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THE DISTRIBUTION AND ELIMINATION OF ERRORS IN THE MAZE

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In the solution of the maze problem, animals do not distribute their errors equally between the various cul de sacs; apparently these blind alleys do not offer equal incentives to entrance. Neither do the cul de sacs present the same difficulty in mastery; the tendency to enter certain alleys is eliminated much sooner than in the case of others. The principles determining the relative frequency of entrance into the various alleys, and the factors governing the order of their elimination are inadequately known.

Vincent[1] has published data concerning the first problem. Hubbert[2] and Vincent[1] have investigated the second question, and Watson,[3] on the basis of Hubbert's results, has contributed to the discussion.

Watson contends that if food satisfaction is a causal agency in selecting the true path and thus eliminating the cul de sacs the latter part of the maze should be mastered first; hence the cul de sacs should be eliminated in the order of their nearness to the food box. He therefore concludes that food satisfaction can not be regarded as a selective agency because only seven of Miss Hubbert's eighty-four rats eliminated the six errors in the exact order of their spatial contiguity to the food box.

[1] Vincent. The White Rat and the Maze Problem. *Jour. Animal Behav.*, **5**, 367-374.
[2] Hubbert. Elimination of Errors in the Maze. *Jour. Animal Behav.*, **5**.
[3] Watson. Behavior, p. 268.

Watson's argument, to my mind, contains two fallacies: 1. A causal factor can mediate an invariable result (without any exceptions) only under the ideal condition that it is the only causal agency involved. Needless to say such a condition does not obtain in any science, to say nothing of animal behavior. The ideal effect of any hypothetical cause is always somewhat altered, distorted, or even obscured by the influence of other factors which can not be controlled. Hence general tendencies and results must be utilized as diagnostic symptoms in the search for causal conditions. Viewed in this light, Hubbert's results support rather than disprove the efficacy of the alleged principle of selection, for the general trend of the order of elimination is that of the spatial contiguity of the alleys to the food box. According to my computations, 80% of her rats eliminated the 6th error before the 5th, 50% the 5th before the 4th, 47% the 4th before the 3rd, 73% the 3rd before the 2nd, and 70% the 2nd before the 1st. Determining the average number of trials necessary to eliminate each cul de sac, the order of elimination for the entire group was 6-5-3-4-2-1, where the successive errors are numbered in order from the entrance. This order gives by the rank method a positive correlation of .943 between quickness of elimination and propinquity to the food box. The average number of trials necessary to eliminate the last three errors was less than that for the first three for 90% of the rats. Surely there is a very pronounced tendency for the errors to be mastered in proportion to their nearness to the food box, and the deviations from an *exact* correlation for each rat may well be due to the operation of other causal agencies. The existence of other efficacious agencies, viz., recency and frequency, is admitted by Watson. 2. Granted that food satisfaction is the only effective agency involved, yet a *perfect* correlation between speed of elimination and nearness to the food box, as demanded by Watson, would not obtain. According to the hypothesis the order of elimination will be determined, not by the spatial arrangement of the cul de sacs in relation to the food box, but by the temporal relation of the errors to the food experience. The temporal order in which the cul de sacs are entered is not the same as their spatial order in the maze. Not all cul de sacs are entered on each run. An animal may enter alleys 1, 3, and 5, and skip 2, 4, and 6. The matter is further complicated by the phenomenon of returns. The tendency to return toward the entrance box is very persistent during the early stages of learning, and in any trial we may have a temporal order of 1-3-6-1-2-3-4-5-4. According to the hypothesis this trial will tend to eliminate alleys 3, 4, and 5 prior to 6.

Hubbert's results, however, neither prove nor disprove the efficacy of food satisfaction as an eliminative agency. Although a high degree of correlation obtains between rate of elimination and nearness to the food box, one should still refrain from generalizing on the basis of one maze. Different maze patterns may give other results. A correlation between two factors does not always indicate a causal relation between them; both may be the result of some more fundamental condition.

