

STUDIES IN INDIVIDUAL DIFFERENCES IN MAZE ABILITY

V. LUMINOSITY AND VISUAL ACUITY AS SYSTEMATIC CAUSES OF INDIVIDUAL DIFFERENCES, AND AN HYPOTHESIS OF MAZE ABILITY¹

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I. PROBLEM

As factors or conditions which cause variation in behavior, luminosity and constitutional visual acuity may be logically classed as independent variables. For instance, two animals of *equal acuity* might be exposed to a problem-solving situation, in which for one animal the degree of luminosity was experimentally made high but for the other animal it was experimentally made low, and accompanying this variation in visual stimulation, a difference in behavior might be discerned between the two individuals. On the other hand, two animals might be exposed to a problem-solving situation, in which *the luminosity was equal*, but if these two animals differed in visual acuity (as do pigmented-eyed and pink-eyed rats), a difference in behavior might be discerned between the two individuals. The writer has termed the first type of causal variation *introactive* since it arises within the experimental situation itself, whereas the second type has been termed *anteroactive* since variation in acuity occurs anterior to the time of the experiment and is a function of previous experience or of the inherited nature of the individuals (9, section C). This paper describes the results of two experiments on maze ability in rats in which the purpose was to estimate the degree

¹ This is the fifth paper of a series on individual differences in maze ability among rats (6, 7, 8, 9). For full details of experimental procedure, see (6). The experiments described here are, in part, a direct continuation, under altered controls, of the experiments described in the previous paper (9).

to which such introactive and anteroactive variation in visual factors acted as causal differentiae of individual differences in maze ability, but with special reference to the differences which appeared in the late stages of learning.²

II. METHODS

For the determination of the effect on maze performance of variation in luminosity, we had to choose between two methods. The first method is the conventional experimental-group versus control-group set-up, in which the experimental group would run the dark maze and the control group would run the lighted maze, the difference in learning between the two groups, aside from that due to sampling errors and errors of measurement, being the measure of the effect of stimulus variation. The limitation of this method lies in the difficulty of getting the two groups equal in average constitutional acuity, and to insure this equality, one would have to run two rather large random samples of animals. But the second method, the one we actually used, absolutely insures this equality in acuity, for the group running in the dark and that running in the light is the *same* group of animals. The procedure consists in running a group of animals on a lighted difficult maze until they plateau in learning, that is, until no further effects of training are evident; then the lights are turned off for several succeeding trials. Since constitutional acuity is thus held constant, any change in behavior besides that due to sampling errors and errors of measurement can be set down as due only to change in stimulation. The limitation of this method lies in the possibility that the change in behavior may be interpreted as "emotional up-set" pursuant upon the animals being suddenly immersed in darkness. But if the fact appears, however, that this sensory change is *not* accompanied by a significant mean change in behavior, then this method enables us to prove conclusively that visual luminosity per se *at this late stage of learning*

² For a brief review of the literature on the sensory control of the maze, see the recent paper by Hunter (1). Previous experiments have not dealt, it seems, with individual differences in ability but with the effect of sensory changes on the average (?) rat.

is not a significant cause of variation in behavior. This method tells us nothing, of course, regarding the effect of luminosity change at the early stages of learning.

For the determination of the effect on maze performance of individual differences in visual acuity, there are likewise two methods available. The first is that of running under equal conditions of luminosity two types of animals of known difference in visual acuity, and the difference between them, apart from sampling and measuremental errors and spurious selection, is to be set down to differences in acuity. Two such different groups are, as we have said, pigmented-eyed and pink-eyed rats, which are known to differ in acuity (2). The limitation of this method lies in the requirement of having large numbers of animals in each group, and in possible errors of selection. In a previous paper (7), the writer cited evidence that pigmented animals differed slightly from albino animals where maze luminosity was held constant, but there we could not decide whether the difference was due to sampling errors or to the possibility that the pigmented animals were a more stupid strain due to experimental selection. The second method, which we actually employed here, requires the use of the same group of animals throughout and the correlation between individual differences which appear under lighted conditions and those which appear in conditions of darkness. Now, if individual differences in the lighted maze depend upon the differential constitutional visual acuities of the animals, say, in such a way that those who see better do better, or in any way in which the visual capacity of the animal operates in his learning, then if the light is suddenly turned out, the rank order will be seriously altered, for those who, say, have been superior by virtue of special superiority in visual acuity, will now be bereft of this capacity and their finding of the correct path must now depend upon other sensory cues than visual. Hence, if we find that the correlation between performance under lighted conditions and performance under conditions of darkness is low, this fact suggests that the constitutional capacities upon which individual differences in these two performances hinge are quite different and are, in the lighted maze, correlated with visual acuity, in the

dark maze, correlated, say, with orientational capacity. But if, on the other hand, the correlation between performance in the light and in the dark maze remains as high as that between two adjacent periods of learning on the lighted maze, this fact would suggest that differences in constitutional visual acuity play no rôle whatever in determining individual differences in ability at these late stages of learning. This method tells us nothing, of course, of the differential use of vision during the first stages of learning.

