

In this work, however, one must be careful not to assume that excellent performance on the maze necessarily measures the same processes that are measured by human intelligence tests, though it seems clear that maze-running is in one sense a test of the differential adaptive capacity of the organism and hence a type of behavior relevant to the general problem under consideration.

In the material presented below Tryon has summarized his own most important experiments in this field:

XIII. GENETIC DIFFERENCES IN MAZE-LEARNING ABILITY IN RATS

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The experimental geneticist is inclined to be somewhat skeptical of conclusions from nature-nurture studies on human beings. The complex breeding system deriving from the adventitious circumstances of 'young love' and the wide differences in environments into which the progeny of such matings are born and reared present such a complex matrix of determiners of 'mental' differences that it would appear hopeless to endeavor to separate out the relative effects of those termed 'nature' and those termed 'nurture.' Furthermore, the indubitable tendency in the uncontrolled human environment for different genotypes to seek out different environments, and conversely, for different environments to select special genotypes, and all this to an unknown degree, creates a correlation between nature and nurture that confounds any analyst who has neither an hereditary nor an environmental axe to grind. And on top of it all, to make the confusion worse, are the ambiguous psychological omnibus tests of mental ability, about the psychological validity of which the most able psychologists cannot agree.

After several centuries of the type of groping called 'natural history,' the biologist in his rôle as experimental geneticist has discovered that the only way to get definite answers to the nature-nurture question in plants and animals is to establish a pure strain experimentally by means of a controlled selective breeding schedule and then experimentally to vary systematically the milieu for different samples of the strain. The logic is, indeed, very simple: In a given species, (1) hold heredity constant by choosing a pure strain, then study the effects of different environment on it, and (2) hold the environment constant, then vary heredity by studying the development of different pure strains in it, and (3) compare the relative effects of the two types of

variations that are, respectively, nature and nurture. Though the logic is simple, its experimental execution is arduous, often requiring many years of work even when investigating only one character in one species.

As the psychologist cannot, of course, perform such experiments on human beings, he must turn to animals. During the last three decades, the animal psychologist has developed techniques for the reliable and valid measurement of individual differences in numerous psychological characters of animals, especially of rats. The securing of definite answers to the question of the relative effects of nature and nurture on psychological characters is thus made possible. An experimental genetics focused on animal *behavior* and ultimately based on studies of numerous species of animals varying in phylogenetic complexity should give us the answers we wish. Only the most egregious 'special creationist' would argue that the findings of such a comparative psychological genetics would have no applications to man.

The attempts of the writer to design and execute such a psychological genetics experiment are outlined below. The essential aims have been to establish under environmental control a maze-bright and a maze-dull strain of rats, to determine the nature of the genetic determiners at work, to discover the constancy of this psychological difference throughout a large range of the rats' life span, and to find important biological and psychological correlates of the differences in this maze ability. Finally, the effects of systematic environmental changes on each strain are to be investigated. Though the work has now been in progress eleven years, it is in many respects still preliminary. Findings are complete with respect to some of the objectives but not to others. A brief summary is presented below under the various types of analyses.

1. Proof of the Inheritance of Individual Differences in Maze Ability

An experiment¹ was begun in 1927 that had as its purpose the establishment by selective breeding of a pure line of maze-bright and a pure line of maze-dull rats. Each animal was run nineteen trials through a seventeen-blind T maze. His score was the total number of entrances into blind alleys. The breeding schedule consisted in mating together the brightest rats within each of the brightest litters, the dullest within each of the dullest. Rigorous environmental controls were effected (1) by instituting standard procedure of animal care and of breeding, (2) by using an automatic mechanical device for delivering the animals into the maze without handling, and (3) by employing an electric recorder for the scoring of each rat's maze run. These controls have remained constant for eleven years. Selective breeding has been

