scores were below the highest normal pattern score. Again the results were in harmony with our theory.

Finally, the following check was made. It was reasoned that if it was the shortness of the runs on unit I and unit VIII (as in short cut 1-8 by a long diagonal), and not merely the length of the diagonal, that caused distortion of the maze (and consequently poor performance), then a run through a short cut with a long diagonal that nevertheless preserved the normal length of runs on units I and VIII should be executed correctly. Such a short cut was offered by moving unit I four and one-half feet to the right, keeping it pointed in its normal direction. Then a long diagonal was placed from unit I in its new position to the *right end* of unit VIII. The units of corner I were removed. (We designate this "short cut I," though it does not appear in fig. 3.) One trial on this short cut was given, on day 90 (fig. 5). The score was definitely within the criterion. The same sort of short cut should have been tried on the other side of the maze, namely, from unit VIII to the end of unit XV by a long diagonal, but unfortunately the spatial limitations of the room prevented this.

When we ask why distortion of the rectangularity of the mazeshape should cause poor performance on the short cuts that produced the greatest distortion, the answer, in the light of the interpretation on pages 26 and 27, would seem to be that such mazeshape distortion is also a disturbance of stimulus patterns. Thus short cut 1-8 by a long diagonal (A) disturbs the stimulus pattern (1) because it truncates the integrated group of stimuli (tactual, olfactory, and kinaesthetic) that are normally received on units I

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and VIII, and (2) because the angular turn from unit I to the short cut path is considerably less than a right angle, that is, the deviation from the straight course on unit I is very slight. This latter circumstance, we may say, has the effect of confusing the stimulus group of the short cut path with that of unit I. If one were to express this in mentalistic terms one would say that the rats were misled into "thinking" they were on unit I when actually they had turned into the short cut path.

The same considerations hold for short cut 8-15 by a long diagonal (B). Here also we have a shortening of the stimulus group of units VIII and XV, and the slight, confusing turn from the straight course on unit VIII. Short cut 1-15 from middle of unit I (C) has no confusing turn from the normal path, the short cut path being at right angles to unit I, but the considerable shortening of the stimulus groups of units I and XV is clearly apparent.

But to make our hypothesis of stimulus-pattern disruption adequately explanatory, certain other factors must be taken into consideration. The five different short cuts that were made either by short diagonals (F and G), or at right angles (D and E), or from the end of unit V extended (H), were executed within the criterion. But all these short cuts cut out one or two groups of short runs and turns, that is, the blind arrangements in corners 1 and 2, and this also must be considered disruption of stimulus patterns. Yet these short cuts were correctly performed. We seem forced to assume either that the excision of one or two blind arrangements is a stimulus-pattern disruption of a minor sort, that is, incapable of disturbing the total response, or that a particularly important integration of stimulus groups was formed between the stimulus groups of unit I and unit VIII, and between those of unit VIII and unit XV. Whatever assumption we make, the actual results on the short cut trials demonstrated that the running of the entire lengths, or at the minimum the greater part of the entire lengths, of two sides of the maze was necessary for accurate short cut performance. The running through of blind arrangements in the corners was not necessary. But this capacity of adequate response with variation (within limits) of the stimulus pattern has been demonstrated heretofore. This demonstration, in the writer's opinion, is for psychology one of the most significant results of Lash-

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ley's investigations. The evidence is conclusive that, on the one hand, responses may be independent of the particular sensory cells stimulated and of specific stimuli, and, on the other hand, that habits acquired do not necessarily utilize patterns *identical* with those employed during the process of learning.

Correct performance on short cut trials such as we observed in our rats would, in human beings, be attributed by all except the extreme behaviorists to a function which we should certainly designate as mental. We should say that in human beings the ability to perform short cuts correctly would be dependent on some such mental function as the apprehension of the spatial relations of the various parts of the maze, or we may say, more broadly, that such behavior is intelligent, as opposed to behavior rigidly associated with specific stimuli and inadequate when specific stimuli or small groups of stimuli are disturbed or excluded. The capacity to respond adequately with the changing (within limts) of the stimulus pattern and even with the exclusion of groups of stimuli is of the essence of intelligent behavior. Such behavior is in general described in its mental aspect as dependent on the grasping of relations; in our experiment, spatial relations.

