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HERITABILITY OF NUMERICAL FACILITY

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Summary.—In this preliminary work 33 pairs of MZ twins and 12 pairs of like-sexed DZ twins, 32 boys and 58 girls, 40 of whom were Negro and 50 white, whose ages ranged from 13 to 18, were given the Simple Arithmetic Test (after B. N. Mukherjee) understood to be outstanding with respect to the size of loadings and purity of the numerical facility factor (Factor N). Using three different heritability ratios, (1) the Holzinger heritability coefficient, (2) the heritability ratio proposed by Nichols, and (3) the F ratio (Block), the relative intra-pair similarity of MZ and like-sexed DZ twins in mathematical test performance was determined. All the MZ correlations, except one, were greater than the corresponding rs for the DZ twins. Four of the seven differences were significant ($p \leq .10$). The difference between the totals was significant ($p \leq .10$). The results suggest that numerical facility is a unitary ability independently inherited with as much as 72% of the within-family variance determined by hereditary factors.

Factor analysis is generally conceived as having originated in Spearman's (1904) early attempt to determine and measure "general intelligence" objectively. In the half century that followed, Spearman's unidimensional methods were extended to multiple-factor analyses (Thurstone, 1947, 1948), and as early as 1938 Thurstone postulated the existence of a number of primary abilities, factors understood to constitute discrete components of cognition and causes of individual differences in intelligence test performance. Differences in the cognitive performance of individuals were taken to be demonstrable functions of a limited number of reference abilities. An adequate description of the cognitive domain would require only a taxonomic list of a limited number of such faculties. Such a restricted list of "parameters," "faculties," or "abilities" would afford a parsimonious comprehension of what would otherwise be an enormously complex record of behaviors.

The underlying assumptions of factor analysis include (1) the conviction that a limited number of abilities make up the composite tested by familiar intelligence tests and (2) that not all such distinguishable abilities participate equally in every instance of cognitive activity. Such activity rather represents a dynamic system which can be understood in terms of a finite number of parameters operating, at various times, singly or in clusters (in varied combinations) to produce varied overt behavior.

The intercorrelations of performance on tests designed to measure aspects of cognitive activity permit the extraction of such distinguishable factors. Thurstone's (1938) original analysis extracted 13 factors, identifying 7 with assurance. Of those, numerical facility, facility in numerical calculation best exemplified in the simple functional operations of addition, multiplication, subtraction, and division, has proven to be one of the most consistently and impressively established in experimentation and analysis. Since Thurstone's pioneer studies, numerical facility (Factor N) has been identified in no less than 50 published studies. Tests involving the four arithmetical operations are characteristically outstanding with respect to purity of the factor and size of loadings. While tests involving scrambled words, backward writing, four-letter words, incomplete words, memory for numbers, counting, plotting on numbered coordinates, and even reading comprehension display moderate loadings on N, the ability to perform simple numerical operations defines this factor (Botzum, 1951).

Since the publication of Thurstone's original taxonomy, factor analysts have identified approximately 60 unitary mental factors and postulated the existence of over 120 (Guilford, 1959, 1960; Harmon, 1960). Throughout this proliferation of factors, N has remained one of the most consistently reported distinct parameters, with numerical operations tests being its clear and dependable reference vector. The persistence and distinctiveness of N increase the likelihood that it represents a discrete faculty.

Factorial methods were developed primarily for the purpose of identifying the principal unitary abilities whose individual and/or collective activity was understood to explain cognitive performance. No effort was made to determine the origin, nature, and locus of such faculties. Nonetheless, Thurstone (1938) was sufficiently impressed by the uniqueness and stability of N to suggest:

> The insistence of the numerical factor makes it almost certain that it represents a unique ability, but one is puzzled about its psychological or genetic character in view of the fact that calculation is more naturally thought of as a cultural rather than as a biological category. There seems to be some evidence for the genetic interpretation of number facility as an inherited trait. Occasionally this ability is found to be extremely conspicuous even at an early age, and seems to be more or less independent of other abilities (p. 79).

He was later (Thurstone, 1948, p. 406) to suggest that discrete abilities might be inherited, irrespective of the fact that such abilities can only manifest themselves in a suitable environment (numerical facility could only manifest itself in a cultural environment possessed of an appropriate number system; nonetheless, individuals will display performance differentials difficult to attribute to environmental factors alone). Thurstone went on to indicate that it is well established that certain mental faculties, N among them, can remain intact and even of superior quality in cases when *S* is otherwise so poorly endowed mentally that he must be institutionalized. Such faculties seem to be discrete, unitary, and determined, to a substantial degree, by hereditary factors.

