

# STUDIES IN INDIVIDUAL DIFFERENCES IN MAZE ABILITY

## IV. THE CONSTANCY OF INDIVIDUAL DIFFERENCES: CORRELATION BETWEEN LEARNING AND RELEARNING<sup>1</sup>

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### I. INTRODUCTION

#### *A. Problem*

If the differences between individuals in a given ability are caused by stable differences in hereditary constitution, one would expect the differences to persist in general throughout the duration of life, provided all individuals live in the same environment.<sup>2</sup> Individuals respectively superior and inferior in a certain ability when measured early in life would be respectively superior and inferior in the same ability after a lapse of time. The evidence of constancy of the I.Q. over a long period is thus often interpreted as indicating hereditary determination. But the *single* evidence

<sup>1</sup> This is the fourth of a series of studies on individual differences in maze ability. The first (8) showed that individual differences were determined almost completely by systematic factors, the second (9) showed that these systematic factors could not possibly be ascribed to conditions correlated with physique (such as age, weight, sex and pigmentation), the third (10) showed that the systematic differentiae at work were fairly general, occurring in two maze abilities, and this, the fourth, attempts to show that these systematic factors are fairly constant throughout at least one-fifth of the rats' lives, and suggests that the factors are of hereditary origin.

To the National Research Council, the writer herewith expresses his indebtedness for the fellowship granted him, during the tenure of which he was enabled to collect some of the evidence presented here. To the Department of Psychology, University of California, he wishes likewise to express his gratitude for the facilities extended to him.

<sup>2</sup> By hereditary constitution is meant the "phenotypic" expression of the given "genotype;" by environmental factor is meant what the geneticist calls "modification," namely, any factor or condition which causes individuals of the *same genotype* to differ in structure or behavior.

of a high correlation between two measured performances of the same ability separated by an interval is itself not *proof* of hereditary determination, for one may argue from it that (1) early differences in environmental training are the determiners of the differences on the first as well as on the second occasions of measurement, or (2) immediate environmental factors of a chance sort cause individuals to take a certain rank order in performance on the first occasion of measurement and that this rank order is *stamped in*, as it were, by this first experience and then *transferred* to the later performance.

The only method of removing the effect of these two types of environmental factor is, it seems, by experimentally controlling them. If attempts at control are successful, then a high correlation between the first and second measurements should be assignable to hereditary determiners. This paper proposes to describe three experiments on maze ability in rats in which high correlations were found between errors made in an original learning series of maze runs, and errors made in a relearning series given at a much later date. Attempts were made to control vitiating environmental sources of variation before and during the original learning series.

It is to be noted that previous experiments on this problem have uniformly shown low correlations between learning and relearning in rats. But these low correlations are open to the interpretation that errors of measurement so adulterated the measures that no *systematic* hereditary or environmental causes were manifest. Failure of such correlations to be significantly positive is also open to other interpretations. A hereditarian would argue that the low correlations indicate the operation of independent genetic (i.e., hereditary) factors determining learning and relearning. A euthenist would argue that environmental conditions occurring before or during original learning cause differences in the first performance, and that other environmental conditions uncorrelated with the first and occurring during the interim between original learning and relearning, or during relearning itself cause differences in the second performance. These two sets of environmental conditions, being independent, would thus cause a low correlation between the first and second measurements.

Thus we see that a low learning-relearning correlation argues *uniquely* for neither heredity nor environment, while a high correlation argues for hereditary determination only if there exists plausible evidence that *environmental factors have been controlled*. Our problem then boils down in the main to attempting to control ambient environmental influences, so that to the extent to which a positive correlation does occur, we may assume that it is due to common hereditary causes.

*B. Factors affecting individual differences in learning and relearning*

The above considerations indicate that the causal factors at work are highly complex, therefore, to avoid being befogged in a haze of circumlocutions, I present the schema in figure 1 in which the sundry factors are represented by symbols. In this figure are shown the observed learning curve,  $O_{a_1}$ , of a given individual,  $A$ , to the left, and his relearning curve,  $O_{a_2}$ , to the right. The symbols sprinkled throughout the diagram represent various factors which conceivably could affect his and other  $O$ 's learning curves, as follows:

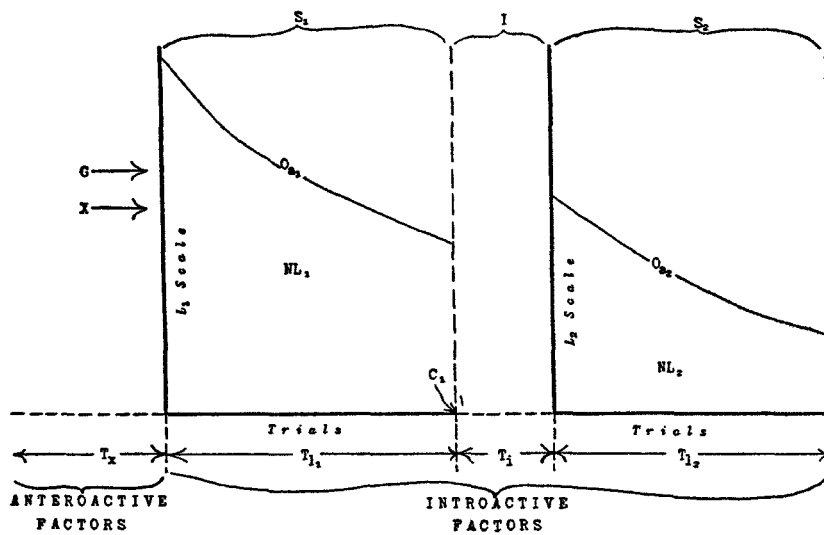


FIG. 1. SCHEMA DEPICTING THE FACTORS AFFECTING INDIVIDUAL DIFFERENCES IN LEARNING AND RELEARNING

$L_1$  scale: the original learning curve ordinate, which is a function of the *type* of material learned, *amount* of material, and *score* earned.

$NL_1$ : total amount of original learning permitted, bounded by the initial trial and the arbitrary "cut-off" point,  $C_1$ .

$T_{i_1}$ : amount of time through which original learning proceeded.

$I$ : interspersed training or conditions between original learning and relearning. These may be *controlled*, consisting in the giving of systematic practice in other functions or in the holding constant of conditions, or they may be *uncontrolled*, consisting in diverse experience, often called "rest."

$T_i$ : amount of time of the interlude,  $I$ .

$X$ : previous training or conditions which occurred before learning. These may be *controlled*, consisting in the giving of systematic practice on other functions or in the holding constant of such training or conditions, or they may be *uncontrolled*.

$T_x$ : time which elapsed before learning. This time indicates the age of the animals at initial learning.

$S_1$ : conditions or differential training called into existence by the experimental situation itself, and not existing before the experimental period. Such conditions may be *controlled*, consisting in the permitting of systematic variation in time of day, order of running, reward, sensory cues, health, weight, etc., or in the holding *constant* of conditions, or they may be *uncontrolled*, consisting in the permitting of unsystematic variations in sensory cues, procedure, reward, etc.  $S_2$  represents analogous conditions or experiences obtaining during relearning.

$G$ : hereditary (genotypic) constitution of the group of individuals being experimented upon, one of whom we have symbolized as  $O_a$  in the figure.

Each of these symbolized factors or conditions are possible causes of individual differences, for by holding all but one of them constant, variations in the remaining variable factor or conditions may conceivably be accompanied by differences in learning behavior. A more complete analysis should be made in which each would be analyzed into more or less independent sub-factors

or sub-conditions. Perhaps others than these should be added. To the writer, the ones presented constitute a good tentative system of causal factors which are fairly independent of each other.

In terms of this schema, our problem is that of attempting to control other factors than *G* and *I*, either by holding these other factors constant experimentally or by showing that the permitted variations in them did not affect learning or relearning.

*C. Nature of the action of these factors on individual differences*

To facilitate our analysis, we must define certain terms which describe the possible types of action of these factors on individual differences.

The term *anteroaction* shall mean the action of those factors which exist before learning. Such factors are *X*, *T<sub>s</sub>*, and *G*. Anteroaction refers only to the objective fact that these factors were in existence before learning, and they may continue to work throughout the whole experimental period.

The term *introaction* shall mean the action of those factors, not in existence before learning or relearning but arising within or during the course of the experiment. They arise primarily from the experimental conditions themselves or from conditions interpolated at some point during the experimental period. Such factors are *S*, the *L* scale, *NL*, *Tl*, *I* and *T<sub>i</sub>*.

The familiar term, *retroaction*, represents a special type of introaction which appears only within a special type of experimental set-up, namely, the learning-relearning experiment. If, during the interpolated interval, *T<sub>i</sub>*, the conditions, *I*, are of the uncontrolled sort, called "rest," then an individual who begins relearning with a poorer score than at the end of learning is said to have experienced "forgetting," for which a more objective term would be *uncontrolled negative introaction (or retroaction)*. If, on the other hand, the subject begins to relearn with a better score than at the end of original learning, he is said to have experienced "unconscious improvement," for which a more objective term would be *uncontrolled positive introaction (or retroaction)*. But if the interpolated conditions have included

controlled systematic practice on some other material, such as, in one of our experiments, the learning of a second quite different maze, then the "experimental subject" who earns a poorer re-learning score than a "control subject" who showed the same original learning efficiency but who experienced "rest" during the interpolated interval is said to have experienced "retroactive inhibition," for which a more objective term would be *controlled negative introaction*. Conversely, an experimental subject who does better than his control subject is said to have experienced "facilitation" by virtue of his interpolated practice. Here again, the preferred objective term would be *controlled positive introaction*.

The italicized terms are objective in the sense that they imply nothing as to the physiological or the "conscious" effect of the interpolated experiences, whereas such terms as "forgetting," "inhibition," and "facilitation" may have such connotations. Since most animal and human learning experiments tell us little of the physiological mechanisms involved, and since with animals the "consciousness" analysis is necessarily unapproachable, we need terms describing the objective effect on learning and re-learning of certain objectively stated factors or conditions. To avoid philosophical issues, we shall not state that the physiological or "consciousness" analyses are not objective, but rather that our experimental-statistical descriptions are *more* objective than they.