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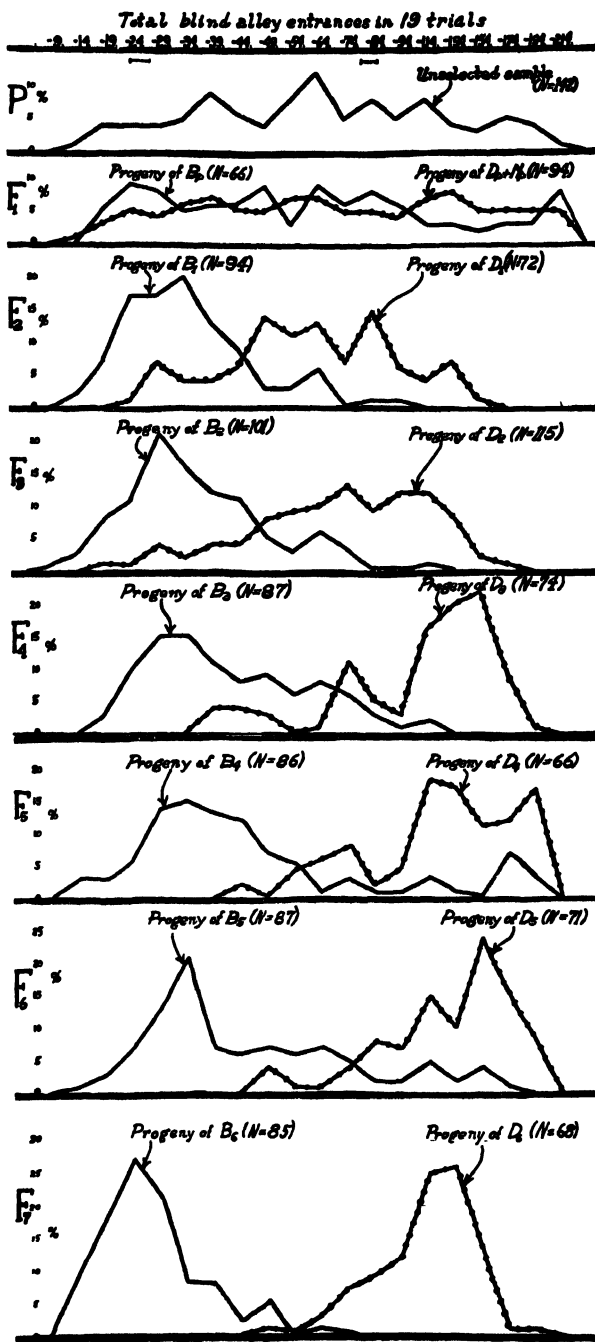


FIG. IV. — EFFECTS OF SELECTIVE BREEDING ON MAZE-LEARNING

Along the top is the scale of brightness as evidenced by the total number of blind-alley entrances made in nineteen trials. All the distributions below use this common top scale. For instance, a bright animal who made from ten to fourteen errors would fall under the scale step, the upper limit of which is marked -14, a dull who made from 195 to 214 errors would fall under -214, etc. The first generation of rats, marked "P" to the left, is shown just below the scale. The total number of P rats was 142, and the percent of them lying at each point on the scale is indicated in the distribution. The brightest of these were bred together, and then the dulllest, giving the two F_1 groups, as shown. The selective breeding effects are shown down to the F_7 , where progeny of B_6 (bright F_6) are markedly different from the progeny of D_6 (dull F_6).

continued for eighteen generations. As success in establishing strains of bright and dull animals is crucial to the proposed project, I present in Figure IV the basic data showing the effects of selective breeding through the F_7 generation. For brevity, I have not presented all the later generations, but