This paper presents data on two mazes, and in addition Miss Vincent has kindly furnished me records for six mazes. A cul de sac was considered eliminated when but one entrance was made in ten successive runs. The number of trials necessary to eliminate each alley was determined for each animal and the average number of trials for the group was thus computed for the various cul de sacs. These values constitute the order of elimination for the group. This temporal order of mastery was correlated by the rank method with the spatial arrangement of the alleys in relation to the food box. Table I designates the various mazes, gives the number of cul de sacs in each, the number of rats employed, and the correlation data for each maze pattern. Mazes I-a to I-e have the same pattern, a slight modification of the Hampton Court arrangement; they differed only in the arrangement of sensory factors. I-a presented a uniform sensory interior; I-b had the true path painted white and the blinds black; I-c had the true path painted black and the blinds white; in I-d an olfactory trail was laid in the true path, while the trail was inserted in the cul de sacs for I-e. II-a and II-b were alike except that the alleys of II-b were without sides. The records for the above mazes were obtained by Miss Vincent. Mazes III and IV were somewhat similar in pattern but radically different from patterns I and II. Maze V refers to the circular maze used by Miss Hubbert whose data are given for comparison.

TABLE I

CORRELATION BETWEEN QUICKNESS OF ELIMINATION AND NEARNESS TO THE FOOD BOX

Maze	Number of cul de sacs	Number of rats	Percentage of correlation
I-a	7	10	.607
I-b	7	10	.714
I-c	7	9	.178
I-d	7	6	—.643
I-e	7	6	—.358
II-a	7	6	.750
II-b	7	6	—.822
III	11	16	.563
IV	9	15	.666
V	6	84	.943

Varying degrees of positive correlation between the two factors were obtained for six of the nine mazes. None of our values are as high as that obtained for Miss Hubbert's maze. There are, however, three exceptions to a uniform positive correlation; in these three mazes the errors were mastered in proportion to their nearness to the maze entrance. This lack of a uniform positive correlation can be interpreted in two ways. 1. If food satisfaction is an effective agency of elimination, its influence is overcome by some other selective factors which are peculiar to three mazes. 2. On the other hand we may suppose that food satisfaction is non-effective and that all of the above correlations (both positive and negative) are to be explained in terms of a single principle. The latter hypothesis is the preferable one.

Miss Vincent suggested in her paper the possibility that the ease of elimination is a function of the strength of the tendency to enter an alley, and that in a general way the relative attractiveness of the various alleys can be measured by the frequency with which they are entered. Cul de sacs with the greatest error score offer the most inducement to entrance, and the stronger the attraction, the larger will be the number of trials necessary for elimination. On this basis a negative correlation will obtain between the number of errors for each alley and the order of mastery. To test the hypothesis, the various cul de sacs were now ranked in the order of number of entrances made by the group for the successive stages in the mastery of the maze. Correlation data were computed by the ranking method with much detail but since these results were uniformly consistent for all stages of learning, we give in table II the values for representative stages. The first horizontal column states the correlation values for the various mazes between the order of elimination of the alleys and the relative number of entrances made by the group as a whole for the first trial. The second column gives similar data in relation to the total number of errors made during the second and third trials. The last three columns state the results in reference to the total number of errors made in the first five runs, the second five runs, and from the eleventh trial until the maze was mastered.

TABLE II

Correlations Between Quickness of Elimination and Number of Errors at Different Stages of Learning

Trials	I-a	I-b	I-c	I-d	I-e	II-a	II-b	III	IV
1	–.571	–.821	–.535	–.714	–.892	–.321	–.642	–.654	–.133
2- 3	–.535	–.643	–.892	–.857	–.643	–.107	–.321	–.300	–.166
4- 5	–.642	–.571	–.821	–.535	–.500	–.642	–.964	–.764	–.350
1- 5	–.714	–.892	–.750	–.857	–.857	–.143	–.642	–.758	–.116
6-10	–.857	–.857	–.678	–.750	–.857	–.857	–.571	–.518	–.583
11-until learned	–.500	–.785	–.857	–.535	–.321	–.928	–.000	–.973	–.866