III. EXPERIMENTAL DETAILS

The maze. The maze used was the automatically operating 17 blind T-maze called maze X in the previous papers of this series. For complete details as to its design and the experimental particulars involved in the running of the animals, see the first study (6 p. 157).

The animals. Two experimental groups, run a year apart, were used, the second one serving only to check the results of the first. Group I consisted of 46 animals drawn from the original population used in the inheritance problem being investigated by the writer (5), and is the same group as that called group I in the previous paper of this series (9). Group II consisted of 25 animals drawn from the F_1 population and is the same as that called group II in the previous paper. Since the change in visual luminosity occurred immediately at the end of the relearning series discussed in the preceding paper, all of the data describing the animals in that paper refer to the animals in this, and for complete details regarding these subjects the reader is referred to the previous paper.

Visual stimulus control. The maze was located in a room in the middle of the basement of the building. Three walls and the ceiling and floor were completely opaque (there were two doors in one wall), and the remaining wall was opaque except for a closed window, which was, however, permanently screened off by an opaque black cardboard. When the lights were turned off, the room was completely dark. The maze was on a table about three feet high. About two and one-half feet above the maze and at fairly equal

intervals around it, were nine 60-watt electric lights (as shown in 6, figure 1). Each light was in a reflector which threw the rays up to the white ceiling, which was about four feet above the maze, so that there was uniform indirect lighting of the maze units.

Scoring the performance. The scoring of the animals' path in the maze was automatic [see Tolman, Tryon, and Jeffress (3)]. Briefly the floors of the maze units were balanced on central fulera, and in such a way that as the animal walked upon them, they dipped into mercury cups under the floor and thus made electrical contacts. These contacts were transmitted by electric wires to another room where the electrical recorder was located. The recording method used on lighted runs was thus the same as that used on the dark.

Procedure. The reader is referred to the preceding study for the experimental procedure. The period there called "relearning" was the same as the lighted period which we will consider here. Briefly, each animal made one trip a day through the maze and received his daily ration of food at the end. Before he began running the maze he experienced a "test-breaking" practice, then he was given 20 runs on maze X. After this "original learning" the rats of group I experienced breeding conditions and ran 20 trials on another maze, and finally ran 13 relearning trials on maze X. On the 14th trial of relearning, the lights were turned off, and in this dark maze, the animals ran until the 17th trial. The rats of group II had a similar series: Twenty original learning trials on maze X, an interval of breeding conditions only, and finally 13 relearning trials, then the 14th to 16th trials in darkness.

IV. RESULTS

A. *The effect of variation in luminosity*

1. *Learning curves.* In figure 1 error curves of group I and group II are plotted. The abscissa represents the successive relearning trials from 6 to 17, the ordinate, mean errors per trial. The curves represent only the *end* of learning, which included, it must be remembered, 5 relearning trials preceding those shown in figure 1, as well as the 20 original learning trials. As will be