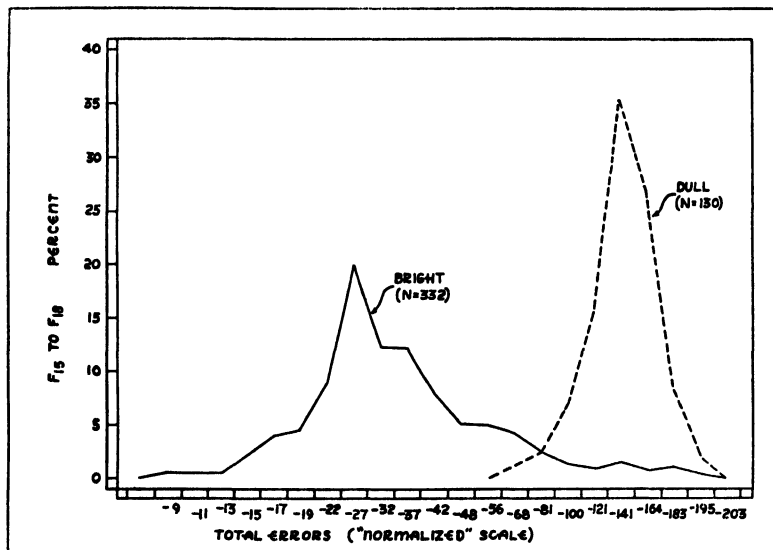


FIG. V. — BRIGHT AND DULL STRAINS OF THE FIFTEENTH TO EIGHTEENTH GENERATIONS

to show the latest results, I have given in Figure V the results in the F_{15} , F_{16} , F_{17} , and F_{18} generations. In this figure the distributions of the two strains are shown for these later generations combined. There appears to be a law of diminishing returns, for after the F_7 negligible effects of selective breeding are noted. The results for all generations will be depicted in final form in terms of the improved normalized scale.

2. The Genetic Basis of Differences in Maze-Learning Ability

What is the genetic factor basis of differences in learning ability? How many factors must be postulated and what is the nature of their interaction? Geneticists propose a multiple cumulative-factor theory as the genetic explanation of the plant and animal characters that have statistical frequencies similar to those of maze-learning. One crucial experimental test of this theory is the cross between the pure lines at the two extremes of the scale. The F_1 progeny of such a cross should show a homogeneous median performance. The next generation progeny of the F_1 should vary widely over the whole scale. Figure VI shows the actual results of such a test on our behavior

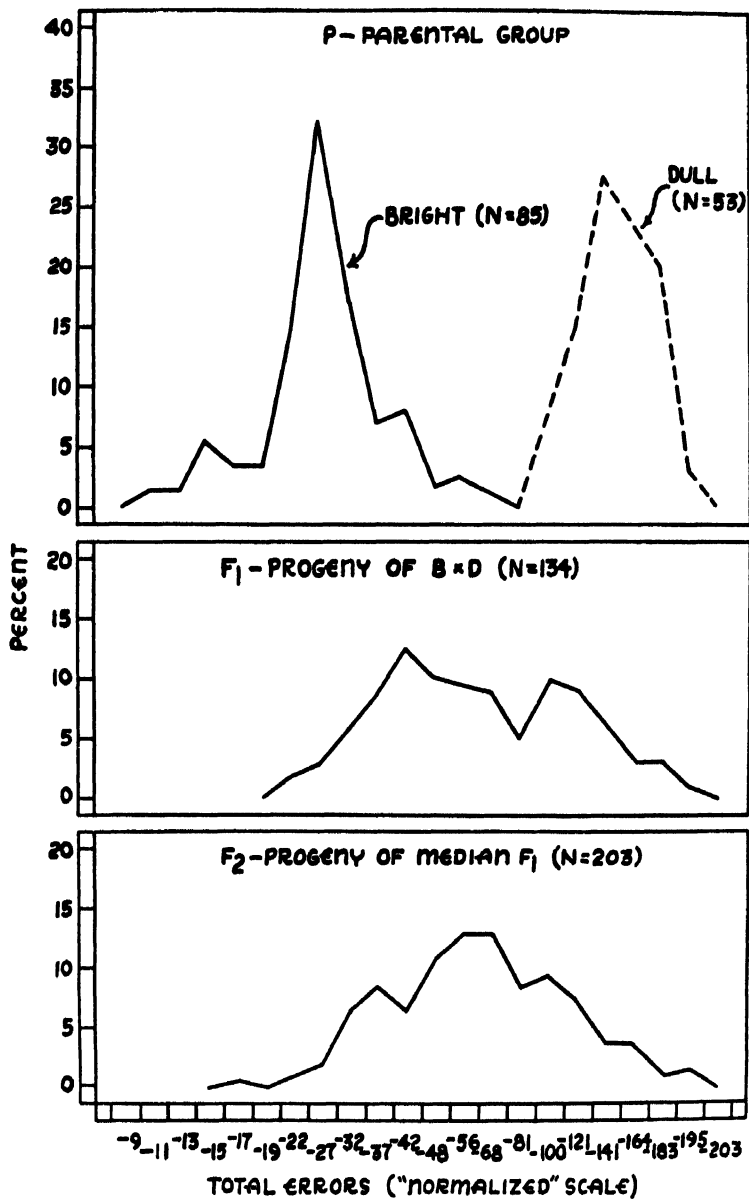


FIG. VI. — F_1 AND F_2 OF BRIGHT × DULL

trait. The F_2 progeny of the F_1 do *not* vary more than the F_1 . Because the going theory was not verified, I repeated this crucial type of cross several years after the first attempt, but the results were the same. Figure VI combines the findings of both series of experiments.