The results of the "put on" runs can be interpreted in terms of the foregoing theory of intelligent behavior, and that such an interpretation is possible tends to corroborate the theory. A glance at the error curves of figures 5 to 9 will show that the error score of the "put on" run invariably exceeded by a significant amount the error score of the coresponding short cut run, even where the short cut scores were too high to come within the criterion. It will be recalled that in the maze of Experiment I as well as in the present maze, the run from the starting platform to and over the short cut path was found essential for correct performance in the rest of the maze. The fact that even the short cut trials poorly executed had fewer errors than the corresponding "put on" runs points to the importance of the run from the start to the short cut path. Why was this run essential? A great disruption of the stimulus pattern, or considerable shortening of stimulus groups, we have seen, disturbs behavior. In the "put on" runs large stimulus groups were completely left out; the pattern of stimulation, though capable of considerable variation yet calling forth adequate response,

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was here too greatly distorted or, more precisely, truncated by the exclusion of a large first part of the stimulus pattern. We may express the matter in mental terms by saying that the rats, in order to be able to use their knowledge of spatial relations, must be offered the elements that are to be related, that is, they must run over the element (part of the maze up to the short cut) that is to be related to another element (part of the maze beyond the short cut). Only when the two parts are thus offered can the rats perform correctly. And when the parts are offered they must, we have seen, be presented in such a way that large stimulus groups are not cut out, or, to express it in mental terms, the parts must be presented in such a way that their spatial relations are not obscured by the spatial and physical features of the short cut path.

One other point concerning "put on" runs should be considered. It will be recalled that in the maze of Experiment I, performance on a certain "put on" run suggested the possibility that the long run over unit XVIII plus the two forced turns at the ends of unit XIX may have acted as a kinaesthetic cue for the good performance beyond unit XIX. But this possibility was not borne out by other performances. Regarding the present maze, it may be asked whether, in the "put on" run that began at the left end of unit VIII ("put on" run corresponding to short cut 1-8 by a long diagonal), the encountering of corner 2 may not have presented kinaesthetic cues that re-aroused the kinaesthetic pattern and thus caused good performance in the succeeding (third) corner. Inspection of the data sheets reveals that this was not so; errors in corner 3 for this "put on" run numbered 17, whereas for the various trials of the corresponding short cut 1-8 by a long diagonal they varied from 4 to 7. We may conclude that the encountering of corner 2 from the left end of unit VIII did not produce good performance in corner 3; in other words, that no adequate kinaesthetic cues were presented. Whether the traversing of both corners 1 and 2, beginning at the upper end of unit I, would give good performance in corner 3 is a further question, but a "put on" run from this point was not tried because it did not correspond to any short cut.

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DISCUSSION

Our conclusions are that rats can learn to run with a fair degree of accuracy a maze of average difficulty in the absence of specific intra- and extra-maze stimuli, that the accurate running cannot be due solely to the formation of a kinaesthetic sequence of movements, and that, in view of these facts, we may posit in rats a capacity, which may be called mental, of apprehending the spatial relations of the major parts of the maze. On the strictly behavioral side we have described the short cut performance of the rats as the capacity to respond correctly with limited modification of the stimulus pattern that is the basis of the response. This capacity, we have suggested, is the distinguishing characteristic of intelligent behavior, and may be described in mentalistic terms as the apprehension of relations of whatever sort.

Although the conclusions just stated are drawn from results on a maze in which the units were continually shifted about and from results on special kinds of runs, that is, short cut and "put on" runs, we would also assert the presence in rats of a capacity to apprehend spatial relations even in mazes which are kept constant in all respects. Indeed, such a capacity should have been guessed by experimenters long before this from results on many different mazes. Lashley⁽⁸⁾ had postulated such an ability in rats in 1929: "There is clear evidence that the animals acquire some general orientation in addition to the habits of making particular turns and at present this orientation can only be described as an abstraction* of a general direction from the diverse directions of the successive alleys." The fact, observed by various investigators, that blinds pointing in the general direction of the food are most difficult to eliminate in the learning process, points to the same sort of abstraction of general direction from diverse directions. Behavior in which such an abstraction is manifest surely cannot be rigid response to specific stimuli; there are apparent in such behavior forward-pointingness and anticipation that imply mental functions. The disproportionately large number of entrances into food-pointing blinds⁽⁶⁾ indicates response to a general stimulus-pattern but with unfortunate minor reactions as to detail.