To sum up, nothing more is meant by the term anteroaction than that the factor having this effect existed before learning, introaction indicates the effect of a factor appearing at any time within the experimental period. Control refers to the degree to which these factors or conditions are regulated and measured. Positive and negative refers only to the arithmetic results. The terms, therefore, are equally applicable<sup>4</sup> to human and sub-human behavior.<sup>5</sup>

<sup>5</sup>The schema and terminology suggested above are *general* and have been applied here only to the special experimental set-up of learning,  $L_1$ , and relearning,  $L_2$ . Now  $L_1$  and  $L_2$  may, however, represent two quite different scales measuring two quite different abilities. Such is the set-up in the typical "trans-

*D. Previous research on this problem*

The writer has discovered only four previous researches on the community of function between learning and relearning in animals. These were made by Heron (2), Liggett (4), Hunter and Randolph (3) and Webb (11). The researches are summarized in table 1. The extreme left column denotes the sundry factors or conditions which influence individual differences, and each experimenter is given a column in which, opposite the given factor, a statement is made as to how the particular experimenter controlled or varied that particular factor.

The bottom row of the table shows that the correlation between learning and relearning were practically zero, though in the case of Heron's and Webb's experiments the number of cases is so few as to place uncertainty upon the statistical results. Assuming for the sake of argument that these coefficients are really zero, no evidence is apparent to show that these results do not derive entirely from the operation of errors of measurement. The material which the animals were required to learn was of the simplest sort, and it is likely that no *systematic* differences either of environmental or hereditary origin were measured during learning or relearning. No evidence is offered to show that these measures had high internal reliability, and no corrections for attenuation are given. The writer interprets these results to mean that, since the material was so simple, potent anteroactive and introactive unsystematic  $S_1$  factors were entirely responsible for individual differences in original learning, and other

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fer" experiment, where the experimental subject experiences  $L_1$  before  $L_2$ , whilst the control subject experiences "rest" only before  $L_2$ . If the experimental subject is superior to the control in  $L_2$ , then  $L_1$  is said to have a "positive transfer" effect upon  $L_2$ , though a more objective term would be that of *controlled positive anteroaction*. If the experimental subject is inferior in  $L_2$  to the control, the function,  $L_1$ , is said to have a "negative transfer" or "interference" effect, though here again the more objective term would be *controlled negative anteroaction*.

The two different habits may be learned *simultaneously* by the experimental subject, his performance being compared to two controls, one learning only  $L_1$ , the other learning only  $L_2$ . Superiority of the experimental over the control would here indicate the controlled positive introaction of the two habits upon each other, whilst inferiority would be described as controlled negative introaction.

TABLE 1  
 Summary of previous researches on the correlation between learning and relearning with special reference to the nature of control of  
 sundry factors and conditions and to the correlations found

FACTOR OR CONDITION	HERON (RATS)	LIGGETT (CHICKS)	HUNTER AND RANDOLPH (RATS)	WEBB (RATS)
$X$ = previous experience.....	Not stated	Not stated	Not stated	"Naive"
$T_a$ = age (days).....	50-70	25	30-40	49-84
$L_1$ scale = material; score.....	Inclined plane box; time	Straight maze (St), T-maze; time	Straight maze, T-maze, sawdust box; time	Carr type maze; trials, errors, time
$NL_1$ = learning permitted.....	6 trials	St: 7 trials; T-m: 3 trials	3 trials on all	Perfection
$T_1$ = duration of learning.....	6 days	St: 7 days; T-m: 3 days	3 days for all	Variable
$S_1$ introactive influences on learning.....	Not stated	Not stated	Not stated	Partially stated
$I$ = interspersed conditions.....	"Rest"	"Rest"	"Rest"	Control: exercise; Exp: another maze
$T_i$ = duration of $I$ .....	60 days	St: 33 days; T-m: 33 days	30 days	30 days
$L_2$ scale = material; score.....	Same as $L_1$ scale	Same as $L_1$ scale	Same as $L_1$ scale	Same as $L_1$ scale
$NL_2$ = relearning permitted.....	6 trials	St: 7 trials; T-m: 3 trials	3 trials on all	Perfection
$T_2$ = duration of relearning.....	6 days	St: 7 trials; T-m: 3 days	3 days for all	Variable
$S_2$ introactive influences on relearning.....	Not stated	Not stated	Not stated	Partially stated
$G$ = genetic sample.....	Not stated	Not stated	Not stated	Not stated
$N$ = number of cases.....	20	48	Approximately 30	From 6 to 12
Correlation coefficient between learning and relearning...	$r = -.01$	$r_{..} = .304$ $r_{mm} = .038$	$r$ 's not significantly different from zero	$r$ 's probably not significantly different from zero



independent uncorrelated introactive unsystematic  $S_2$  factors caused the variation in relearning, hence the correlation between these two measures was low. The effect of such factors could be nullified, the writer submits, by increasing the reliability of each measure by the methods described in a previous paper (8, p. 148 ff.). Had this been done, there is no reason to suppose that more deep-seated hereditary systematic factors could not have operated in occasioning a high learning-relearning correlation. But hereditary factors could occasion such a correlation only if the animals differed genetically. The experimenters offer no evidence, however, that the groups represent heterogeneous genetic samples.

## II. RESTATEMENT OF THE PROBLEM

Our problem is to hold time of practice,  $T_i$  and  $T_r$ , the amount of practice,  $NL_1$  and  $NL_2$ , and the  $L$  scales constant for all animals during learning and relearning. To what degree, then, is the variation found between the individual curves,  $O$ 's, caused by variation in other environmental and genetic factors? The effect of  $T_r$  and  $T_i$ , the duration in time of previous experience and of the interpolated interval, will be found from their respective correlations with performance. Previous anteroactive experience,  $X$ , we shall attempt to control by holding it as constant as possible for all animals. Any significant variations in it, however, which would affect original learning we shall attempt to annul in relearning by the method of introducing an interpolated period of considerable duration in which conditions,  $I$ , are uncorrelated with  $X$ . Thus we have attempted to remove  $X$  and  $I$  as factors tending to make a *positive* learning-relearning correlation. Introactive factors,  $S_1$  and  $S_2$ , we shall attempt experimentally to hold constant. But those  $S_1$  factors which vary and which may affect individual differences in learning we have likewise attempted to annul as a source of positive correlation between  $L_1$  and  $L_2$  by giving the long interim,  $I$ , and then permitting relearning to occur under  $S_2$  conditions which are, as far as is known, uncorrelated with  $S_1$ . If we have thus controlled these sundry environmental factors or rendered them

impotent as systematic causes of individual differences which would operate over the entire period to cause a positive learning-relearning correlation, then a high correlation between learning and relearning will indicate the causation by stable hereditary factors of individual differences in ability. It is just these hereditary differences which, by extensive random sampling, we have attempted to make as variable as possible. Failure to find a *unity* correlation will indicate the existence of independent hereditary or environmental factors causing individual differences in original learning, retention over the interval,  $I$ , and relearning.

### III. EVIDENCE RELATING TO THE EFFICACY OF EXPERIMENTAL CONTROL

We shall consider successively the sundry factors and conditions enumerated above, in particular, noting the effects upon the learning-relearning correlation to be expected when variance occurs in each one of them, and shall then cite our evidence bearing on our attempts to control them or to measure statistically the effects of them on individual differences. Three different experiments were performed. Two groups of animals, group I and group II, learned and relearned the maze under essentially the same conditions, with the exception that group I learned a different maze in the interim between  $L_1$  and  $L_2$ , while group II experienced rest. Group III learned the maze in one experimental setting, then relearned the same maze in a different general setting.

#### *A. The $L_1$ and $L_2$ learning scales*

In our experiments we have held the  $L_1$  and  $L_2$  scales *constant* by virtue of their being the same scale. This scale consisted in a 17 unit automatic T-maze described in detail elsewhere (5, 8), the score being the number of partial or full entrances into blinds. It was so constructed as to render high reliability of individual measurement.

#### *B. The genetic sample, G*

The hereditary constitution of the animals we wished to make as normally variable as possible, for it was just the effect of these

genetic variations which we wished to study as the cause of individual differences in learning and relearning. If we succeeded in holding environmental conditions constant then the source of variation between animals in original learning would be in their genotypic natures, and this being the case, the sole source of correlation between learning and relearning would be in common hereditary factors operating over the whole experimental period.

The numbers of animals in each sex, and in the pigmented and albino categories are shown in table 2. Group I contained 46 animals drawn from the original parental sample (P) in the inheritance experiment on which the writer is engaged (7) and this sample is fully described elsewhere (8, p. 161). Particular

TABLE 2  
*Distribution of animals according to sex and pigmentation in the three groups*

GROUP	MALES	FEMALES	PIGMENTED	ALBINO	TOTAL
I	23	23	18	28	46
II		25	11	14	25
III	15	21	19	17	36
Total.....	38	69	48	59	107

efforts were made to have this sample constitute a random representation of rat talent. Group II consisted of 25 ( $F_1$ ) children of the parental sample. Group III consisted of 36 ( $F_2$ ) great-grand-children of the P generation.

Since the magnitude of correlations is so sensitively affected by the heterogeneity of the sample (8, p. 151) we must ascertain the degree of selection in our experimental groups by comparing their means and sigmas of total error scores with that of an unselected sample of rats. To secure the requisite unselected sample, I have chosen at random 340 rats from the P and  $F_1$  generations used in the inheritance problem, and have calculated the mean and sigma of their total errors in original learning (trials 2 to 19). These and the analogous constants of our groups were as follows:

	MEAN	SIGMA
340 random P and F <sub>1</sub> rats.....	74.7 ± 2.6	48.5 ± 1.9
Group I.....	79.3 ± 7.4	50.0 ± 5.2
Group II.....	88.1 ± 10.9	54.6 ± 7.7
Group III.....	68.9 ± 6.9	41.4 ± 4.9

It must be evident that in the light of the standard errors of these constants,<sup>4</sup> the mean and sigma of group I do not greatly differ from those of the random sample, whereas group II is probably slightly more variable, and group III slightly less. We are prevented from using the conventional formula for calculating the standard error of the difference between the constants of the random sample and those of I and II because some of the rats in the random sample were also in I and II.

