The Hereditary Abilities Study: Selection of Twins, Diagnosis of Zygosity and Program of Measurements

H. ELDON SUTTON,[1] STEVEN G. VANDENBERG[2] AND PHILIP J. CLARK[3]

Institute of Human Biology, University of Michigan, Ann Arbor

THE USE OF TWINS in genetic research dates back to Galton, who was among the first to recognize the genetic significance of monozygotic and dizygotic types. When the two members of a set of monozygotic twins live under different environmental conditions, they provide an efficient basis, by virtue of their genetic identity, for ascertaining the effects of these different environments on specified characters; and when both monozygotic and dizygotic types are maintained in comparable environments the genetic identity of the monozygotic sets affords a basis for evaluating the relative contribution of genetic factors to the differences within pairs of dizygotic twins. Among the studies of the latter type are those of Dahlberg (1926), von Verschuer (1927), Newman, Freeman, and Holzinger (1937), Thurstone, Thurstone, and Strandskov (1953); Cattell, Blewett, and Beloff (1955); Berry *et al.* (1955); Gartler *et al.* (1955); Vogel and Wendt (1956); Osato and Awano (1957); and Osborne and De George (1959). An extensive bibliography of twin research is given by Gedda (1951).

The proportion of the variation in a trait which is attributable to genetic factors has been called heritability. The term heritability is also used to describe the component of increased variability within dizygotic twin pairs compared to monozygotic twin pairs. Since the dizygotic twins share many genes when compared to a random pair of individuals in the population, the heritability measured with twin studies is obviously not identical to the quantity measured by other approaches. The two should be related, however.

A fundamental assumption underlying the estimation of heritability from a comparison of identical and fraternal twins is that the environments of the two members of a set of monozygotic twins are neither more nor less different from one another than are the environments of the two members of a pair of dizygotic twins of the same sex. Actually there is some reason to question this assumption, since such phenomena as imbalance in the mutual circulation of monochorial embryos may result in a greater difference in the prenatal

Present addresses: [1]*Department of Zoology, The University of Texas, Austin;* [2]*Department of Pediatrics, University of Louisville, Louisville, Kentucky;* [3]*Department of Zoology, Michigan State University, East Lansing.*

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TABLE 1. SUMMARY OF SEROLOGICAL STUDIES AND BACKGROUND INFORMATION OF THE TWIN SUBJECTS

Kindred number	Individual number	Sex	Age to nearest year	Serological data: ABO	MN	Rh	Kell (K)	Duffy (Fya)	Secretor	Probability of Monozygosity*	Religious background†	Years of education: Father	Mother	Occupational rating ‡: Father	Mother
A. Concordant twin pairs believed to be monozygotic															
3534	16557 16558	♂	13	A_1	MN	R_1R_2	—	+	—	0.94	P	16	18	73	79
3540	16572 16573	♀	13	A_1	MN	R_1R_1	—	+	+	0.88	P	10	12	73	68
3541	16574 16575	♂	12	O	M	rr	—	+		0.87	P	12	11	68	68
3543	16579 16580	♀	16	B	M	R_1R_2	—	+	+	0.93	P	14	10	58	—
3544	16581 16582	♂	15	O	M	R_1r	—	+		0.86	C	12	12	47	—
3545	16583 16584	♂	18	O	MN	R_1r	+	+		0.91	P	9	8	67	—
3550	16593 16594	♂	17	O	M	R_2r	—	+		0.89	P	12	12	62	—
3552	16597 16598	♂	13	O	MN	R_1r	—	—		0.88	P	23	19	89	—
3554	16601 16602	♂	17	B	MN	R_1r	—	+	+	0.90	C	12	12	73	—
3555	16603 16604	♀	18	A_1	M	R_1r	—	—	—	0.94	P	6	12	73	—
3559	16611 16612	♀	13	O	MN	R_1r	—	+		0.85	P	8	9	65	—
3565	16626 16627	♂	16	A_1	N	R_1R_2	—	+	+	0.91	C	6	6	60	60
3566	16628 16629	♂	18	B	MN	R_1R_1	—	+	+	0.91	G	7	5	72	—
3567	16630 16631	♀	18	O	N	R_1R_1	—	—		0.91	P	9	9	79	—
3568	16632 16633	♂	15	A_1	M	R_1r	—	+	+	0.88	P	20	12	93	—
3569	16634 16635	♂	17	O	MN	R_1r	+	—	+	0.94	P	14	11	74	69
3572	16640 16641	♂	15	O	M	R_1r	—	+		0.86	P	16	16	79	78