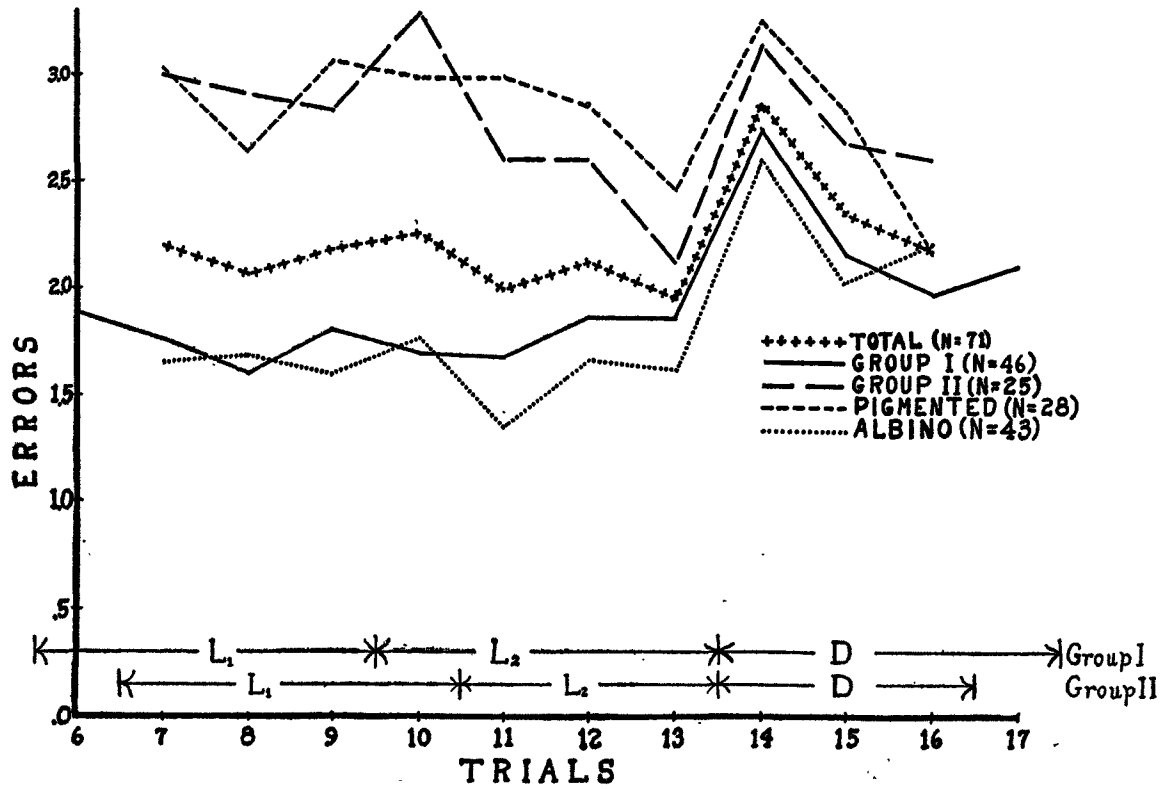


FIG. 1. ERROR CURVES FOR VARIOUS GROUPS ON CERTAIN LATE TRIALS OF RELEARNING
 The ordinate represents the mean errors per trial, the abscissa represents successive trials. The trials designated by L_1 , L_2 , and D represent periods in which the maze was lighted (L) or in darkness (D).

shown below, the original mean score on the first trial of *original* learning was about 10.0 errors, an ordinate clear out of the picture as represented in figure 1. Thus, by the 6th trial of relearning, shown as the first abscissa in figure 1, the groups had reached a high degree of efficiency. The curve of group I (solid line) shows that from relearning trials 6 to 13, the animals plateaued in the learning of the lighted maze, but that the sudden darkening of the maze on the 14th trial resulted in an average loss of efficiency of about one error. On the 15th, 16th and 17th trials they about reached their old level of efficiency. The curve for group II (long dash line) is more irregular, doubtless because of fewer animals, and shows that the animals improved slightly during the lighted period (trials 7 to 13). When suddenly thrown into darkness on the 14th day, they, too, lost efficiency of about the same amount as that of group I. In the next 2 trials they approximately regained what they had lost. When all animals are thrown into a total group of seventy-one animals in order to reduce to a minimum the fluctuation due to sampling, their error curve (plus line) shows the same plateau during the lighted period, the same loss of efficiency noted in the two-subsamples when the lights were turned off on the 14th day, and the return to old efficiency on the succeeding 2 trials. The results suggest rather strongly that the loss of efficiency was primarily occasioned by emotional up-set on the first day of darkness, and that the animals had recovered from this up-set by the following day and continued to run the maze by the utilization of the same capacities employed in the preceding lighted period.

Figure 1 shows only the end of the real learning curve, and this loss of efficiency on day 14 was negligible when compared to the amount of learning which had preceded the trials which are shown in figure 1. A population of 222 animals (from which groups I and II were representative sub-samples) made five times as many errors on the first day of running maze X in "original learning," namely, 10.0 errors (4, p. 79). To show the high degree of efficiency these animals had attained by the trials given in figure 1, I shall give the mean number of errors made by the larger sample on the first seven days of "original learning:" 10.0, 8.9, 7.5, 6.1,

5.5, 4.8 and 4.6. Thus it is obvious that such a loss of efficiency in groups I and II of from a mean of about 2.0 errors on day 13, to 2.9 errors on day 14 is fairly negligible when compared with the distance in knowledge which these animals (a sample of about one-third of the 222 mentioned above) had already progressed.

2. *Difference between means.* We have yet to prove that the loss of efficiency is due to anything else than chance fluctuations of sampling, though the appearance of the same loss of efficiency in group I and II in these two rather independent experiments separated by about a year would suggest strongly a *real*, though slight, loss. I have totalled the errors of each animal for the several trials occurring in the dark maze, and those on an equal number of trials preceding the turning off of the light. For each group there resulted two variables:

- Group I: L_2 = Total errors made on lighted maze on trials 10, 11, 12, and 13.
 D = Total errors made on dark maze on trials 14, 15, 16, and 17.
 Group II: L_2 = Total errors made on lighted maze on trials 11, 12, and 13.
 D = Total errors made on dark maze on trials 14, 15, and 16.