With one exception, a uniform negative correlation was obtained, the values ranging from —.107 to —.964. The exception refers to the final stage in the mastery of maze II-b. This record hardly invalidates the uniformity of the results as this maze was mastered very easily and but few errors were made after the tenth run. In considering the validity of this correlation, the uniformity for all mazes and for the various stages of learning must be emphasized. A single correlation value may well be due to chance in view of the paucity of data for which the correlation was calculated. But chance is pretty well eliminated when the computation is repeated 54 times and consistent results are secured. We may then safely conclude that some degree of negative correlation obtains for all stages of learning between quickness of elimination and the tendency to enter the cul de sacs, that in a general way those blind alleys which for some reason offer little inducement to entrance are easily eliminated, while cul de sacs which present the most enticement to exploration are the hardest to master. This correlation is *a priori* logical, for it is reasonable to expect that the strongest tendencies will be the hardest to overcome. Our results thus establish one of the factors underlying the order of error elimination, viz., that this order is a function of the strength of the entrance attraction characteristic of the various cul de sacs. It is admitted that other selective factors may also be efficacious; otherwise higher correlation values should have been obtained.

The validity of the above principle of explanation is supported by the data of table III, giving the correlation values between the number of errors for the various cul de sacs and their spatial order in the maze. A positive correlation obtains for the six mazes I-a, I-b, I-c, II-a, III, and IV. In these cases the animals entered the various cul de sacs with a frequency roughly proportionate to their proximity to the point of entrance, and it was for these six mazes that a positive correlation was found between order of elimination and nearness to the food box (table I). In other words the first cul de sacs were entered the most frequently and were the last to be eliminated. In mazes I-d, I-e, and II-b, on the other hand, the animals for some reason entered the last cul de sacs more frequently than the initial ones (negative correlation between number of errors and nearness to entrance), and in these cases the final errors were the last to be eliminated (table I).

TABLE III

Correlations Between Nearness to Entrance and Number of Errors at Different Stages of Learning

Trials	I-a	I-b	I-c	I-d	I-e	II-a	II-b	III	IV
1..........	.322	.929	.822	–.964	–.107	.000	–.607	.846	.750
2- 3..........	.250	.679	.036	–.928	–.107	–.392	–.214	.709	.666
4- 5..........	.232	.143	.215	–.321	–.750	.143	–.892	.373	.800
1- 5..........	.322	.715	.679	–.928	–.214	–.107	–.607	.846	.700
6-10..........	.286	.786	.643	–.250	–.500	.465	–.107	.573	.733
11-until learned..	.215	.250	.179	–.285	–.071	.536	.393	.500	.417

It is thus the phenomenon of error distribution in the maze that demands explanation in order to comprehend the order of elimination. Our results enable us to offer but few explanatory suggestions in regard to error distribution.

1. The persistent tendency for rats to keep returning to the point of entrance after exploratory excursions operates to increase the number of entrances into the initial cul de sacs. This returning tendency is well known, and it is at once obvious that these returns must result in repeated explorations of the initial

cul de sacs. All other factors being equal, we should expect that the relative number of entrances into the various cul de sacs will be roughly proportionate to their nearness to the point of entrance. This influence of returns is further indicated by two features of the data: a. In mazes I-d and I-e there is a negative correlation between number of errors and nearness to the entrance, the greater number of errors being made in the final cul de sacs (table I). The opposite relation, however, obtains for mazes I-a, I-b, and I-c, in which the greater number of entrances were made in the initial cul de sacs. This difference in the distribution of the errors among the cul de sacs is due entirely to differences of the sensory character of the mazes, for exactly the same maze pattern was used throughout and the objective environment of the mazes was identical in all cases. Mazes I-d and I-e differed from the others in that an olfactory trail was laid, either in the true pathway or in the cul de sacs. This trail produced several characteristic peculiarities of behavior, one of which was a noticeable diminution of the number of returns. Miss Vincent kept no separate record of the number of returns, but she noted this feature of the behavior and frequently discussed its significance with the writer at the time. The degree of returning also accounts for the different distribution of errors in mazes II-a and II-b (table III). Again the same pattern was used and the maze was located in the same objective environment in both experiments. The only difference consisted in the presence and absence of sides to the runways. Maze II-b was without sides and their absence caused the animals to follow one edge of the platform with their paws or vibrissae much in the same manner as did the olfactory trails. Following an edge caused a noticeable diminution in the number of returns and thus accounts in part for the difference of error distribution in the two mazes. b. The returning tendency is quickly eliminated in the course of maze mastery, and we should thus expect that the relative frequency of entering the initial cul de sacs will be gradually diminished during learning for those mazes in which returns are an effective factor in error distribution. Such a diminution obtains for mazes I-a, I-b, I-c, III and IV (table III). In all five cases there is a high positive correlation between number of errors and nearness to the entrance, but this correlation keeps decreasing with the number of trials; in other words the number of errors in the initial blind alleys is decreased more rapidly than for the final cul de sacs.