* Italics ours.

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When, after a thirteen-day period during which the maze was kept constant, the units were suddenly interchanged, the result was a complete disruption of the maze habit. This pointed to the great importance of intra-maze tactual and possibly olfactory stimuli (extra-maze auditory and olfactory stimuli were found by rotation of the maze to play no significant rôle). But there is evidence from our experiment and from Lashley's investigations that reactions were made not to individual specific stimuli but rather to groups of stimuli, and, on a higher level, to patterns of groups of stimuli. We have reason to believe that tactual, olfactory, and kinaesthetic stimuli had become integrated into stimulus groups and these groups in turn into wider stimulus patterns. Response was to patterns of excitation, not to specific stimuli. Performance on short cut trials showed that within limits the pattern of excitation could be changed yet call forth adequate response. The changing of tactual and olfactory stimuli throughout the maze, however, disrupted stimulus groups too greatly. Tactual and olfactory stimuli that had been associated with kinaesthetic stimuli were changed when units were shifted; the kinaesthetic stimuli alone were unable to guide response correctly, and this because response had not been to kinaesthetic stimuli alone but to groups of which these kinaesthetic stimuli were parts.

With regular unit-shifting on alternate runs the error curves show a slow and jagged but nevertheless steady descent (fig. 4). The extreme slowness of the curves' descent contrasts strongly with the precipitous drop when the maze was constant. The stability of intra-maze tactual and olfactory stimuli was undoubtedly essential to rapid learning. The lack of stability prevented the formation of the stimulus groups and patterns that we postulate as the basis of response. With constant unit-shifting, integrations had presumably to be made among kinaesthetic stimuli only, and under such circumstances learning was retarded. This suggests that in general the exclusion (or rendering inoperative) of stimuli of one or more sense modalities has the effect of retarding the learning process. Tryon,⁽⁷⁾ on other evidence obtained with normal rats in an alley maze, has come to this conclusion. However, comparisons of the rates of learning of normal, blind, and anosmic rats do not in general support this.

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SUMMARY

We may summarize for both experiments as follows:

1. The maze performance of blind rats that had learned an unchanged maze was greatly disturbed when the parts of the maze were interchanged, the pattern of the maze, however, remaining the same.

2. With constant and regular interchanging of maze parts, relearning of the maze was greatly retarded, but learning was nevertheless evident.

3. There was evidence from Experiment I that interchanging of maze parts from the very beginning of training would also have retarded learning.

4. Results, in terms of error scores, when the maze was rotated and food and food box removed, strongly indicated that extramaze auditory and olfactory stimuli played no significant rôle.

5. From the above evidence it was concluded that for blind rats intra-maze stimuli are important factors in maze learning, but that response was to integrated groups of stimuli rather than to individual specific stimuli. The question whether disturbance of maze performance following unit-shifting was due to distraction or to disturbance of stimuli that had become directive, was found to be irrelevant.

6. Results on different short cuts demonstrated that the rats were not running the maze in a purely kinaesthetic manner.

7. Because kinaesthetic running was thus disproved, and because extra-maze stimuli were found to have no influence while dependence on specific intra-maze stimuli was made impossible by constant unit-shifting, it was suggested that correct short cut performance could be attributed to a capacity of apprehending spatial relations. But in strictly behavioral terms correct short cut performance may be described as a capacity to respond adequately to a variable stimulus-pattern.

8. Differences in performance between the long-diagonal short cuts and the other short cuts, and the performance on "put on" runs, indicated the extent to which the stimulus pattern could be changed and yet produce correct response. 9. Finally, it was suggested that the distinguishing characteristic of intelligence is just this capacity, demonstrated in rats, of behaving efficiently in spite of a changing pattern of stimulation. Such behavior, viewed mentalistically, is commonly attributed to a mental function, namely, the apprehension of relations.

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