The procedure is to compute the mean efficiency of the lighted period, L_2 , and the mean efficiency of the dark period, D , find the difference between these means as the measure of the loss of efficiency, and observe whether this difference is significant in the light of its sampling error.

	M_{l_2}	M_d	$(M_{l_2} - M_d)$	Diff/ σ_{diff}
Group I.....	7.2 \pm 1.2	9.0 \pm 1.2	-1.8 \pm .49	-3.7
Group II.....	7.3 \pm 1.5	8.4 \pm 1.6	-1.1 \pm .77	-1.4

For group I, the loss of efficiency, i.e., difference between M_{l_2} and M_d , is more than three times its sampling error and may be considered real, but for group II, the difference is only one and a half times its error, hence its reliability is questionable. Because of the consistent tendency of the group II curves to behave like those of group I, the writer feels that the difference between means for group II failed of being statistically reliable only because of the small number of cases in group II, and would conclude that the difference is a real one.

3. *Percentage determination of variance in behavior by variation in visual stimulation.* Having ascertained that the mean loss of efficiency due to change in visual luminosity was probably a real one, we have now to determine whether systematic variation in luminosity within the limits controlled in our experiments may be considered of any great *importance* or weight as a cause of systematic differences between individuals. What we desire experimentally is two groups absolutely identical in mean efficiency and variation in efficiency up to the 13th trial, then one of these groups, the "experimental group," should be run in the dark for the next 4 trials, the other, the "control group," should be run in the light for the next 4 trials. Using the variance (σ^2) of total errors made in the last 4 trials as the measure of individual differences, one should then determine "the total variance of individuals due to all causes *including* variation in luminosity," this being the variance when both the experimental and control group are thrown together into one distribution. The additional statistic necessary is "the variance of individuals due to all causes *except* variation in luminosity," and this is the variance in either the control or the experimental group, for in *each* of these groups visual luminosity is held constant (the weighted average variance of these two sub-groups would normally be taken). It must be quite evident that the degree to which the total variance due to all causes is greater than the variance due to other factors than luminosity-change would be a measure of the additional variance among individuals occasioned solely by systematic variation in luminosity. If, for instance, the total variance between individuals is not significantly greater than the variance due to other factors than visual stimulation, then the luminosity factor is negligible as a cause of individual differences in maze ability.³

³ One assumption involved in this argument is that light and darkness, as we have used them, are two separated points on the *same* scale of luminosity. This seems correct, for we could lower by gradual *degrees* the luminosity from light to dark. Another assumption is that, within the ranges employed, the correlation between luminosity, y , and performance, x , is linear. *A priori*, the writer can think of no reason why this assumption is not valid, though the more scientific procedure would be to run n different groups of animals equal in all other respects than running the maze under n degrees of luminosity varying from light to com-

The datum which we actually possess is that of the experimental group mentioned above, namely, the variance of group I individuals who on trials 14 to 17 ran the maze in the dark. We do not actually possess the variance of a control group who ran trials 14 to 17 in the light. But we have data which enable us to estimate this last variance with great accuracy. Since the rats of group I had plateaued in the lighted maze from trials 6 to 13, we shall not be far off if we extrapolate their performance from 14 to 17. We shall do this by assuming that the mean and sigma of errors in the trials on the lighted maze from 10 to 13, would not be greatly different from the mean and sigma which they would have earned had they run in the light on trials 14 to 17. In brief, then, we actually possess the mean and sigma of an experimental group running in the dark from 14 to 17 (this is the variable, D), and are using the mean and sigma of this same group on 10 to 13 as evidence of what would have been obtained in a control group running in the light from 14 to 17 (this is the variable, L_2).

Our first statistic is the variance among individuals due to all causes, including variation in visual luminosity. This is the variance of scores when both the experimental (D) and control group (L_2) are thrown into one distribution. The total variance is found by the use of Yule's formula, as follows:⁴

Variance between individuals in errors made on four late trials (X), and which may be ascribed to all factors including variation in luminosity

$$= \sigma_x^2 = \frac{\sigma_{l_2}^2 + (M_{l_1} - M_x)^2 + \sigma_d^2 + (M_d - M_x)^2}{2} = 70.432 \quad (i)$$

plete darkness, and to plot the n mean maze scores against the n degrees of luminosity, and then to observe the degree of linearity. The problem is not sufficiently important to warrant such an extensive experiment, it would seem, and in view of the negligible difference actually found above between mean error scores under the two extreme degrees of luminosity, the results in such an experiment would probably be negative. The final assumption is that the distribution is homoscedastic in the y variable. Evidence that this condition holds here will be seen from table 2, shown later, in which the variances of errors on L_2 and D are equal within their sampling errors.