We need to develop and verify a factor hypothesis consistent with the facts of Figures IV, V, and VI, and with the results of certain back-cross experiments. One method is that of expressing a given hypothesis concretely in terms of a dice-pattern. A random parental population is then set up in which the score of each fictitious individual is determined by a dice throw. These 'individuals' are then 'bred' according to the actual breeding schedule of the rat experiment and the theoretical results compared for fit with the experimental findings. The hypothesis that gives the best fit and that is most consistent with genetic theory will be the one finally chosen. I have performed several such artificial experiments, and from these it appears that the most promising hypothesis investigated to date is one that postulates multiple factors, some dominant for bright performance, some (but fewer) dominant for dull, and some cumulative. The effects of linkage and crossing-over, and of reciprocal crossing — that is, bright male $\times$ dull female vs. dull male $\times$ bright female — must be investigated.

3. Biological Correlates of Brightness and Dullness

Large groups of bright and dull animals have been carefully measured in respect to brain size and weight, body weight, and fertility. Significant differences have been discovered. The bright animals show physical superiority throughout, except in the one particular of fertility.¹ Because of the intensive inbreeding that has occurred during the process of selective breeding, the evaluation of these findings is to some extent equivocal.

4. The Constancy of Differences in Ability

The extent to which brightness and dullness persist throughout the lives of the animals was investigated. One hundred and seven animals were measured in maze ability when they were young; then an interval of seven months, amounting to about two-thirds of a rat's life span, was permitted to elapse before remeasurement. The correlation between the early and late measurements was .80, indicating a high degree of constancy. For different subgroups that experienced different degrees of environmental variation during the intervening period between measurements, the correlation was the same — a result suggesting that environment as varied in these experiments plays a negligible rôle in this ability.

¹ The difference between the N 's of the bright and dull groups of Figures IV, V, and VI is a function of the number of matings made by the experimenter and not of differential fertility.

5. Psychological Nature of Brightness and Dullness

A variety of experiments were conducted that aimed to provide some insight into the psychological nature of the differences between the bright and dull groups.

a. Evidence from Ratings of Emotional Characteristics. Using reliable, objective rating scales, carefully standardized on a large group of preexperimental animals, three judges independently rated 234 bright, dull, and stock animals on their hiding, avoidance, and escape reactions to controlled handling by the experimenter, and on their reactions to novel inanimate objects in the maze situation. The results show clearly that the bright animals are most adjusted 'emotionally' in the maze-learning situation, whereas in response to handling they are 'neurotic.' Exactly the reverse is the case for dulls.

b. Evidence from a Cluster Analysis. In addition to the measures of emotionality, this same group of 234 animals was measured on eleven different aspects of efficiency at different stages of learning the maze; for example, efficiency as measured by errors, speed (rate) of running, hesitation time at choice-points. The significant result from the analysis appears to be that the hereditary difference in maze ability, which was itself discovered by selection on the basis of errors only, is reflected in all the measures of efficiency as well as in those of emotionality.

c. Evidence from Experiments on the Sensory Nature of Ability Differences. Are bright animals superior to dull because of superiority in *sense acuity*, or does their superiority reside in a capacity for *abstracting* the spatial relations of the complex maze path? On the sense acuity hypothesis, one would assume that during the 19 trials in the maze the bright animals had learned to follow visual, auditory, kinesthetic, tactual, and olfactory cues by virtue of genetic superiority in their senses. Five experiments were conducted to investigate this hypothesis. In each experiment about 70 bright and 70 dull animals were subjects. Stated briefly, the technique was that of experimentally disrupting cues of the various sense modalities on the trials following the nineteenth. In every experiment the bright animals showed relatively negligible disturbance; many showed no disturbance at all as a consequence of cue disruption. These results fail to support the sense theory, but rather support the view that bright animals are superior to dull in a capacity to *generalize* the spatial pattern.