#### C. Amount of learning and relearning, $NL_1$ and $NL_2$

The *amount* of learning and relearning permitted is one of the most important conditions affecting the learning-relearning correlation. In general, this correlation will be *lower* in proportion as original learning ( $NL_1$ ) is made (1) to include the most unreliable parts of learning, such as early trials, and (2) to include *too much* original learning. Some previous experimenters allowed original learning to include only the first few trials (Heron, Liggett, Hunter and Randolph) the reliability coefficient of which was nearly zero, and then after an interval,  $I$ , the animals have been run again. The fact of the first measures being unreliable *necessarily* makes the learning-relearning correlation low. Corrections for attenuation can compensate for the errors of measurement, but such corrections have ordinarily not been made. In the other extreme, some experimenters (Webb) permitted original learning to consist in the bringing of *every* animal to the same point of efficiency, namely perfection, where perfection is defined as an arbitrary number of trials without error. This left little to be relearned for any of the animals, and it has not been shown that *reliable* differences in such relearning existed.

In our experiments an attempt to avoid some of these diffi-

<sup>4</sup> All figures after ± are standard errors.

culties was made by running all the animals the same number of trials, these trials being cut off at a stage of learning where individual differences among rats were great, and where the total errors made on the stages preceding the "cut-off" showed a high reliability coefficient. At the end of the 19th trial in original learning, it was evident that sufficient measures had been secured to render a high reliability coefficient and that there still existed great variability among the individuals. Indeed, for a random sample in the parental (P) generation, the reliability coefficient of total errors made up to and including trial 19 proved to be  $.9876 \pm .0014$  (P.E.) (see 8, p. 165). As to variability on the last stage of learning, the writer has given detailed evidence elsewhere (6, p. 79). For 222 animals the standard deviation of errors on successive sixths of learning came out as follows: 6.7, 9.5, 9.8, 9.8, 9.1, and 8.5. Thus on the last sixth of original learning, namely, total errors on trials 17, 18, 19, the sigma of this total was 8.5, a little more than one error less than maximum variability, 9.8, but far from zero, which would have been the sigma at the ultimate stage of original learning at which all the animals would be equally perfect.

The amount of relearning permitted was that involved in 13 trials. The relearning was cut off at the end of the 13th trial, because sufficient relearning measures had been secured by the 13th trial to insure a high reliability coefficient of total relearning scores.

#### *D. Duration of practice, $T_1$ , and $T_2$*

In many functions, variations in the time over which the same amount of practice has been distributed affect performance. But in our experiments this time has been held constant for all animals: 19 days for learning, 13 days for relearning, i.e., one trial a day. The time factor cannot affect individual differences in this case, though if we attempted to compare the learning-relearning correlations of our experiments with those of other writers in which the same number of trials were distributed over fewer days, a procedure which requires animals to run several times a day, this difference in distribution of practice might show

different results. The influence of distribution of practice upon correlations has not, to the writer's knowledge, been investigated.

*E. Previous experience, X*

The euthenist's argument is that individual differences in ability are largely engendered by differences in early experience. This differential experience would thus be urged as a potent one in causing a high learning-relearning correlation. We have attempted to control anteroactive experience by exposing all rats to what appeared to be relatively the same environment. This is an exceedingly important consideration in the inheritance problem (in which the animals in groups I, II, III were subjects), for it was desired to raise children of Bright and of Dull parents in the same environment. Very special efforts were made to keep ambient influences the same for all the cages in which these animals lived before they learned the maze (7). Each animal lived with its siblings until shortly after weaning time (30 days), when it was numbered by punching its ears. Then it was placed with 4 animals from other litters in a cage in which it lived until it ran the maze. Each living cage possessed an ever-present supply of food and water. All cages were cleaned at the same time and in the same manner. Even so, it would be naïve to suppose that life within a cage was *identical* for all animals. Any rat experimenter knows that the social life within a cage is extremely variable and complex. But it would not seem likely that the differences in experiences of different rats in the same cage would to any significant degree *cause* differences in the later learning of the maze under remote solitary experimental conditions.

*F. Age, T<sub>a</sub>*

The mean ages of the animals on the first day of learning and of relearning, as well as the sigmas of these ages are given in table 3. The ages at original learning lay within the range of four to twelve months. For a random sample of animals, in which the range in age was as great as that in any of these groups, the writer showed in a previous paper that there was a correlation of .05

$\pm .05$  (9). Hence age, though not controlled, was, nevertheless, not a factor affecting the learning-relearning correlation.

*G. Duration of the interval,  $T_i$*

It is an axiom in psychology that the more distant in time the original learning the more relearning is required, other things being equal. And if variation in the lapsed interval had any effect in our experiments, it would reduce the learning-relearning correlation.

The means and sigmas of the ages in days at original learning, at relearning, and of the interval in days between the first day of learning and the first day of relearning are given in table 3.

TABLE 3

*Means and sigmas of ages and interval (in days) between learning and relearning in the three groups*

GROUP	AGE AT LEARNING		AGE AT RELEARNING		INTERVAL	
	Mean	Sigma	Mean	Sigma	Mean	Sigma
I	232.6 $\pm$ 9.5	63.7 $\pm$ 6.7	464.7 $\pm$ 9.9	66.1 $\pm$ 7.0	231.5 $\pm$ 2.8	18.7 $\pm$ 2.0
II	168.0 $\pm$ 4.4	22.2 $\pm$ 3.1	363.8 $\pm$ 8.4	42.0 $\pm$ 5.9	195.7 $\pm$ 5.6	28.0 $\pm$ 4.0
III	161.2 $\pm$ 4.8	28.6 $\pm$ 3.4	357.6 $\pm$ 6.8	40.8 $\pm$ 4.8	196.4 $\pm$ 8.5	51.1 $\pm$ 6.0

Attention should be given primarily to the last two columns under "Interval," where it may be noticed that group I experienced on the average an interval of about eight months, and II and III of about six months. Observe in the column, "Sigma," that the individuals varied greatly in the interval between learning and relearning, and that those in group III were almost three times as variable according to the sigma as those in I, namely, 51.1 as compared to 18.7. Do we find a correlation between such variations in interval and relearning? The correlation coefficients between interval in days and total relearning score for the three groups were as follows:

Group I  $r = .03 \pm .15$   
 Group II  $r = .22 \pm .19$   
 Group III  $r = -.12 \pm .17$

In view of their standard errors, all of these coefficients are not significantly different from zero. Deterioration of efficiency due to lapsed interval *per se* is certainly not a significant factor affecting individual differences when this interval is as long as that experienced by our animals.

#### *H. Interpolated conditions, I*

The effect of the experiences encountered during the intervening months between learning and relearning would be to reduce the correlation between these two performances. In our experiments no attempt was made to control them in any systematic way, and they did, in fact, vary quite extensively. Up to the end of original learning an attempt had been made to hold environmental conditions constant, so that differences in learning would be those of genotype. If now, considerable environmental variation was interpolated, we wished to discover just how much this variation would upset the original individual differences in ability. If, despite this interpolation the learning-relearning correlation was high, then here was evidence that genetic causation was extremely potent, whereas environmental variations were of little consequence in ability. Since these interpolated conditions were quite uncorrelated with those which obtained before and during original learning, then it was furthermore evident that if we had not satisfactorily controlled earlier anteroactive factors and if they had been significant in causing individual differences, these interpolated conditions would serve in the determining of individual differences in relearning to annul the effects of the preceding environmental variations, for these interpolated conditions would constitute *new* introactive factors which would cause a new rank order in relearning uncorrelated with that in original learning. But if we secured a high learning-relearning correlation, this would indicate that we had satisfactorily controlled previous training and introactive  $S_1$  factors, and that the rank order was not determined by these factors but by deep-seated genetic ones.

What evidence do we have regarding the amount of variation in interpolated conditions?



During the interim, all of the animals experienced the variable conditions of breeding. The males and females resided in the breeding cages for variable amounts of time. Some of the females littered twice, some once, some not at all. All the rats in group I were run on another maze, maze Y. The correlation between the two maze performances is treated elsewhere (10). The rats in group III were moved by truck from the basement of one building to the fifth floor of another a quarter of a mile away and installed in new living quarters which were superior in lighting and ventilation to the old. These animals were also dipped for parasites several times. Some of the females littered in the new quarters. To sum up, the several groups experienced interpolated conditions, as follows:

- Group I: Variable breeding conditions, learning another maze, and "rest."
- Group II: Variable breeding conditions, and "rest."
- Group III: Variable breeding conditions, removal to new quarters, and "rest."

There is no evidence here to indicate that these intervening conditions were correlated with anteroactive and introactive  $S_1$  factors occurring respectively before and during original learning. In fact, the evidence indicates complete lack of correlation, for the animals were thrown with quite different rats from those with whom they lived before original learning, and experienced quite different biological and physiological conditions as well as, in group III, general environmental conditions.

Now, if these intervening conditions affect ability, one would expect the group which experienced the greatest variation in them to be the one which showed the *lowest* learning-relearning correlations. This would probably be group III. Somewhat higher, perhaps, should be group I, whose experience was more controlled, and highest should be, it seems, group II which experienced only breeding conditions. But if our results show a high and fairly equal correlation for each of these groups—if there is no tendency for a systematic increase of  $r$  as one goes from group III to I to II, then this is a telling argument against the position that interpolated environmental factors play any significant rôle in causing individual differences in these abilities.