⁴ For a similar use of formulae (i) and (ii), see the second paper of this series (7, formulae 5 and 4), in which the percentage determinations of the variance in maze ability by variance of age, weight, sex and pigmentation were estimated.

The second statistic needed is the variance among individuals due to all causes except variation in visual luminosity. This is the variance of scores when visual stimulus is held constant, and is the average of the variance of the experimental and control group, as follows:

Variance between individuals in errors made on four late trials (X), and which may be ascribed to all causes *except* variation in luminosity (Y)

$$= \sigma_{x.y}^2 = \frac{\sigma_x^2 + \sigma_y^2}{2} = 69.622 \quad (\text{ii})$$

The value of (ii) subtracted from (i) gives the amount of variance among individuals due to variation in luminosity alone. This value is $70.432 - 69.622 = .810$. The proportional contribution of this variance due to visual stimulus change is $.810/70.432 = .012$. Thus only twelve-thousandths of the variance among individuals which occurred on a late stage of learning when such a great change of luminosity was introduced can be ascribed to that change. We accordingly conclude that at the last stages of learning denoted by L_2 and D , change in luminosity is indeed a negligible cause of difference between individuals.

B. The effect of variation in visual acuity

1. *Learning curves of albino and pigmented animals.* The eyes of hooded and self-colored animals are pigmented, and it is known that the visual acuity of pigmented animals is superior to that of albinos (2). Now, if differences in visual acuity are important in determining individual differences in maze ability, then one would expect some characteristic difference to appear between the pigmented-eyed and the pink-eyed rats when both were thrown into darkness on the 14th trial in learning. The learning curves of 28 pigmented and 43 albino rats are plotted in figure 1. On the 14th day both types of animals seemed to have been about equally affected by the sudden change from light to dark, both losing nearly the same amount in absolute efficiency. There is no evidence to show that the pigmented animals, with better acuity, were more hampered by the change than were the albino.

If superior visual acuity had any effect at all in maze ability, it was probably deleterious, for, as was also noted in a previous paper in this series (7), the pigmented animals consistently made more errors in the lighted maze than the albinos. Then when they were thrown into darkness, they lost slightly in efficiency on the 14th day, as we noted, but after that they began to improve and on the 16th day, in the dark, they were equal in efficiency to the albinos. Such a result would be expected on the hypothesis that visual acuity to a slight extent hampered the pigmented animals in the lighted maze (perhaps visual cues were disturbing), and when they were thrust into a condition in which their superior acuity could not operate, they soon showed equal ability to animals who did not possess superior vision. The evidence is, however, rather meager. The more conservative position for us to hold on the basis of the pigmented vs. albino curves is the conclusion that variation in visual acuity plays but a slight rôle in variation in maze-ability at these late stages of learning, with a possible mental reservation that to the extent to which visual acuity operates at all, it is in the direction of disturbance.

2. *Correlation between ability in the lighted maze and ability in the dark maze.* Our other line of evidence as to whether differences in visual acuity affect ability in the maze, is that of determining the correlation between ability in the illuminated maze, L_2 , with ability in the same maze when the lights are turned off, D . If this correlation coefficient is unity, then individual differences in the lighted maze cannot be ascribed to acuity differences, for it means that the animals took the same rank order in the dark when the acuity factor could not possibly operate. Now, it is quite improbable that the correlation between the abilities shown on two adjacent periods of learning *in the lighted maze* would be *unity* and it does not follow, therefore, that a coefficient less than unity necessarily imputes to L_2 the involvement of visual acuity, a capacity non-operative in D . If the correlation between errors made on L_2 and on D is no lower than that between L_2 and L_1 , the lighted period preceding L_2 , then the failure of the r_{L_2D} to be unity cannot be ascribed to the removal of such a significant visual factor, since L_2 and L_1 both represent condi-

tions in which such a factor could fully operate. Our analysis includes, then, the correlating of L_2 with D , and also of L_2 with a preceding lighted period, L_1 . This will be done with both group I and the check sample, group II. It remains for us to define L_1 for the two groups.

Group I: L_1 = Total errors made on the lighted maze on trials 6, 7, 8, and 9.