d. Evidence from an Analysis of the 'Qualitative' Behavior of Bright and Dull Animals in the Maze Situation. To investigate further the differences between bright and dull animals in the nonsensory determinants of their maze behavior, I analyzed the frequency pattern of errors made in the 17 blind alleys of the maze by 500 bright and 500 dull animals. As the error patterns of the two types of animals were quite different, especially in the later stages of learning, I attempted to deduce the existence of a number of psychological

gradients of a nonsensory spatial character that theoretically determined the behavior of brights and dulls. As the postulation of such gradients constituted being 'wise after the event,' I then attempted to predict the pattern of errors made by 150 animals in a quite different twenty-blind maze. The correlation between the predicted error pattern and the actual error frequencies was .70, and with minor changes in the weights of the gradients, the correlation was .92. The hypothesis of nonsensory gradients is therefore supported.

e. Evidence from the Study of the Behavior of Maze-Bright and Maze-Dull Animals in Other Problem-Solving Situations. To what degree does hereditary brightness and dullness represent a *general* capacity to learn? In one experiment 150 animals were run through another maze. In another study, conducted by Krechevsky, bright and dull groups were studied in a brightness discrimination box. At the present time Searle is engaged on a program of observing the performance of bright and dull animals in a number of tasks requiring discrimination of distance, angles, and brightness. From the work done and under way, and from published data of other workers showing the relation between maze-learning and other types of learning, the evidence clearly supports the view that maze-learning is *specific*. The doctrine of alleged 'general ability' supported by many psychologists has not been substantiated in rats.

6. Prospectus

Future lines of research are clearly indicated.

One of these, as pointed out earlier, is the study of the effects of experimentally induced environmental variations on the two strains. The general question is this: What sorts of environmental variables of a psychological and biologically pathological character will make hereditarily bright animals dull, and hereditarily dull animals bright? No systematic experiments of this sort have yet been performed. The only relevant data we have are from the experiments on constancy and cue variations cited above. After the rats had first learned the maze to the best of their capacities, the introduction of unsystematic though extensive variations in milieu in different groups during the interval between the original learning and retest did not affect the test-retest correlations. In the stimulus disruption tests, extraordinary variations or deprivations of stimulus (that is, environmental) features did not significantly affect the bright-dull differences. But it is to be noted that these environmental variations occurred *after* the maze had been learned to the level of capacity. These observations would seem therefore to verify the hypothesis that after hereditary capacity has expressed itself in the building up of habits and concepts, the effects of gross environmental changes are negligible. On the other hand, we know as yet nothing about the effects of gross milieu changes before and during learning.

Another problem that calls for study is a systematic examination of the

physical growth and behavior development of the *young* of the bright and dull lines. An extensive series of observations was made on the sensory and motor development of 50 progeny of bright and 50 of dull from birth to 30 days of age. These observations were purely exploratory. A program of research in this field, based on this preliminary work, is to be instituted.¹

In Section XIV Dr. Edgar A. Doll summarizes the present state of knowledge concerning the psychological effects of cerebral birth lesions on the intellectual achievements of patients so afflicted. The reader should also consult in this connection the excellently worked-out case of Gesell (63, 67).

XIV. PSYCHOLOGICAL CONSEQUENCES OF CEREBRAL BIRTH LESIONS

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Congenital palsy is probably as old as the race. Modern attention to this problem usually dates from 1839, when William J. Little, an English orthopedist, described some of the consequences of birth lesions. The physical condition has since generally been termed 'Little's disease.' More recently the term 'birth injuries' has been employed as a popular expression for this condition in its more general aspects. This is a somewhat unfortunate term, since to many it connotes obstetrical trauma, whereas, as a matter of fact, congenital birth lesions may occur at almost any stage of the reproductive process from late pregnancy to early neonatal life. Prenatal infection, trauma, malformations, or other pathology may be present before birth. Prematurity of birth, with weakness in the circulatory system producing brain hemorrhage, is a further consideration. In the birth process itself pelvic malformations, primaparity, type of presentation, size of the infant, and other considerations may induce complications of labor. Labor may be prolonged, severe, assisted by instruments, modified by drugs, and so forth. These abnormal conditions are some of the hazards of delivery that obstetrical skill may not be able to surmount.

Likewise, deficient animation at birth, ill-advised methods of resuscitation, early postnatal trauma from the handling of the infant, neonatal infectious diseases, and other pathology producing essentially the same effects as obstetrical or prenatal embarrassments are commonly grouped among the gross complications that may attend the reproductive process as a whole.

¹ References to previous publications on the experiments described in Section XIII are 198, 199, 200, 201, 202, 203, 204, and 205.