*I. The introactive factors and conditions, S<sub>1</sub> and S<sub>2</sub>*

*Unsystematic variations* in experimental procedure, sensory cues, etc., would have the effect of reducing the correlations between learning and relearning, since, being unsystematic, they would rarely persist in the same way for the same animals at the different occasions of measurement. We attempted to hold such factors constant experimentally. Regarding original learning, rather complete details have been given elsewhere of the "test-breaking" practice, the procedure of running, the control of incentive and of the environs generally (5, 7, 8). When the animals came to relearn the maze they were again put through a "test-breaking" series. This practice series was an abridgment of that used before original learning, the five trials on the practice path before relearning being identical with practice trials 3, 8, 10, 11, and again 11, which preceded original learning. On the first day under experimental conditions, the relearners were weighed and put in their respective compartments in the revolving table which automatically delivered the rats into the maze (see 5), the second day they experienced the first three runs on the practice path, the third day the last two practice runs, and the fourth day they entered the maze proper for their first maze run. In all other respects for groups I and II the conditions of learning and relearning were identical. For group III the maze was in the new quarters when it was relearned. In installing the maze in the new quarters, the experimenter was forced by exigencies of space to alter the practice path in two slight details. In the new setting, the same type of indirect lighting was installed, but due to sundry special features of the ceiling and walls the luminosity of the maze alleys was greater than that in the old set-up. In the old quarters the maze room was separated from the living cages of the other animals, but in the new quarters the maze and animal colony were in the same large room, but the maze proper was screened from the living cages by a wooden partition. In the old quarters, the animals had a light burning over their compartment in the revolving table at night, but in the new they were in darkness at night.

In summary, then, for groups I and II an attempt was made to

keep unsystematic introactive factors *constant and identical* during learning and relearning; for group III an attempt was made to keep these factors *constant* for all animals during the two occasions of measurement though the constant conditions of relearning were not the same as the constant conditions of original learning.

Certain *systematic* variations could not be avoided. Such a one is, for example, order of running. The same serial order was permitted on every trial in learning, but a different uncorrelated order was arranged in relearning. Hence, order of running *per se* would not produce a positive correlation between learning and relearning but would only tend to reduce the correlation.<sup>5</sup> An examination of the records, however, shows no significant correlation between order and ability in either learning or relearning. Another systematic source of variation between animals is weight. This variable condition could conceivably have an anteroaction effect on ability, by virtue of its existence before learning. Such variation is probably due to heredity, certainly not to food supply, for *previous to running*, an unlimited supply was before each animal. Elsewhere it has been shown that such variation in weight previous to learning was uncorrelated with behavior (9). *During the running*, changes in weight due to changes in health or to the animals all being given the same amount of food, a condition which might affect ability since it might affect *incentive* to run (the heavier animals being penalized, the lighter overfed), might conceivably affect performance. But here again these factors have been shown to be null, for weight at the end of learning was uncorrelated with ability, as was shown in a previous paper (9).

<sup>5</sup> The writer cannot present any good evidence on this point since he adopted the practice of placing at the end of the running order those animals who, on the basis of their "test-breaking" performance, seemed most likely to be the slowest and possibly the stupidest when they ran the maze. The object of this was to avoid such animals slowing up the schedule inordinately and to facilitate the elimination later of the most recalcitrant of these animals without markedly disturbing the running order of the other animals. On the average not more than five per cent of the animals were thus placed at the end of the series. These dull animals at the end would probably occasion a *slight* positive correlation between order of running and errors made, but this would be a spurious correlation due not to the effect of order of running on ability but rather to the effect of ability on order of running (through the mediation of the experimenter).

There remains the possibility that chance variations in experience during the first trials are the crucial factors in determining individual differences in ability. If these chance variations were potent causal factors in determining individual differences in learning one would expect the first trial to correlate very highly with the next trial. On the other hand, if the chance variations are virtually irrelevant as causes of individual differences, then the correlation between the first day and the second would be nearly zero. In another place the writer has given evidence as to the correlation between these two days on each of two different mazes (6, p. 80). A sample of 96 individuals on whom first day records were obtained in the running of maze X gave a correlation of first with second day errors of  $.14 \pm .10$ . For a sample of 107 animals who ran on another maze, maze Y, the correlation between first and second day's performance was  $.05 \pm .10$ . This indicates that there was no systematic transfer of chance experience on day 1 to ability on day 2. But later, the correlations between days 3 and 4 were, for maze X,  $.70 \pm .05$  and for a second maze, maze Y,  $.63 \pm .06$ . These results indicate, it seems, that the first chance experiences were virtually irrelevant as systematic causes of individual differences, but that genetically superior animals, for instance, whatever their first day's experiences rapidly reached their superior level and tended to keep it, whilst genetically inferior animals, whether by chance they did well or poorly on the early trials, were unable to profit by their experience and early became and remained inferior throughout.

The environmentalist argument regarding *relearning* would be somewhat as follows: By the end of original learning the different degrees of ability (knowledge of the maze) among the animals have been *trained into* the animals, and these trained differences are *transferred* to (retained until) relearning. This transfer of training would account, according to this argument, for the positive correlation between learning and relearning. If this theory were true, one would expect the last stage of learning to correlate *highest* with trial 1 on relearning, less with trial 2, and progressively less with later relearning trials, since there would be greatest transfer between the more adjacent periods. For 44

animals<sup>6</sup> of group I the correlation between total errors made on the last three trials of original learning (trials 17, 18, 19), and trials 1, 2, 3, 4, 5 of relearning months later were as follows:

*Errors on relearning trials*

	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4	TRIAL 5
Total errors on last trials of original learning (trials 17, 18, 19) . . . . .	.35 ± .13	.47 ± .12	.77 ± .06	.76 ± .06	.70 ± .08

Thus we see that the correlation between total errors on the last three trials of original learning and the first day of relearning was only .35, and that as relearning proceeded the correlation *rose*! Just such a result as this would be expected if individual differences in ability as measured on the last stage of original learning were largely genetically determined whereas those on the first trial of relearning were largely chance. Because of forgetting, the first relearning trial would consist, as on the first day of original learning, largely of chance blundering into blind alleys. But as relearning proceeded, then the genetically superior animals would again find their superior level, the more poorly endowed their inferior level. That is, the genetically caused differences would again *emerge* in relearning just as they did in original learning, and the correlation between successive trials in relearning and the genetically determined differences in originally learning would gradually increase. This result we have found. But the environmentalist might argue from these findings that, true enough, the first day's running in relearning is largely chance due to forgetting, and that it would take several trials for the animal to remember (or transfer) his former experiences in the maze to the latter. According to this argument, he, too, would expect the correlations to rise. But this argument attempts at the same time to embrace and to deny trained-in chance *experience* as the potent factor in individual variation, for it admits the potent operation of more *remote* experience (itself supposedly

<sup>6</sup> A first day's score on relearning was not obtained on two animals of group I, hence the records of these animals had to be deleted from these correlations.

the result of chance), and denies the potency of more immediately contiguous chance experience. The evidence shows that the rank order on the first trial of relearning is relatively uncorrelated with remote experience as represented by the last stage of original learning ( $r = .35$ ). If chance experience is the important factor, one would then expect the chance happenings which cause the *new* rank order on the first day of relearning to determine largely the rank order on successive relearning trials and rather completely to smother out the old experiences, certainly those which occurred the distance of from six to eight months before, an amount of time equaling about one-fifth of the rat's life span.

#### IV. RESULTS RELATING TO CONSTANCY OF INDIVIDUAL DIFFERENCES

##### A. *Graphs of performance of individual animals during learning and relearning*

In place of original records showing the errors made by each rat on successive trials, learning curves of the animals are given in figure 2 for group I, in figure 3 for group II, and in figure 4 for group III. The data on each animal consist in the total errors made on successive stages of learning, each stage consisting of six *trials*. The learning score on stage 1, called  $X_1$ , is the total number of blind alley entrances made on trials 2, 3, 4, 5, 6 and 7;  $X_2$  represents errors on trials 8, 9, 10, 11, 12 and 13;  $X_3$  represents the score on trials 14, 15, 16, 17, 18 and 19. Thus  $X_1$ ,  $X_2$ ,  $X_3$  represent successive thirds of *original learning*. Stages of *relearning* have been represented analogously,  $X_4$  representing trials 2, 3, 4, 5, 6 and 7 of relearning, and  $X_5$  represents trials 8, 9, 10, 11, 12 and 13. It is to be noted that, just as with  $X_1$  of original learning, we have excluded the first "chance" trial from  $X_4$  of relearning.

The total errors on each of the successive stages of learning and relearning for each of the 46 animals in group I have been plotted in figure 2, in which the abscissa represents the successive periods,  $X_1$  to  $X_5$ , the ordinate the number of total errors made. Each animal has a learning curve, that is, a line graph connecting his successive scores, this line being solid within the

learning and within the relearning period, but being dashed between his performance on the last stage of original learning,  $X_3$ , and first stage of relearning,  $X_4$ . Thus the dashed line covers