Group II: L_1 = Total errors made on the lighted maze on trials 7, 8, 9, and 10.

a. The reliability coefficients and other constants of the variables

In order to have our correlations reflect the true community of function between the sundry variables, it is necessary to correct

TABLE 1

Means and sigmas of the half-measures, the odd-even correlations, and the reliability coefficients (r) of total measures, with standard errors

	GROUP I			GROUP II		
	L_1	L_2	D	L_1	L_2	D
M_o	3.5 ± .6	3.6 ± .6	4.7 ± .6	5.8 ± 1.0	3.5 ± .7	3.9 ± .7
M_e	3.6 ± .6	3.6 ± .6	4.3 ± .7	6.2 ± 1.2	3.8 ± .8	4.5 ± .9
σ_o	3.9 ± .4	4.2 ± .4	4.1 ± .4	5.2 ± .7	3.7 ± .5	3.6 ± .5
σ_e	4.1 ± .4	4.2 ± .4	4.7 ± .5	5.8 ± .8	4.1 ± .6	4.4 ± .6
r_{oe}.....	.90 ± .03	.93 ± .02	.84 ± .04	.87 ± .05	.91 ± .03	.87 ± .05
r.....	.950 ± .015	.965 ± .010	.914 ± .027	.933 ± .027	.954 ± .018	.929 ± .028

the raw coefficients for attenuating errors of measurement (un-systematic causes of variation between individuals). This requirement necessitates the calculation of reliability coefficients, which in our case was done by splitting the measures in each variable into comparable odd and even halves, correlating these half-measures, and estimating the reliability coefficient of the whole measures by the Spearman-Brown formula, $r_{oe} / (1 + r_{oe})$. In the case of group I, since L_1 , L_2 , and D each represents the total errors made on 4 trials, the half-measures for each variable were odd and even trials. In the case of group II, since L_2 and D each represents the errors made on only 3 trials, the half-measures for each of these variables could not be in terms of trials, and hence they were chosen as total errors on odd and on even *blinds*. For

group II the half-measures of L_1 were errors on odd and even trials. The resulting constants are given in table 1. That the reliability coefficients of the major variables satisfy the definition and requirements of such constants (see 6) is evident from the fact that the half-measures of the major variables are random fractionations and from the fact that the differences between sigmas of half-measures are not significantly greater than zero. To ascertain whether or not the sigmas of the comparable half-measures are not significantly different, I have chosen the largest differences to be found in group I and in group II and calculated the requisite standard errors of these differences.⁵ For group I this is the half-measures of D , in which $\sigma_o - \sigma_e = 4.1 - 4.7 = -.6 \pm .4$, and for group II this is also the half-measures of D , in which $\sigma_o - \sigma_e = 3.6 - 4.4 = -.8 \pm .4$. In the first case the difference between the sigmas is only one and a half its standard error, in the second case the difference is only twice its standard error. Thus, there is no evidence here that our half-measures do not represent comparable halves of the whole measures, and we may therefore conclude that the reliability coefficients represent proper values.

b. The raw and true correlation coefficients. Since the correlation between ability in the lighted maze and ability in the dark maze engages our greatest interest, the correlation plot from which $r_{l,d}$ was calculated is reproduced for group I in figure 2, and for group II in figure 3. An examination of these plots leaves no doubt that an animal who was bright in the light was bright in the dark, and one who was dull in the light was dull in the dark, and that this correlation was true all along the scale of ability, both in group I and group II.

The raw correlation coefficients calculated from these plots, and these corrected for attenuation are given in table 2, which

⁵ The standard error of the difference between two sigmas was determined from the formula used by Kelley, T. L., *Statistical Method*, 1924, Macmillan, p. 184, involving his formula (121) which assumes rectilinearity, homoscedasticity, and equal kurtosis of the half-measures. These assumptions are fairly satisfied by our data.

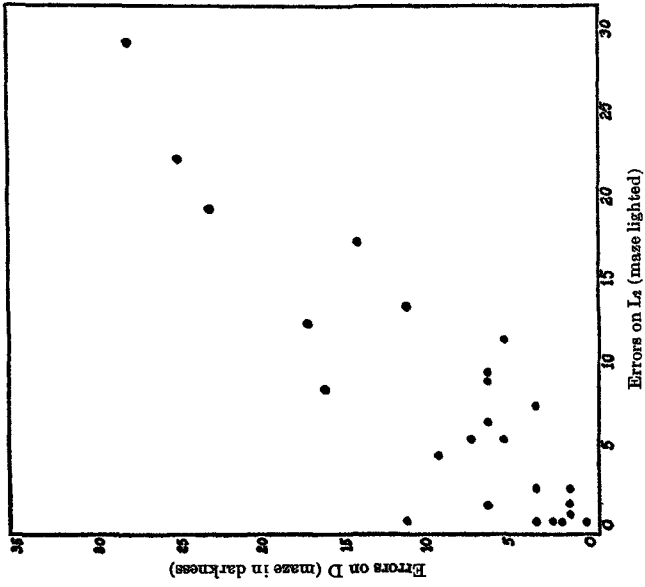


Fig. 3

FIG. 2. CORRELATION PLOT SHOWING RELATION BETWEEN ERRORS MADE IN THE LIGHTED MAZE (L_2) AND ERRORS MADE IN THE DARK MAZE (D) FOR GROUP I ($N = 46$)