2. The sensory character of the maze influences the distribution of errors in other ways than by minimizing the number of returns. The tendency to follow the edge or an olfactory trail evident in mazes I-d, I-e, and II-b operated to reduce the total number of errors. This fact is well demonstrated in Miss Vincent's paper. The operation of the tendency was relatively more effective in the initial than in the final stages of learning, and Miss Vincent interpreted this fact as due to the shift in control from olfactory and cutaneous cues over to kinaesthetic factors; when the maze is run in terms of kinaesthetic stimuli, the trail factor is no longer present and the rat is subject to the enticements of curiosity, distractive odors, etc. I wish to suggest a similar explanation of the greater frequency of entrance into the final cul de sacs in these three mazes. Starting from the entrance box, the rats are at once dominated by the stimulus characteristic of the trail. This sensory trail is followed and possible exploratory excursions due to curiosity, fear, and other motives are eliminated. As a consequence relatively few errors are made in the first sections of the maze. As the final sections are reached, however, the dominance of the trail motive is weakened and other enticements begin to operate. The weakening of the trail motive may be conceived under such terms as habituation or adaptation. The strength of other motives such as fear, curiosity, and the returning tendency may progressively increase with the distance traversed; the concept of summation of stimuli may be applicable here. The strength of the olfactory stimulus from the food box must necessarily increase as the final sections of the maze are reached. One can hardly suppose that the actions of an organism so complex, alert, variable, and thoroughly alive as is the rat can long be continuously dominated by a single motive. Some shift of motives during a run must be presupposed irrespective of the explanatory difficulties involved. Our hypothesis then assumes that the animals in these three mazes start out on each run under the dominance of the trail motive which tends to prevent errors. As the final section of the maze is reached, there occurs a shift of motives, and these new motives, such as food odor, fear, curiosity, etc., tend to produce errors. As a consequence of this shift of motives

during each run the greater number of errors will be made in the final cul de sacs in these three mazes. It is also possible that the same principle, a shift of motives, will account for the greater frequency of entrance into the initial cul de sacs in the normal mazes; in this case the shift will be from fear and curiosity over to the food odor. The odor of food as the rat reaches the final sections should be sufficiently directive as to minimize the number of errors relative to those made when the animal's acts are controlled primarily by curiosity and caution.

3. The distribution of errors is influenced by certain peculiarities of the cul de sacs other than their positional relation to the point of entrance. Since the influence of this factor may vary according to the stage of mastery, a separate treatment is necessary for its effects upon the initial and final distribution of errors.