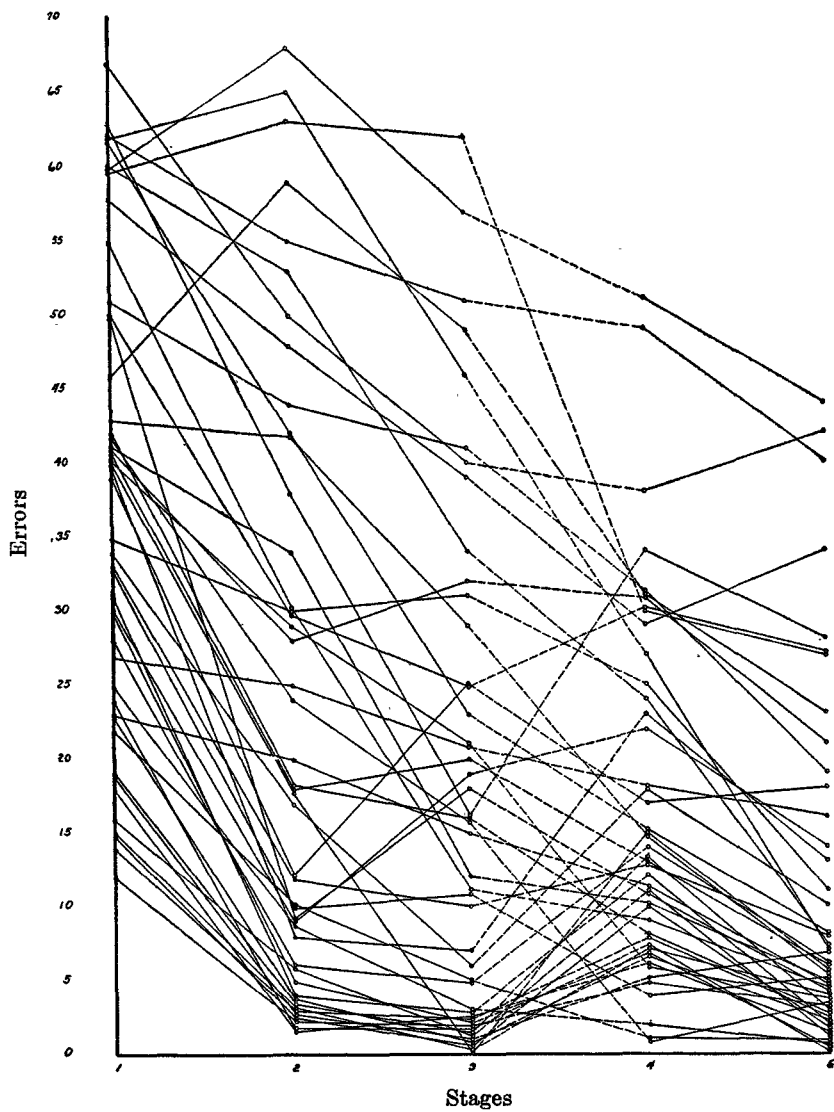


FIG. 2. LEARNING CURVES OF ANIMALS OF GROUP I

the interim between learning and relearning. The 46 learning curves of group I shown in figure 2 are those of the sample of rats which represents a fairly random selection, as we showed on an earlier page. During the interpolated period these animals experienced breeding conditions and likewise learned a second maze.

A study of this figure divulges a number of interesting facts. First, the curves show a marked degree of *parallelism*, a fact which indicates a constancy of individual differences over the entire period of learning and relearning. For example, a bright animal who made few errors on the first stage of learning,  $X_1$ , tended to be bright clear through the period even to six to eight months later on  $X_5$ , the last stage of *relearning*. The amount of criss-crossing of curves is negligible (except, as we saw above, between the last trials of learning and the first several trials of relearning) and where it occurs it is confined to a narrow range on the learning scale. But the bright and dull animals systematically differed in the absolute consistency of their performance, for the bright animals (at the bottom of the ordinates) show a higher degree of parallelism and lack of criss-crossing than the dull animals at the top of the figure. These facts show conclusively therefore that while there was a pronounced source of systematic variation between individuals, the systematic factors were apparently more stable at the bright end of the scale of ability, that is, there is a pronounced positive correlation between ability and variability. Even over the interpolated interval, between  $X_3$  and  $X_4$ , (recall that each represents errors on 6 trials) while considerable parallelism exists throughout the range of ability, the bright are more consistent than the dull.

*Second*, as to the nature of *improvement* during the learning and relearning process, the bright animals made their major improvement by  $X_2$ , at which stage of learning they had approached the final limit of learning, i.e., zero errors. On taking up relearning at  $X_4$ , the bright animals *suffered a loss* of efficiency as compared to the efficiency shown at  $X_3$ , the last stage of learning. Now the dull animals, on the other hand, show almost inverse relationships: Their major improvement was not at the first stages of



original learning, that is, between  $X_1$  and  $X_2$ , but it seems to have been fairly equally gradual throughout the whole experimental period. During the interval in which the animals ran another maze the reverse introactive effect of this interpolated experience occurred among the dulls as compared with that among the brights. The dulls *enjoyed a gain* in efficiency in this maze ability. All of the 12 dullest animals show an improvement on the first stage of relearning as compared to the last stage of learning, while the 13 brightest animals show a loss! Now the magnitude of these changes was, however, not so large as to occasion any overlapping, for of the 12 dullest who gained, the best of these did not do as well on the first stage of relearning as the worst of the 13 brightest who lost. That is to say, except for the first several *trials* of relearning (as noted earlier) individual differences as to rank order in ability were preserved even though the dulls improved and the brights lost. The interpolated training had the effect of reducing the group variability.

What explanations may be offered, however, for this gain of the dull and loss of the bright? In the first place, the fact of the brights having approximately reached the final limit by the  $X_3$ , the last stage of learning, *prevented* them from showing a gain in relearning. There was simply no room for improvement, and only room for loss. The supposition is tenable that had the scale been longer, i.e., the maze more difficult, and had the brights not reached the final limit of this more difficult performance by  $X_3$ , they, too, might have improved. The *absolute* loss in efficiency among the brights on  $X_4$  was small, about one *cul-de-sac* entrance a trial, and just chance factors alone could account for this divergence from true ability. And since these chance factors could operate only to make for a loss of efficiency, and not for a gain of efficiency (there being no room for gain, since the animal could no do better than zero errors) we find uniformly a loss among these bright animals. These chance factors (which affect dulls as well as brights) operated more potently on the first stage of relearning than on the last two stages of learning, thus the bright animals were less capable of approaching the final limit on  $X_4$ , than on  $X_2$  and  $X_3$ . But this explanation of why the

brights lost does not explain why the dulls gained. Chance factors would make the dulls equally as likely to gain as to lose. The positive introactive (facilitating) effect of learning the intervening maze seems to offer the best clue here. We may assume either that the animals transferred to maze X relearning either *specific* habits formed on the intervening maze, maze Y, or *improved methods* of learning. Now, since the two mazes differed so radically in their specific concatenation of blinds, the first type of transfer seems less likely to have occurred than the second. Stated succinctly, but rather crudely, what happened to the animals during their experience on maze Y was that they *learned how to learn* so that when presented with maze X on the later occasion, they made more progress on the first seven trials, six of which are represented in  $X_4$ , than on the whole nineteen of original learning. It is not, however, in the province of this paper to go extensively into this matter, since we have no crucial evidence bearing upon it. Before leaving this question, we must point out that this interpolated training, whatever its nature, was not of enough importance to upset significantly the rank order of individuals. Those bright and those dull on original learning continued respectively as bright and dull during relearning, and the interpolated training did not upset this arrangement of ability. The arrangement of talent seemed to be fundamentally determined and to be relatively unaffected by such variation in intervening experience.

Turning now to our second experiment, performed a year later than the one above, we may observe the 25 learning curves of group II in figure 3. This group, it will be remembered, was more variable than the random sample. During the intervening period it experienced only rest and breeding conditions. Thus it serves as a "control" group against group I which enjoyed the same experimental conditions but in addition experienced the learning of the interpolated maze. Group II was not a perfect control because of its slightly greater variability. But animals in group II having the same curves of original learning as those in group I may be considered "controls" of the latter, and may be compared in relearning as to the relative retroactive effects of interpolated

conditions, that is, with due regard to unreliability due to sampling. The curves in figure 3 separate into three groups, easily discerned in the figure, one of 9 dulls, one of 8 medians, and one of 8 brights.

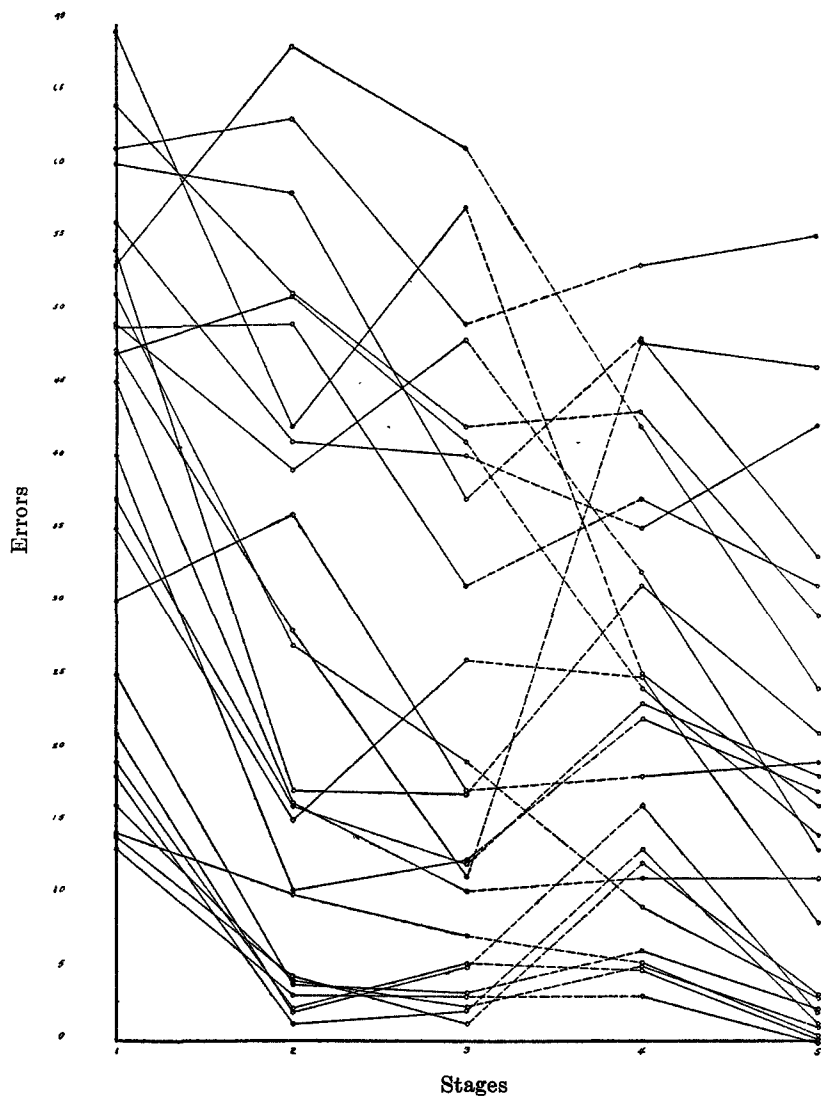


FIG. 3. LEARNING CURVES OF ANIMALS OF GROUP II

This figure shows certain striking corroborations of the facts noted in figure 2, and certain differences. *First*, here again is to be seen a high degree of parallelism of curves, showing that individual differences were wide and fairly constant throughout the whole experimental period. The 9 dulls and the 8 brights never overlapped either during learning or after the long interval of rest. Here again we note the correlation between ability and variability, for the dulls showed considerably more absolute fluctuation than the brights. In this second experiment, performed independently of the first, we have another proof of the potent operation of fundamental systematic factors and of the observation that these systematic factors quantitatively vary in the stability with which they express themselves in behavior.