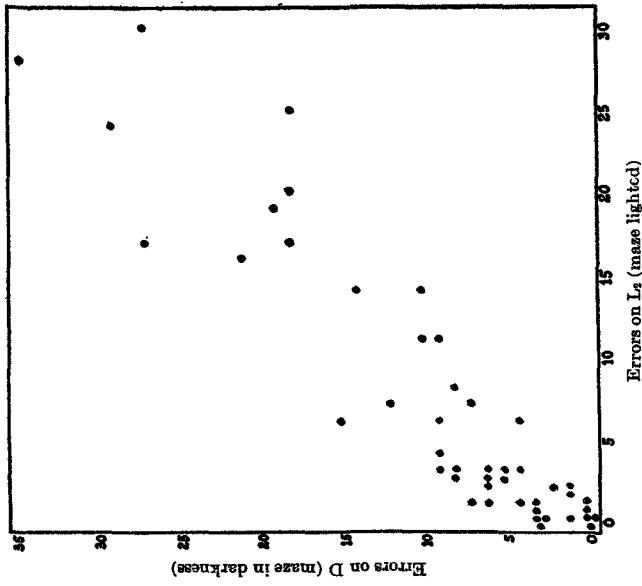


Fig. 2

FIG. 3. CORRELATION PLOT SHOWING RELATION BETWEEN ERRORS MADE IN THE LIGHTED MAZE (L_2) AND ERRORS MADE IN THE DARK MAZE (D) FOR GROUP II ($N = 25$)

also contains the raw and true correlations⁶ between the two lighted periods, L_2 and L_1 .

The true correlations (in italics) of table 2, show at once that individual differences in the lighted periods, L_1 add L_2 , were largely determined by the *same* systematic factors, the correlations being for group I, .977, and for group II, .975. But individual differences in ability in the lighted maze, L_2 , and in the dark maze, D , were likewise largely determined by the same systematic factors, the true correlations between these two abilities

TABLE 2
Raw and true between L_1 , L_2 , and D , means and sigmas, and standard errors of constants

	GROUP I	GROUP II
Correlations:		
L_1L_2 : raw.....	.91 ± .03	.91 ± .04
<i>true</i>	<i>.977 ± .038</i>	<i>.975 ± .037</i>
L_2D : raw.....	.92 ± .02	.88 ± .05
<i>true</i>	<i>.978 ± .007</i>	<i>.933 ± .036</i>
Means:		
L_1	7.1 ± 1.2	12.0 ± 2.1
L_2	7.2 ± 1.2	7.3 ± 1.5
D	9.0 ± 1.2	8.4 ± 1.6
Sigmas:		
L_1	7.8 ± .8	10.7 ± 1.5
L_2	8.3 ± .9	7.6 ± 1.1
D	8.4 ± .9	7.8 ± 1.1

being, for group I, .978, and for group II, .933. And since individual differences in D could not possibly have been due to systematic differences in constitutional visual acuity, this factor being experimentally excluded, then individual differences in L_2 or L_1 could not possibly have depended to any significant extent on differences in visual acuity.

⁶ The true correlations were computed from formula (155a) given by Kelley, T. L., *op. cit.*, and the standard errors of these were computed from his formula (161).

V. AN HYPOTHESIS OF MAZE ABILITY

The results presented above prove, in the first place, that such an introactive factor as visual stimulation may undergo considerable variation without constituting a significant cause of individual differences in maze ability as measured at a late stage of learning. This fact, together with the facts found in the previous paper (9), namely, that very extensive introactive systematic and unsystematic environmental variations interpolated at a certain point in the learning trials had no significant effect in up-setting individual differences, *suggest* that the most potent causes of individual differences do not lie in such introactive factors, but rather that the important differentiae of individual differences lie within the individuals themselves, and exist anterior to the time of measurement, i.e., are "brought to" the experiment by the organisms themselves.