a. *Initial distribution.*—From the data of table III it is obvious that the initial errors (first five trials) are never distributed in the exact order of the spatial arrangement of the cul de sacs. A few blind alleys are generally responsible for the deviations, and these are listed in table IV. The first columns give the various mazes with the number of cul de sacs belonging to each. Each cul de sac is numbered in order from the point of entrance. In the column headed "plus" are listed those alleys in which the number of entrances exceeds that to be expected on the basis of a perfect correlation. In the "minus" column are those alleys in which the number of entrances is less than the normal. The first group of mazes are those in which a positive correlation obtains between the distribution of errors in the first five trials and the proximity of the cul de sacs to the point of entrance. In the last group of mazes the initial errors are distributed proportionate to the spatial contiguity of the cul de sacs to the food box. The five mazes, I-a, I-b, I-c, I-d, and I-e, are identical in pattern; in the first three the sensory conditions were such that the greater number of errors were made in the initial cul de sacs; in the last two, the first cul de sacs were the least attractive. In spite of this radical difference of error distribution in the two groups, the same cul de sacs are responsible for the deviations from a perfect correlation in every case. The first cul de sac is much less alluring in the initial trials than its position would justify. On the other hand No. 6 was invariably attractive for it was entered much more frequently than one would expect if the spatial order of the cul de sacs were the only factor determining the distribution of errors in the initial trials. Likewise No. 3 was relatively difficult in two cases, and No. 4 three times. Comparing mazes II-a and II-b of like pattern but with a different distribution of errors, we find that No. 7 is easy in each case while No. 4 tends to be difficult. Chance will account for the deviations in part, but chance can not invariably favor certain cul de sacs. The tendency toward uniformity in the character of the deviations for the same maze pattern must be due to peculiarities of the cul de sacs other than their spatial position in the maze. Certain ones are relatively easy to avoid, while others are prone to be entered.

The susceptibility of the animals to these favored cul de sacs is, however, an individual matter. In maze III, No. 8 received more than its due share of entrances, yet this alley was not entered at all in the first five trials by four of the sixteen rats; in fact one animal did not enter this alley once in fifty trials, while another rat entered but three times in fifty runs. This avoidance of the difficult errors by certain rats can in part be explained in terms of the habits acquired by those animals in traversing the first section of the maze. Let us suppose that the first section of a maze contains no blind alleys but consists of a series of runways so arranged as to necessitate alternating right and left turns of 90°. At the end of this section there is presented a choice between two paths,—a "straight ahead" error, and a turn of 90° leading to the food box. It is conceivable