*Second*, we find again that the bright animals reached their final arbitrary limit of ability approximately by  $X_2$ , but that over the interval,  $X_3$  to  $X_4$ , they all suffered a small loss of efficiency which was then rapidly gained by  $X_5$ , the last stage of relearning. The 9 dulls learned at a fairly constant rate, but after the interval of rest they did not show the marked improvement shown by the dulls of group I. Of the 9 dulls, 4 lost and 5 gained. On the whole, the interpolated experience seems to have had no systematic introactive effect on the dulls, for as a group they preceded in relearning just as if no long interval had been interpolated. Since there was no intervening training in maze learning, no positive transfer effects were to be expected. Whatever failure of efficiency occurred, such as is to be noted among most of the brights and some of the medians and dulls, must be put down to chance factors, or, possibly, to failure of retention. Much failure of retention could not be expected of the dulls, for by  $X_2$  they had not learned much, whilst among the medians and dulls such failures were possible. Whether the causal factors which occasioned these failures of retention derive from the intervening experience or from hereditary factors is a moot question. Whatever the origin of this differential failure of retention, such conditions or factors that produced it were of negligible importance, for they did not seriously upset the rank order of ability as noted in original learning.

The learning curves of the animals in the third experiment, performed still a year later than the one immediately above, offer certain striking contrasts to the previous curves. This group of

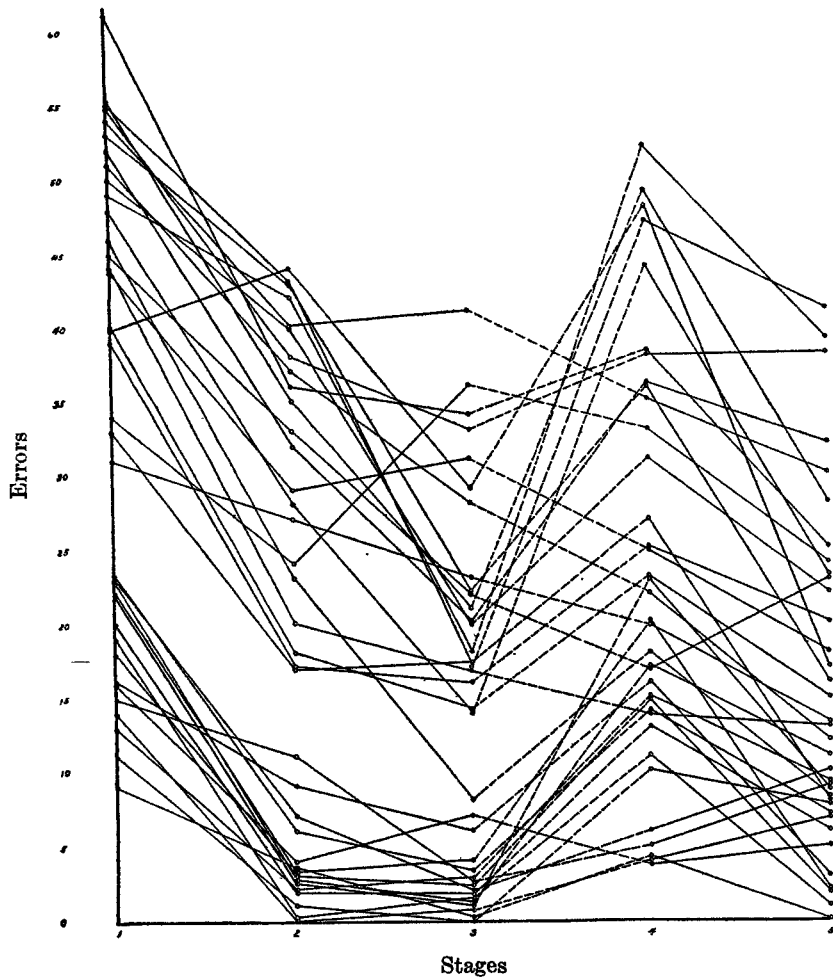


FIG. 4. LEARNING CURVES OF ANIMALS OF GROUP III

animals, group III, was the one which learned the maze in one building and was then transferred to new quarters in another building some distance away, where the animals relearned the same maze in a new set-up. While the spread of talent among

these animals was the least of all the three groups, the individuals are more markedly set off from each other than in groups I and II. In figure 4, the curves may be roughly separated into 20 upper dull curves, and 15 lower bright. Even within each of these sets the degree of parallelism is high, constituting a third independent proof of the constancy of individual differences among animals. Among the dulls we again find a tendency for greater variability, though this tendency is not so marked as in the first two experiments. The comparison of this dull group with those in the former groups is not so valid, since in this group III we did not possess such exceedingly dull animals as occurred in the earlier experiments.

By far the most noticeable difference between group III dulls and the other lies in the extensive loss of efficiency over the interval  $X_3$  to  $X_4$ . Fourteen out of 15 brights lost, as did 13 of the 20 dulls. While it is true that these dulls were at about the same efficiency at  $X_3$  as the *medians* of group II, who also showed losses over the interim, the magnitude of the losses of the group III dulls as well as of the group III brights is apparently greater than that of corresponding animals in group II, the control group. The gains which the remaining 7 dulls and 1 bright showed were of small magnitude and were probably no greater (and perhaps less) than what one would have expected had learning proceeded without interruption and at the same rate as that which obtained from  $X_1$  to  $X_3$ . From these results we must conclude that the removal from one place to another, or the relearning in new experimental environs—it is not evident which—had a negative interactive effect upon the learning process. But here again we must note that these losses of retention were not of sufficient degree to upset significantly the fundamental systematic difference in ability between the brights and dulls. Animals bright in learning or dull were respectively bright and dull in relearning. Undoubtedly the loss of retention was not exactly a constant for all animals, nor was it completely correlated with original learning, for there is a greater degree of criss-crossing of curves between  $X_3$  and  $X_4$  than between any other adjacent stages of learning. We must therefore admit the limited operation of certain factors

occasioning loss of retention between  $X_3$  and  $X_4$  that are independent of those operating during the other adjacent stages. What is so surprising, however, is the narrow range of these independent factors, for they do not reduce the correlation between  $X_3$  and  $X_4$  to a magnitude much lower than that which is found between other stages of learning or of relearning. This fact we may discern from a gross perusal of the curves of figure 4, but to get a more refined statistical expression of it we must turn to the next and final section where the correlation coefficients are given.

### B. Correlation between learning and relearning

1. *Correlation between total learning and total relearning.* The first correlation to be presented is between total errors made in

TABLE 4

*Raw and true correlations between total errors made in original learning ( $X_L$ ) and total errors made in relearning ( $X_R$ ) for the three groups; reliability coefficients, means and sigmas of the variables*

GROUP	CORRELATION BETWEEN $X_L$ AND $X_R$		RELIABILITY COEFFICIENT		MEAN		SIGMA	
	Raw	True	$X_L$	$X_R$	$X_L$	$X_R$	$X_L$	$X_R$
I	.79±.05	.81	.989±.003	.980±.006	79.3± 7.4	27.4±3.5	50.0±5.2	23.4±2.5
II	.79±.07	.81	.990±.004	.976±.009	88.1±10.9	40.0±6.0	54.6±7.7	29.8±4.2
III	.85±.05	.88	.983±.006	.961±.013	68.9± 6.9	39.1±3.9	41.4±4.9	23.6±2.8

original learning from trials 2 to 19, which we shall denote by  $X_L$ , and total errors made in relearning from trials 2 to 13, to be denoted by  $X_R$ . This correlation is given for the three experimental groups in table 4.

The numerical values of the coefficients in columns 1 and 2 of this table show for all three groups a high correlation between learning and relearning. The reliability coefficients (columns 3 and 4) of the sundry variables are so high that corrections for attenuation<sup>7</sup> which give the true  $r$ 's of column 2 are not very

<sup>7</sup> No standard errors of true  $r$ 's are given here or later because of the excessive labor involved and because the reliability coefficients were so high as to make the true  $r$ 's only negligibly greater than the raw  $r$ 's, for which standard errors are given in the tables. The  $\pm$  values after all reliability coefficients are derived from the nomograph of Cureton and Dunlap (1).

much larger than the raw correlations of column 1. Now it is to be noticed that group III, which experienced the most diverse intervening environmental influence by being moved to new quarters and relearning the maze there, does in fact show the *highest* learning-relearning coefficients. This group also experienced the greatest variation of time interval between learning and relearning, as we have seen. But these greater environmental variations did not, it seems, disturb the rank order in original learning to any greater degree than did interpolated variations disturb that in groups I and II. Group I, which learned another maze during the interpolated interval, did not suffer, it seems, more than group II which had no such experience, for their correlations are identical. Notice, however, that group I was affected in its mean relearning score, for its average number of errors in relearning is significantly lower than that of the other groups. Apparently learning the interpolated maze has had, however, only a slight variable effect on individuals, for the learning-relearning coefficient is not significantly lower than that of the other groups. We must conclude from these data, therefore, that the vast differences in interpolated environmental conditions between the three groups has not significantly affected individual differences.