Since the time of Thurstone's original speculations, increased experimental and statistical sophistication, expanded computer capacity for processing the increasing amount of available data, conjoined with the development of psychogenetics (the study of the relation between genetic constitution and manifest behavior), provide the essentials for an experimental determination of the heritability of at least some of the primary mental abilities. The study of concordance and discordance in the performance of monozygotic (MZ) and dizygotic (DZ) twins permits the determination of heritability indices for specific mental abilities, particularly when those abilities are as well defined and experimentally well established as N.

MZ twins provide psychogeneticists with sample populations in which genotypic variability is reduced, theoretically, to an absolute minimum and the effects of environmental variables are minimally obscured (Osborne & Gregor, 1966). Whatever intraclass discordance there is in the test performance of MZ twins is theoretically attributable to ecological influences alone while intraclass discordance in the performance of DZ like-sexed twins is attributable to the combined influence of both ecological and genetic factors. Employing such performance data, heritability ratios can be computed which determine the degree of variance in performance attributable to genetic as distinct from environmental factors.

While the relationship between genetics and behavioral variation is best understood in cases in which major metabolic and anatomic deficits are involved (major gene determinations), there is little doubt that polygenic variability influences individual psychological behavior in a significant, if mechanically obscure, fashion (Scott & Fuller, 1951; Fuller, 1951, 1957, 1960; Rainer, 1962). With the increased confidence with which the zygosity of twins can be determined, the measure of that influence can be established with greater precision. In the past like-sexed twins conceived to be MZ were, in fact, DZ and vice versa. The effect of such errors in determination was to obscure the influence of heritability of traits being studied. Today, new serological tests permit the determination of zygosity with a higher degree of confidence than was possible in the past. This increased confidence provides the opportunity for more precise measurements of the influence of heredity.

The purpose of the study was to give an initial estimate of the heritability ratio for Factor N. The fact that numerical operations tests have been shown to be almost "pure" numerical tests, providing a clear and dependable reference vector for N (Adkins & Lyerly, 1952, p. 12), and the availability of experimental populations in which genotypic variability can be maximally reduced, permit an initial heritability index of this specific factor to be determined. Anything more than a preliminary estimate would require (1) more precise knowledge of the mechanics of polygenic inheritance, (2) a more searching analysis of the relationship between the inheritance of physical and psychological traits, and (3) with respect to the present employment of the Simple Arithmetic Test as the test vehicle, a more sophisticated analysis of parts of the test as diagnostic of N.

METHOD

Subjects

Same-sexed adolescent twins from metropolitan Atlanta, Georgia, served as

Ss. The sample included 33 pairs of MZ twins and 12 pairs of DZ twins. There were 32 males and 58 females; 40 *Ss* were Negro and 50 were Caucasian. Their ages ranged from 13 to 18 yr.

The zygosity of the twins was established by serological tests performed under the supervision of Mrs. Jane Swanson of the Minneapolis War Memorial Blood Bank. All *Ss* were subjected to serological tests for the following factors: A, B, O, M, N, S, s, P_1, P_2, Rho, rh′, rh″, Miltenberger, Vermeyst, Lewis, Lutheran, Duffy, Kidd, Sutter, Martin, Kell, and Cellano. Twins whose serological phenotypes were identical were considered monozygous; twins that differed on one or more factors were considered dizygous.

Twelve pairs of twins were diagnosed as definitely DZ, i.e., they differed on at least one independently inherited blood group. Employing only the results of serological tests it was possible to diagnose the remaining 33 pairs as MZ with a 95% probability of accuracy.

Psychological Tests and Procedures

Since tests of the four arithmetical operations have been established as outstanding with respect to size of loadings and purity of the factor N, the test employed was the Simple Arithmetic Test (after B. N. Mukherjee). It is composed of 160 simple arithmetical problems and is divided into seven parts (15, 20, 25, 25, 25, 25, and 25 items). Two minutes were allowed for each part.

Because previous study has shown that *Ss* tend to tire and lose interest in arithmetical operations as they become more difficult, in this test the difficult items are found at the beginning, part 1, while the easiest items are found in part 7.

The test was administered as a group test by trained administrators in accordance with recommended procedures.

Heritability Ratios

To determine the relative intrapair similarity of MZ and DZ like-sexed twins in numerical facility, three different heritability ratios were computed: (1) Holzinger's (1929) heritability coefficient which was computed employing the formula: $H = (rMZ - rDZ)/(1 - rDZ)$; (2) the heritability ratio proposed by Nichols (1965) and computed by the formula: $HR = 2(rMZ - rDZ)/rMZ$; (3) the *F* ratio (Block, 1965) for testing the significance of the difference between the within-set variances ($\sigma_w{}^2$) of MZ and DZ twins computed by the formula: $F = \sigma_w{}^2DZ/\sigma_w{}^2MZ$.