TABLE IV

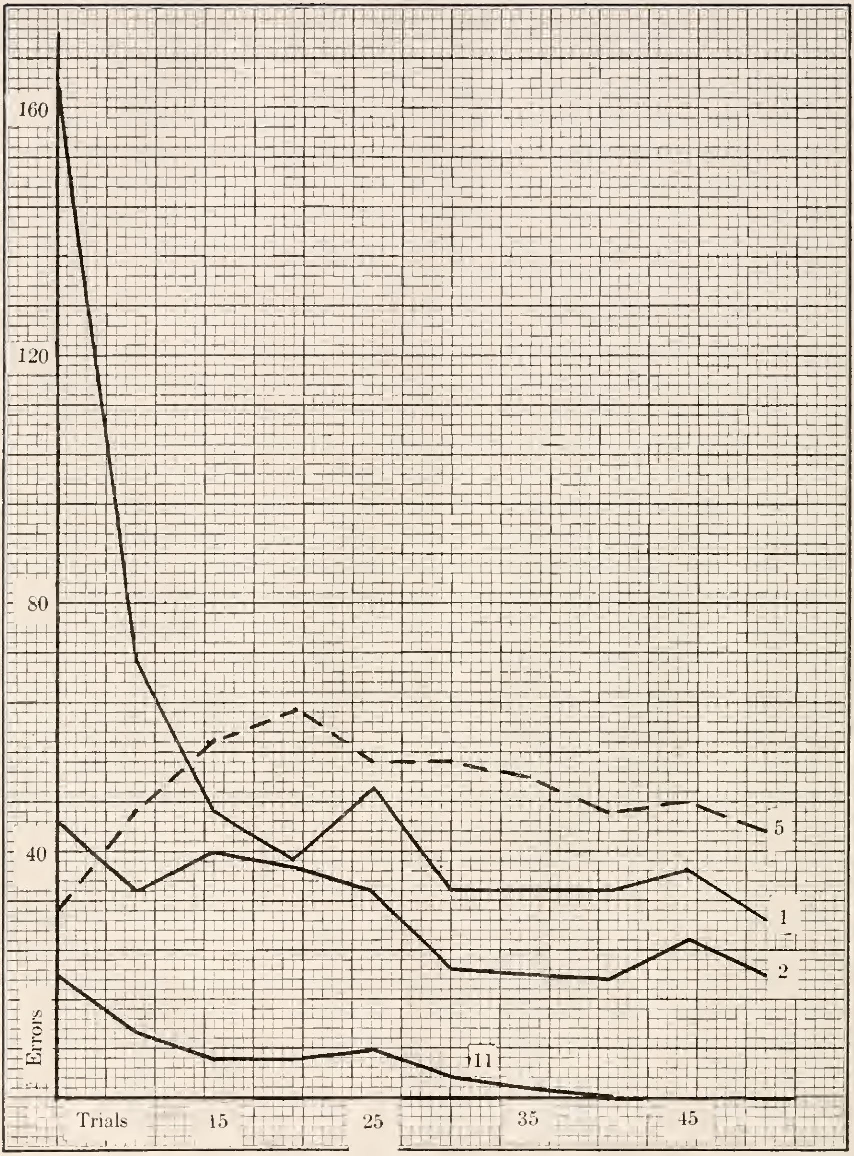
Deviating Cul de Sacs

Maze	Number of cul de sacs	Plus	Minus
A. Mazes exhibiting a positive correlation			
I-a	7	3, 6	1
I-b	7	4, 6	1
I-c	7	4, 6	1, 2
II-a	7	4	1, 2, 3
III	11	8	7, 10
IV	9	3, 4, 8	6
B. Mazes exhibiting a negative correlation			
I-d	7	3, 6	1
I-e	7	3, 6	1, 5, 7
II-b	7	4, 6	3, 7

that a choice between two such possibilities might be determined to a large extent by tendencies aroused in traversing the previous zig zag course. On this hypothesis the attractiveness of any cul de sac in a maze is in part a function of the motor tendencies developed in the prior sections of the maze. The habits aroused in a group of individuals in traversing the initial section of a maze must necessarily have much in common, and yet any part of a maze presents possibilities of wide divergence in the character of the pathway actually traversed. A group will thus approach a cul de sac with some degree of uniformity of disposition toward it, but radical exceptions are possible.

b. *Final distribution.*—The final distribution of errors represents the order of elimination, for eliminated cul de sacs are those which are not entered. As previously developed there is a correlation between the initial distribution of errors and the order of mastery of the blind alleys, but this correlation is far from perfect. It is thus evident that the order of elimination, or the final distribution of errors, is also dependent upon other factors than initial attractiveness. Certain peculiarities of the cul de sacs constitute a determining condition. Some blind alleys are relatively difficult and others are relatively easy to master, and this ease or difficulty of a cul de sac is to some extent independent of its initial attractiveness.

The above principle is well illustrated by mazes III and IV. The eleven cul de sacs of maze III fall into four rather well defined groups as to rate of elimination. The progress in mastery of four cul de sacs typical of these groups is represented by the curves of fig. 1. The alleys chosen as types are 1, 2, 5, and 11. The values represented are the total number of errors made by the group for each successive five trials. Curves 1, 2, and 11 illustrate the first principle that the order of mastery is inversely proportionate to the number of initial errors. No. 11 elicited but few initial errors and was mastered first; No. 1 was the most attractive but the most difficult, while No. 2 occupies a median position between the two. As to progress of mastery the three alleys are to be ranked in order, 1, 2, and 11. No. 5 is the exception which illustrates the influence of the second factor. This cul de sac was the hardest of the eleven to master, and yet its initial attractiveness was no greater than its position would justify. The number of entrances into this alley rapidly


160
120
80
40
Errors
Trials
15
25
35
45
5
1
2
11

increases for the first fifteen runs, and then slowly decreases for the remaining thirty-five trials. More errors were made at the end of the experiment than at the beginning. In considering the individual records, the general features of the group curve are also characteristic of that of fifteen of the animals. In maze III, the difficult group of cul de sacs is composed of alleys 5, 7, and 8. In maze IV, alley 3 was relatively easy while 5, 6, and 9 were the difficult ones.