But why, then, are these correlations not unity? One reason which may be advanced is that while it is evident that learning a different interpolated maze (group I) or being moved and required to learn the same maze in different quarters (group III) may not markedly affect individual differences, still the other type of environmental variation, namely, breeding conditions and "rest," which all three groups experienced might have had a systematic variable retroactive effect on learning to such an extent that a possible unity learning-relearning correlation had been reduced from unity to the order of .81 to .88. The difficulty with holding this view is that in breeding and "rest" there occurred no *training* on any learning functions which could conceivably be *transferred* to relearning. If the interim had any systematic effect at all, such intervening conditions would most likely affect the physical vitality of the animals. But we have already seen



(9) that in so far as physical vitality is measured by the body weight of the animal, it has no effect on maze performance, because the weight-performance correlation is zero.

The explanation for the learning-relearning correlation not being unity must be sought elsewhere, and not looked for, it seems, in the effect of interpolated environmental factors. From the evidence which is next to be presented it is quite evident that had original learning been continued without an interpolated interval the correlation between the errors involved in our original learning, namely, trials 2 to 19, and those in the next thirteen trials (analogous to our thirteen trials after a six to eight months interval) would likewise not have been unity. Had learning been continued without interruption for thirteen trials after  $X_3$ , and had the trials been divided into two stages, call them  $X_4'$  and  $X_5'$ , it is obvious, as we shall see later, that the correlation between  $(X_1 + X_2 + X_3)$  and  $(X_4' + X_5')$  would *not* have been unity. Thus, the factors at work to reduce from unity the correlation between periods of *continuous learning* may be the ones which cause  $X_L$  and  $X_R$  to fail of being unity. In order to study this matter, it will be necessary to examine the systematic change in correlation between periods of continuous learning and see whether the failure of unity correlation between learning and relearning may be ascribable not to factors arising from the interpolated conditions but to those to which we ascribe the failure of unity correlation between periods of continuous learning.

2. *Correlations between successive stages of learning and relearning.*

Each of the five successive variables,  $X_1$ ,  $X_2$  and  $X_3$  of original learning, and  $X_3$  and  $X_4$  of relearning, were intercorrelated with the others. The raw coefficients as well as the true correlations are given for group I in table 5, for group II in table 6, and for group III in table 7. The reliability coefficient of each variable is given in bold face type along the diagonal of each correlation table. The reliability coefficient of a stage was obtained by the Spearman-Brown formula,  $r_1 = 2r/(1 + r)$ , where  $r_1$  is the reliability coefficient, and  $r$  is the correlation between split halves of the stage, i.e., between errors on odd and on even trials. The raw correlations between stages are given in ordinary type in the

correlation tables to the *left* of the diagonal, the true correlations are in italics to the *right*. The mean and sigma of each stage are shown at the top of each table.

TABLE 5  
Group I

	STAGES OF ORIGINAL LEARNING			STAGES OF RELEARNING	
	$X_1$	$X_2$	$X_3$	$X_4$	$X_5$
M.....	37.8 $\pm$ 2.3	23.3 $\pm$ 2.9	18.1 $\pm$ 2.8	16.8 $\pm$ 1.8	10.5 $\pm$ 1.8
$\sigma$ .....	15.8 $\pm$ 1.6	19.8 $\pm$ 2.1	17.0 $\pm$ 1.8	12.0 $\pm$ 1.3	12.0 $\pm$ 1.3
$X_1$	<b>.941</b> $\pm$ .018	<i>.89</i>	<i>.80</i>	<i>.74</i>	<i>.69</i>
$X_2$	<i>.85</i> $\pm$ .04	<b>.980</b> $\pm$ .006	<i>.94</i>	<i>.79</i>	<i>.72</i>
$X_3$	<i>.79</i> $\pm$ .05	<i>.92</i> $\pm$ .03	<b>.979</b> $\pm$ .006	<i>.84</i>	<i>.79</i>
$X_4$	<i>.70</i> $\pm$ .08	<i>.76</i> $\pm$ .06	<i>.81</i> $\pm$ .05	<b>.947</b> $\pm$ .016	<i>.95</i>
$X_5$	<i>.66</i> $\pm$ .08	<i>.70</i> $\pm$ .08	<i>.77</i> $\pm$ .06	<i>.91</i> $\pm$ .03	<b>.972</b> $\pm$ 0.009

TABLE 6  
Group II

	STAGES OF ORIGINAL LEARNING			STAGES OF RELEARNING	
	$X_1$	$X_2$	$X_3$	$X_4$	$X_5$
M.....	39.5 $\pm$ 3.5	26.3 $\pm$ 4.3	22.3 $\pm$ 3.8	23.6 $\pm$ 3.0	16.4 $\pm$ 3.1
$\sigma$ .....	17.4 $\pm$ 2.5	21.3 $\pm$ 3.0	18.8 $\pm$ 2.7	15.1 $\pm$ 2.1	15.4 $\pm$ 2.2
$X_1$	<b>.963</b> $\pm$ .015	<i>.85</i>	<i>.86</i>	<i>.82</i>	<i>.75</i>
$X_2$	<i>.82</i> $\pm$ .07	<b>.983</b> $\pm$ .007	<i>.93</i>	<i>.84</i>	<i>.76</i>
$X_3$	<i>.83</i> $\pm$ .06	<i>.91</i> $\pm$ .03	<b>.980</b> $\pm$ .007	<i>.74</i>	<i>.59</i>
$X_4$	<i>.79</i> $\pm$ .07	<i>.81</i> $\pm$ .07	<i>.72</i> $\pm$ .09	<b>.959</b> $\pm$ .016	<i>.94</i>
$X_5$	<i>.73</i> $\pm$ .09	<i>.74</i> $\pm$ .09	<i>.58</i> $\pm$ .13	<i>.91</i> $\pm$ .03	<b>.976</b> $\pm$ .010

TABLE 7  
Group III

	STAGES OF ORIGINAL LEARNING			STAGES OF RELEARNING	
	$X_1$	$X_2$	$X_3$	$X_4$	$X_5$
M.....	34.5 $\pm$ 2.6	20.1 $\pm$ 2.6	14.3 $\pm$ 2.0	23.8 $\pm$ 2.3	15.4 $\pm$ 1.8
$\sigma$ .....	15.8 $\pm$ 1.8	15.5 $\pm$ 1.8	12.1 $\pm$ 1.4	13.8 $\pm$ 1.6	11.0 $\pm$ 1.3
$X_1$	<b>.962</b> $\pm$ .013	<i>.96</i>	<i>.85</i>	<i>.84</i>	<i>.85</i>
$X_2$	<i>.92</i> $\pm$ .03	<b>.973</b> $\pm$ .009	<i>.89</i>	<i>.85</i>	<i>.84</i>
$X_3$	<i>.81</i> $\pm$ .06	<i>.85</i> $\pm$ .05	<b>.951</b> $\pm$ .016	<i>.72</i>	<i>.74</i>
$X_4$	<i>.80</i> $\pm$ .06	<i>.82</i> $\pm$ .05	<i>.68</i> $\pm$ .09	<b>.951</b> $\pm$ .016	<i>.86</i>
$X_5$	<i>.81</i> $\pm$ .06	<i>.81</i> $\pm$ .06	<i>.70</i> $\pm$ .09	<i>.82</i> $\pm$ .05	<b>.950</b> $\pm$ .016

The first thing to note is the exceedingly high accuracy of measurement in all variables as denoted by the high reliability coefficients for all stages and for all groups. This means that potent systematic factors are at work to differentiate individuals on even so short an interval of learning as a stage of six trials covering a total amount of running time on the average of about fifteen minutes (spread, of course, over six days). It is to be noted that chance errors of measurement are most active on the first stage of learning and of relearning, for the reliability coefficients (for groups I and II) are lowest on these stages. This is important as it supports our contention made earlier in the paper that a plausible hypothesis why the bright animals of groups I and II on the first stage of relearning lost in efficiency on  $X_4$  is that chance errors were greater at this stage. We said there that these animals, having approached the final arbitrary zero error limit of efficiency on  $X_3$ , did more poorly on  $X_4$  because of the increased rôle of chance errors at this  $X_4$  stage, these errors occasioning uniformly a loss in efficiency because they could not possibly occasion a gain. }

The coefficients throughout the tables are of an exceedingly high order, a fact which supports our previous observations as to the general parallelism of the learning curves. Considering the true correlations we note that even between the most remote stages, the first stage of learning,  $X_1$ , and the last stage of relearning,  $X_5$ , the coefficients reach the magnitudes of .69, .75, and .85 for groups I, II, and III respectively, and the *highest* correlations between stages of learning and of relearning are for group I:  $r_{34} = .84$ , for group II:  $r_{24} = .84$ , and for group III:  $r_{24} = r_{15} = .85$ . The writer cannot refrain from emphasizing the significance of these high correlations, for it must be recalled that *these correlations are between two short periods of maze running, amounting in all to about fifteen minutes each but separated by a long interval of from six to eight months time in which the animals were exposed to wide variations in experience.*

Now, a significant fact remains to be divulged. This is that the lowest correlations between stages of continuous learning are no higher than the highest correlations between stages of learning

and of relearning. Observe in the tables that the lowest original learning inter-correlations and highest learning-relearning correlations are as follows:

	GROUP I	GROUP II	GROUP III
Lowest original learning.....	$r_{13} = .80$	$r_{13} = .86$	$r_{13} = .85$
Highest learning-relearning.....	$r_{34} = .84$	$r_{24} = .84$	$r_{24} = r_{15} = .85$

These coefficients mean that there was just as little lack of correspondence in rank order of individuals between certain stages of original learning separated by only a few days as between certain stages of learning separated by six to eight months. May it not be true therefore that those factors which caused lack of correlation between original learning stages were of the same sort, in part, as those which disturbed constancy of individual differences between the more remote stages, instead of special factors that arose from the interpolated interval? In seeking, therefore, the causes of absence of perfect correspondence between stages of continuous learning we may be searching for those factors or conditions which caused the learning-relearning correlations to fail of being unity. What are these factors?