Holzinger (1929) suggested that the best comparison to make in evaluating nature-nurture interaction is that between the intraclass correlation coefficients (*r*) for MZ and DZ twins. His formula gives the proportion of variance produced by genetic differences within families. This method underestimates the effect of heredity in the general population by a factor of two since the genetic overlap of DZ twins is approximately .5 (Gottesman, 1963, p. 8).

The second formula is the ratio of the variance due to heredity and environment common to both twins of a set. Nichols (1965) defines this ratio as the proportion due to heredity of the variance attributable to heredity and major environmental variables. The advantage of this formula is that it does not include error variance and thus needs no corrections for unreliability of the tests. Nichols cautions that, since his heritability ratio depends upon ratios between correlations, it is much more stable when the correlations are high than when they are relatively low.

The *F* ratio compares the within-pair variance of DZ twins with the within-pair variance of MZ twins. Within-pair variance of identical twins is, theoretically, entirely due to environmental influences while DZ within-pair variance is due to hereditary differences as well as to environmental influences. A significant *F* indicates that heredity and environment produce greater differences in DZ than environmental influences alone do in MZ twins.

RESULTS

The new findings are summarized in Table 1 which provides the MZ-DZ intraclass correlations for the seven component parts of the Simple Arithmetic Test as well as the test totals. All correlations were computed on the number of items correct in each case. The three different heritability ratios for each variable accompany the intraclass correlations. All the MZ correlations, except that for part 1, were greater than the corresponding *r*s for the DZ twins. Four of the seven differences were significant ($p \leqq .10$). The difference between the totals was significant ($p \leqq .10$). [This level of significance is reported as this study is considered preliminary and all leads need to be pursued in future work.]

For purposes of determining a preliminary heritability ratio only the differences between the totals were employed. In a later treatment the intercorrelations of the parts of the Simple Arithmetic Test will be considered in order to pro-

TABLE 1
INTRACLASS CORRELATIONS AND THREE HERITABILITY RATIOS FOR NUMERICAL FACILITY

Test	Intraclass *r*		$t_{corr.}$	*H*	*HR*	*F*	*p*
	MZ (N=33)	DZ (N=12)					
Simple Arithmetic, pt. 1	.461	.573	–.404 (ns)	–.263	–.487	.700	ns
Simple Arithmetic, pt. 2	.774	.202	2.170 (.05)	.717	1.477	2.958	.01
Simple Arithmetic, pt. 3	.739	.102	2.227 (.05)	.710	1.725	3.367	.01
Simple Arithmetic, pt. 4	.818	.625	1.099 (ns)	.515	.472	2.114	.05
Simple Arithmetic, pt. 5	.770	.762	.054 (ns)	.036	.022	1.164	.10
Simple Arithmetic, pt. 6	.720	.167	1.943 (.10)	.664	1.537	1.973	.10
Simple Arithmetic, pt. 7	.726	.167	1.977 (.10)	.671	1.540	2.652	.02
Simple Arithmetic, total	.842	.441	1.981 (.10)	.717	.952	3.053	.01

Note.—Correlations were computed on the number of correct answers. *H* = Holzinger's heritability ratio (1929), *HR* = Nichols' heritability ratio (1964), *F* = Block's *F* ratio (1965).

TABLE 2
BIOMETRIC RESEMBLANCE OF TWINS

Test	Intraclass r MZ ($N=33$)	Intraclass r DZ ($N=12$)	$t_{corr.}$	H	HR	F	p
Face Length (mm.)	.84	.69	1.013	.50	.37	2.61	.05
Head Circumference (in.)	.81	.54	1.348	.58	.67	1.67	ns
Standing Height (in.)	.88	.68	1.404	.61	.45	3.07	.01
Weight (lb.)	.84	.72	.821	.43	.28	1.30	ns
Color Blindness (Dvorine)	.85	.04	3.357	.85	2.10	.04	ns

Note.—H = Holzinger's heritability ratio (1929), HR = Nichols' heritability ratio (1964), F = Block's F ratio (1965).

vide an interpretation of the differences between results based on intraclass correlations and those involving the F ratio of the within-group variances.

The results as reported tend to support Thurstone's original conjecture that mathematical facility is a unitary ability, independently inherited, with as much as 72% of the within-family variance determined by hereditary factors. The joint influence of heredity and environment produces significantly greater differences in performance of fraternal twins on tests involving the four arithmetical operations defining N than environmental influences alone produce in identical twins.