This difficulty of any cul de sac must be explained mainly in terms of the animal's organization in reference to it, for all of the blind alleys of mazes III and IV were highly uniform in character. Each consisted of a single straight runway sixteen or twenty inches long. This reduction of the difficulty of a cul de sac to the animal's disposition toward it allows of a common explanation for both the initial and final distribution of errors. The disposition of an animal to enter or avoid an alley is a result in part of the habits of turning already developed. As the maze is mastered, these habits become profoundly modified. Returns and repeated explorations are inhibited and several cul de sacs may be eliminated. Since the attractiveness of a cul de sac is a function of the maze habit and this habit is altered in the course of mastery, it is evident that the initial and the final attractiveness of an alley must be to some extent independent variables. With this conception the disposition to enter an alley may actually increase as well as decrease, and individual exceptions to the group attitude are possible.

Such an explanation is feasible and the conception possesses some degree of *a priori* rationality, but any convincing proof of the hypothesis is more difficult. Chance can not account for the error curve of alley 5 in fig. 1, for the records of fifteen of the sixteen animals conform to its general features. There has been no objective change in the alley itself. Evidently it is the attitude of the animals towards this situation that has been altered. Nor will chance account for the distribution of errors of any individual animal. One rat did not enter alley 5 during the first five runs but made one entrance per trial for the remaining 45 runs. Another animal avoided this alley for eleven runs, alternated between success and error for the next six trials, and the error then became fixed. In another case this cul de sac was avoided twice, entered once, avoided twice, and then invariably entered on all succeeding runs. The eighth cul de sac was avoided six times, entered once, avoided once, and then became fixed; in another case it was avoided for 28 trials, entered three times, avoided for five trials, and then became fixed. The continual avoidance of an error for a number of trials followed by invariable entrance can not be due to chance. Chance may account for the first entrance but the *sudden fixation* of the habit remains inexplicable. This type of behavior may be readily explained by our hypothesis. This alley is so related to the previous sections of the maze that the turning habits necessitated by the latter dispose the animal to avoid it. But these determining habits become altered with successive runs. The avoiding disposition becomes weakened and finally supplanted by the opposite attitude. The alley is thus regularly avoided for a while; there is indecision and alternation for a short period; and this behavior is followed by sudden fixation and invariable entrance. The fixation of this error is not due to repeated entrances. In a sense this error was engrained in the animal's organization before it was entered, because the disposition is the outcome of the entire maze[4] habit developed up to that time.

CONCLUSIONS

The temporal order in which the various cul de sacs are eliminated is roughly correlated sometimes with their spatial order in reference to the food box and sometimes with their order of proximity to the point of entrance.

The temporal order of mastery of the cul de sacs is invariably correlated with their order representing the increasing number of errors made in each. The ease or rapidity of mastery of any cul de sac is thus inversely related to its degree of attractiveness as measured in terms of number of entrances. The problem as to the order of elimination of the cul de sacs must be explained in large part in terms of the distribution of errors.

The factors influencing the distribution of entrances among the cul de sacs are the tendency to return, the character of the motives actuating the animal, and peculiarities of the cul de sacs.

[4] This hypothesis is closely related to Peterson's conception developed in his recent article, Completeness of Response as an Explanation Principle in Learning, Psych. Rev., **23**, 153-162.

The amount of returning will vary with the animal, the maze, the stage of mastery, and the section of the maze.

The character of the motives will shift within a run as progress is made from section to section, and from one stage of mastery to another.

The attractiveness of cul de sacs due to peculiarities of construction or position must in part be interpreted in terms of the animal's organization in reference to them. As a possible hypothesis, it is suggested that these disposing conditions of the organism are a function of the maze habit as developed up to that time. With this conception the individuals of a group may vary in their attitude toward a cul de sac and the attitude of any individual may change as the maze is being mastered.