Our results show, in the second place, that one of these anteroactive factors, in existence before the experiment and brought to it namely, visual acuity, is *not* one of the important underlying factors, at least, it is not operative in the late stages of learning, and since in the previous study of this series (9) *the late stages of this learning ability have been shown to correlate very highly with the early stages*, one may conclude that individual differences in constitutional visual acuity may be safely discarded as an important factor upon which individual differences in this maze ability depend.⁷ Other systematic anteroactive factors which we have already checked off as possible differentiae of ability are sex, age, weight, and pigmentation (7). We are thus beginning to get some notion as to what the causal factors are *not*. Since we have eliminated these factors as causal differentiae, it would seem permissible to speculate as to what *are* the differentiae. Evi-

⁷ One might argue that visual acuity correlated *perfectly* with whatever factors, independent of vision, cause individual differences in ability at the late stages of learning, and hence deprivation of vision would not upset high light-darkness intercorrelations. But the low correlations universally found in human beings between the acuities in different sense modes, and between sense acuities and other mental functions would suggest that perfect correlation between such functions in rats should not be expected.

dence cited in the previous paper, as well as that already obtained in the selective breeding experiment which the writer is conducting and which has as its immediate objective the establishing of a race of Bright and a race of Dull rats (5), indicates that these causal factors are largely *hereditary*, and of the multiple factorial type.

Physiologically and morphologically, the differentiae may reside in the sensory apparatuses and their immediate neural connections, or in the central-neural connections, or in the effector apparatuses, or in all three. We have disposed of the visual sensorium as a possibility, and the writer offers no better evidence than his own subjective judgment, based upon his experience in supervising the running of about a thousand rats on maze X, in support of the tentative theory that the auditory, olfactory, gustatory, thermal, and interoceptive sensory capacities play only a meager rôle, if any, as *differentiae* of ability to learn maze X. If variations in sensory acuity play a rôle at all in determining individual differences in learning, the sense modes which, in the opinion of the writer, seem most likely to be involved are equilibrium, the tactual sense, and proprioception. The writer confesses to a doubt that individual differences in the capacities of even these sense modes plays a considerable rôle in ability. He is arguing not that external stimuli and sensory acuity play no rôle, but that *variations* in these are negligible *differentiae* of ability. He espouses the theory that animals *identical in all constitutional sense acuities* could, nevertheless, differ greatly in ability to learn the maze. The most tenable hypothesis as to the physiological cause of individual differences in maze ability would be the one in which variation in central nervous connectivity is considered the most important differentia. The most profitable research on the physiological causes of individual differences would thus lie, it would seem, in the direction of histological examination of the neural conductors, or in noting the *correlation* between ability before and ability after controlled central neural destruction.

Psychologically, or behaviorally, individual differences in ability to learn the maze X would, in the writer's opinion, hinge upon

the capacity for association, a phenomenon to which the terms conditioning (Pavlov, Smith and Guthrie, Dashiell, etc.), sign-gestalt formation (Tolman), insight-formation (Köhler), re-integration (Hollingworth), etc., are given. This hypothesis minimizes the rôle of sense discrimination as factor in determining individual differences in maze ability, especially insofar as such discrimination hinges upon excellency of the sensory apparatuses (see above). Furthermore, this hypothesis minimizes the rôle of differences in drive (incentive, motivation), for in an earlier paper (7) we saw that individual differences in body weight were not correlated with performance, even though all animals received the same amount of food at the end of the maze run, a condition which would tend to make the heavier animals hungrier than the lighter animals. In brief, then, the tentative hypothesis is held that it is not so much variation in the drive, or in the ability to sense the stimuli presented in the maze, but rather in the ability to associate, integrate, condition, etc., the multiplicity of stimuli presented, that the important differentiae of learning ability (at least as shown on maze X) lie.

Hereditarily, differences in ability to learn are probably multiple-factorially determined, as the writer has elsewhere enounced (5). Thus, the capacity to learn in one type of situation, such as maze X, does not *necessarily* imply the same capacity to learn in all other situations. Indeed the supposition is tenable that abilities shown in two situations may be determined by rather independent factors and hence may correlate very low, though the writer is predisposed toward the view that to the degree to which two situations are highly complex and involve the utilization of many somatic tissues, the correlation between the abilities shown in these situations will be high (8), and to the degree to which the situations tap "narrow" functions, such as sense discriminations, the abilities manifested in these situations will correlate low.

Such an hypothesis points out the field of future experiments in which we would seek to map out, as it were, the psychological, or behavioral, structure of the ability to learn maze X. To do this, we must measure the animals in many capacities, such as sense discriminations, motor activity of sundry sorts, simple

retentions, and more complex learning and insight-forming abilities. The correlation of these with our maze learning ability will thus give us some notion of the psychological nature of the systematic factors causing individual differences in maze performance.

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