Table 2 is provided to permit comparison of the present findings with previously undertaken biometric measurements. Intraclass correlations and heritability indices for height, weight, face length, head circumference, and color blindness are provided. The rs for MZ twin-pairs are consistently higher than those for DZs. The similarity of these results to those reported in separate investigations conducted by Newman, *et al.* (1937), Gottesman (1963), and Shields (1962) is suggestive. Adequate interpretation of such similarities will be a function of increased insight into the mechanics of heredity.

TABLE 3
SUMMARY OF STUDIES OF INTELLECTUAL RESEMBLANCE OF TWINS

	MZ Twins Intra-class r	MZ Twins N	DZ Twins Intra-class r	DZ Twins N	Test
Holzinger (1929)	88	50	.63	50	Binet IQ
Newman, *et. al.* (1937)	91	50	.60	50	Binet IQ
Newman, *et al.* (1937)	.92	50	.62	50	Otis IQ
Blewett (1954)	.75	26	.39	26	PMA
Husen (1959)	.90	215	.70	416	Swedish Military Induction Test
Erlenmeyer-Kimling & Jarvik (1963)	.87		.53		Various intelligence tests
Nichols (1965)	.87	687	.63	482	National Merit Scholarship
Osborne & Gregor (1966)	.76	33	.26	12	Median of Nine Spatial Tests
Present study	.84	33	.44	12	Simple Arithmetic Test (Totals)

Table 3 summarizes intraclass correlations of mental tests from earlier twin research. All MZ *r*s are greater than corresponding *r*s for DZs. The consistency of twin-set correlations for mental ability is suggestive. Regardless of the instrument used to evaluate intelligence and its component factors or the method used to determine the heritability ratio the results are strikingly similar. Naturally the caution that extrapolation from results obtained from a restricted population, affected by a limited range of environmental differences, is made only with some hazard applies here as in all studies of this kind.

Conclusions

In the present study the classical twin method was employed to afford a preliminary estimate of how much of the variability of performance on the Simple Arithmetic Test, diagnostic of N, might be attributable to genetic factors. Improved tests for zygosity were administered and three different heritability ratios were computed for 33 sets of MZ and 12 sets of DZ like-sexed adolescent twins. Six of the seven intraclass *r*s yielded *F* ratios significant at $p \leq .10$. Only in the case of intraclass correlations obtained on part 1 of the test was there an anomolous finding. The *r* for DZs was greater than that obtained for MZs.[1] The range of the remaining heritability coefficient ratios (Holzinger) was from .04 to .72, with MZ intraclass *r*s ranging from .46 to .82 and DZ *r*s from .10 to .76. On the total score for the test the heritability coefficient ratio was .72, the intraclass *r*s for MZs .84 and DZs .44.

The results suggest that Thurstone's original surmise was correct and that N, as a specific mental faculty, is in large part genetically determined. Seventy-two per cent of the variance for numerical facility seems genetically determined, a value that approximates those obtained for a variety of normal mental traits.

Today, a substantial and rapidly growing body of literature supports Hirsch's (1963) suggestion that behavioral genetics is a science basic to the study of individual differences. Certainly the early assumption advanced by Watson (1959, pp. 11, 103), that there was "no real evidence for the inheritance of traits," is more than suspect. Strain comparisons in animals, followed by appropriate genetic crosses, have demonstrated the genetic correlates of behavioral

[1]Part 1 of the test was by far the most difficult. Items in this part called for computation involving three figures within parentheses, multiplication of the result by a factor outside the parenthesis and a subsequent division of the product (e.g., 4(77 + 39 − 7)/7). The scoring formula used was the number right, 15 being a perfect score. The distribution of scores is given below. Approximately 75% of *S*s obtained a score of 0, 1, or 2. Approximately 33% of each group received a score of 0. Furthermore, the *F* was lowest for this test and it was the only test for which *p* was not significant. One can safely conclude that part 1 was not a suitable test vehicle for the population being studied.

Group	Distribution of Scores for Part 1										Σ
MZ *S*s	21	16	15	4	3	1	1	3	1	1	66
DZ *S*s	8	6	4	1	2	1	1	1	0	0	24
Number right	0	1	2	3	4	5	6	7	8	9	

differences. Such experiments have established the genetic correlates for a wide range of normal and abnormal animal behaviors including emotionality, reaction speed, voluntary activity, aggressiveness, mating competition, susceptibility to audiogenic seizure, and preference for alcohol (Fuller & Thompson, 1960). Among humans the systematic study of pedigrees, family resemblances, population differences, and twin comparisons has yielded similar results. Genetic correlates have been demonstrated and heritability ratios have been computed for a variety of normal as well as abnormal human behaviors. The present study contributes to that body of experimental evidence.

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