One of them is beyond dispute and is an indubitable source of reduction of correlation. This is the existence of an arbitrary final zero-limit of ability. It is obvious that as learning proceeds, more and more individuals are thrown into the final category where they differ from each other only by chance errors. These later stages will therefore necessarily correlate low with preceding stages, and theoretically a stage may be reached at which all individuals have reached the final category of highest efficiency and this stage will correlate zero with all other stages. Just the exact effect of such progressive skewness of distribution and correlation is difficult to determine, but none the less it should be admitted as causing a sort of spurious loss of correlation between stages—spurious because the loss of correlation is not due to the introduction of independent systematic variable factors as causes of individual differences in the later stages. Individual differences on all stages of learning could be due to the *same true*

*causes*, yet the true correlations between stages as they grew more and more remote from each other would grow progressively lower due to this progressive skewness. This holds true for continuous learning and likewise would hold true for learning interrupted by an interpolated period. Such a progressive phenomenon leads to the conclusion that the correlations between remote stages of continuous learning as well as between learning and relearning would have been even higher than those shown in tables 5, 6 and 7, if the scale had not had a final arbitrary zero-limit. Had it been steeped in difficulty so as to permit no animal to attain a perfect score but to permit each animal eventually to reach his true physiological limit, this limit being different from that of every other animal not physiologically or psychologically like himself, the correlations between successive stages of learning and relearning would have been higher between remote stages than those which we have found.

On the other hand, we cannot say that independent hereditary or introactive environmental factors do *not* play some rôle. The fact remains that the true correlations between remote stages are of the order .80, and whilst it is obvious that these values are spuriously low because of the operation of the final arbitrary zero limit, and would have been higher had not such an arbitrary condition existed, still it is likely that the correlations would not have been unity. That is, systematic variations in health, incentive, and other short range environmentally introactive factors, or new short range genetic variations may, to a limited extent, enter at different stages of learning and thus account for the loss of correlation.

3. *Correlation of stages of learning and relearning against respectively total relearning and total learning.* In view of the possibility admitted just above that certain residual and independent genetic or environmental systematic factors might occur over a short range of the learning and relearning processes but not throughout the entire two periods, it would be of interest to seek evidence of this phenomenon in the correlations of each stage of original learning with total relearning ( $X_R$ ), and observe the differences between these correlations. Those stages which correlated lowest

would be the most likely ones in which such short range independent factors operated most. We shall likewise examine the correlation of each stage of relearning with total learning ( $X_L$ ). All of these coefficients are given in table 8.

One should first observe the *high magnitudes* of the correlations. Here again we have conclusive evidence of high constancy of individual differences between single stages in one period of learning and a total period of learning occurring from six to eight months earlier or later, as the case may be. Nine of the fifteen true correlations are above .80, and one is .90. Recalling that these correlations are themselves too low by virtue of the spurious diminution effects of the skewness due to the arbitrary final zero-

TABLE 8  
Raw and true correlations of each stage of original learning with total relearning, and of each stage of relearning with total original learning

GROUP	CORRELATION OF STAGES OF ORIGINAL LEARNING WITH $X_R$						CORRELATION OF STAGES OF RELEARNING WITH $X_L$			
	$X_1$		$X_2$		$X_3$		$X_4$		$X_5$	
	Raw	True	Raw	True	Raw	True	Raw	True	Raw	True
I	.69 ± .08	.72	.75 ± .07	.77	.81 ± .05	.83	.80 ± .05	.82	.75 ± .07	.77
II	.78 ± .08	.80	.79 ± .07	.81	.67 ± .11	.68	.81 ± .07	.84	.72 ± .09	.73
III	.84 ± .05	.88	.86 ± .04	.90	.72 ± .08	.76	.81 ± .06	.84	.82 ± .05	.85

limits, one must acquiesce that the high order of these coefficients does not give much support to the theory that short range environmental or hereditary factors or conditions operate to *any extensive degree* in determining individual differences on a given stage of learning or relearning.

The comprehension of the results in table 8 will be easier if we consider each correlation as a *sort of validity coefficient*, that is, all the correlations in columns 1 to 6 are the validity coefficients of the the several stages of learning against the common criterion, relearning ( $X_R$ ), those of columns 7 to 10 the validity coefficients of relearning stages against the common criterion, learning ( $X_L$ ). Thus, in group I these coefficients do not appear to be significantly different from each other for the various stages of learning

or relearning, a result which indicates that independent short range factors affect each stage about equally. In groups II and III, these validity coefficients are not excessively different from each other, though there seems to be a slight tendency for the last stage of learning to have less community of function with the relearning criterion than the earlier stages. This evidence indicates, therefore, that short range hereditary or environmental factors which do not operate throughout the whole experimental period in causing individual differences play about an equal rôle in the various stages of learning and relearning.

But how short is the range of such local independent factors? The following evidence attempts to answer this question. For conciseness we present the average of the correlations in the three experimental groups. Now, between *two adjacent stages* of continuous learning in which short range overlapping factors would operate most potently the average correlations are as follows:

$$r_{12} = .90 \qquad r_{23} = .92 \qquad r_{45} = .92$$

These coefficients are of the order .91. Now, between *two stages separated by an intervening stage*, such as between  $X_1$  and  $X_3$ , where short range factors are less likely to occur than between adjacent stages, the correlation is:

$$r_{13} = .84$$

This means, it seems, that short range factors common to adjacent stages are of greater potency than between stages once removed, and do, in fact, occasion a rise in correlation from .84 to .91. But what, now, is the correlation between a given stage and another period of learning separated from it by six to eight months. If this last correlation is not significantly lower than that between stages once removed, then obviously short range factors do not act for an interval longer than one stage (of six trials). Our last evidence consists in this average correlation between the single stages and the period of learning occurring six to eight months' later (or earlier). These coefficients are:

$$\begin{array}{ll} r_{1R} = .80 & r_{4L} = .83 \\ r_{2R} = .83 & r_{5L} = .78 \\ r_{3R} = .76 & \end{array}$$

And they are not significantly lower than the correlation between stages only once removed. This comparison means, it seems, that between stages more than once removed, short range factors are of negligible consequence in determining individual differences, and that *long* range factors are now the ones that are the significant differentiae. And since these long range factors operate in the stages of original learning where rigorous environmental controls had been enforced, the suggestion is that they emanate from an hereditary source.

## ADDENDUM

To avoid encumbering the text with statistical details pertaining to the calculation of the reliability coefficients of the several

TABLE 9  
*Sigmas of the summed odd and summed even sub-variates of the variables involved in the correlations*

GROUP	$X_1$	$X_2$	$X_3$	$X_4$	$X_5$	$X_L$	$X_R$
I	$\sigma_o$ 7.9±.8	10.1±1.1	8.7±.9	5.8±.6	6.1±.6	25.0±2.6	11.5±1.2
	$\sigma_e$ 8.3±.9	9.8±1.0	8.5±.9	6.5±.7	6.1±.6	25.3±2.6	12.2±1.3
II	$\sigma_o$ 8.8±1.2	10.9±1.5	9.8±1.4	7.6±1.1	8.4±1.2	27.6±3.9	15.6±2.2
	$\sigma_e$ 8.9±1.3	10.7±1.5	9.2±1.3	7.8±1.1	7.2±1.0	27.3±3.9	14.5±2.1
III	$\sigma_o$ 8.0±.9	7.6±.9	6.3±.7	7.1±.8	5.9±.7	20.2±2.4	12.2±1.4
	$\sigma_e$ 8.1±1.0	8.1±1.0	6.1±.7	7.0±.8	5.4±.6	21.5±2.5	11.9±1.4

variables, I append here a consideration of this matter. All reliability coefficients were secured by fractionating each variable into comparable sub-variates, i.e., summed odd and summed even elements (trials), correlating these sub-variates, and putting the  $r$  into the Spearman-Brown formula,  $2r/(1+r)$ . The resulting value satisfies the *definition* of the reliability coefficient of the variable in question provided the sigmas of the sub-variates are equal within their standard errors (see reference 8, p. 154). In table 9 the sigmas of odd and even sub-variates are given for each group and for each variable. It should be evident from a perusal of the values in the table that the members of each pair of



sub-variates are comparable since the sigmas are not significantly different from each other in view of the magnitudes of their sampling errors.

#### V. SUMMARY AND CONCLUSIONS

1. The purpose of the experiments was to determine the degree of constancy of individual differences in maze ability over a long span of the rats' life period.

2. The procedure was to run a group of rats for twenty trials on a 17 unit T-maze (the original learning series), then to interpolate an interval of from six to eight months, after which to run the animals again for thirteen more trials (the relearning series).

3. Special methods were instituted to hold constant environmental variations occurring before and during the original learning series, so that individual differences in this original learning period would be determined by hereditary factors. During the interpolated period, however, considerable environmental variation was permitted, the purpose being to discover whether or not such variation would alter individual differences when the relearning series was later given.

4. Three groups of animals were used, each group experiencing somewhat different conditions during the interim: Group I (46 rats) ran upon another 20 unit T-maze during the interval; group II (25 rats), the control, experienced "rest;" and group III (36 rats) were transported from one building to another, in the second of which they were given their relearning series. All groups experienced variable breeding conditions during the interim.

5. The learning curves of all animals over the entire learning and relearning period show, regardless of the group, a high degree of parallelism, indicating a constancy of individual differences in ability over this long period. The different types of interpolated experience seemed to have occasioned certain differences in the relearning performance, but these were of insufficient magnitude to disturb the rank order of individual differences shown in original learning.

6. The true correlation coefficients between total original learning scores and total relearning scores were high, of the order .81

to .88. The failure of coefficients to be unity is ascribed to several factors: (1) the tendency of the distributions and correlations to become skewed as learning proceeded, (2) the operation of short range independent but systematic hereditary or environmental factors which affected different stages of learning, and (3) the operation of independent hereditary or environmental factors which arose from the interpolating of the interval between learning and relearning. The last factor is considered not to be of much significance, for the learning-relearning correlations were not lower in group III, which experienced the most variable interpolated conditions than that in group II which experienced the least.

7. In view of (1) the marked parallelism of learning curves, (2) the high learning-relearning correlations, and (3) the rigorous conditions of environmental control preceding and existing during original learning, the conclusion is drawn that individual differences shown during these two widely separated periods of learning were occasioned largely by causes of hereditary origin.

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