3576	16650 16651	♀	17	B	M	R_1r	—	—	—	0.96	P	10	9	18	—
3577	16652 16653	♂	17	B	N	R_2r	—	+	—	0.96	G	18	12	87	—
3579	16656 16657	♀	16	A_1	M	R_1R_1	—	+	+	0.89	C	11	10	62	—
3580	16658 16659	♂	17	A_1	M	R_1R_2	—	+	+	0.90	P	12	10	76	—
3581	16660 16661	♀	15	A_1	MN	R_1R_1	—	—	+	0.91	P	8	14	62	62
3595	16680 16681	♂	15	O	MN	R_2r	—	+	—	0.94	P	14	16	69	—
3597	16684 16685	♂	17	B	N	R_1r	—	—	+	0.94	P	11	12	74	—
3599	16688 16689	♂	16	B	MN	rr	—	+	+	0.91	C	6	11	60	—
3600	16690 16691	♀	18	O	MN	R_0r	—	—		0.86	P	8	9	48	—
3601	16692 16693	♂	18	A_1	N	R_0r	—	+	+	0.86	P	12	11	60	—
3602	16694 16695	♀	17	B	MN	R_2r	—	—	—	0.97	P	6	2	40	48
3603	16696 16697	♂	16	B	M	rr	—	+	+	0.92	P	8	14	69	58
3604	16698 16699	♀	16	O	N	R_1R_1	—	+	+	0.89	P	16	11	79	—
3608	16708 16709	♂	15	B	N	R_1R_1	—	—	+	0.94	P	8	12	60	—
3609	16710 16711	♀	15	A_1	MN	R_1R_2	—	+		0.89	P	12	12	60	73
3610	16712 16713	♀	18	O	MN	R_0r	—	—	+	0.93	C	11	12	69	—
3611	16714 16715	♀	17	A_2	MN	R_1r	—	—	+	0.93	C	15	8	47	—
3613	16718 16719	♂	16	A_2	MN	R_1r	—	+	+	0.90	C	12	10	69	—
3614	16720 16721	♂	17	O	MN	rr	—	—	+	0.90	P	14	14	81	—
3619	16730 16731	♀	16	A_1	N	R_1r	—	+	+	0.89	C	10	12	76	—
3620	16732 16733	♀	18	A_1	MN	R_1r	—	+	+	0.87	C	12	11	73	—

3627	16746 16747	♂	17	O	N	R_1r	—	+	+	0.88	P	9	9	69	58
3634	16755 16756	♀	15	A_1	N	rr	—	+	+	0.90	C	6	8	69	—
3637	16761 16762	♀	15	O	MN	R_1R_2	—	+	+	0.89	P	12	16	73	78
3638	16763 16764	♀	18	A_2	MN	R_1R_1	—	+	+	0.91	C	8	3	73	—
3641	16769 16770	♀	19	B	M	R_1R_1	—	+	+	0.92	C	5	6	73	—
3643	16773 16774	♀	16	A_1	M	rr	—	+	+	0.89	P	17	15	84	—
3648	16781 16782	♀	17	A_1	N	R_1R_2	+	+	+	0.95	P	8	8	60	—
B. Concordant twin pairs considered to be dizygotic															
3531	16551 16552	♂	20	A_2	MN	R_1r	—	+	+	0.90	P	17	16	82	—
3578	16654 16655	♂	17	O	M	rr	—	—		0.90	P	12	14	73	78
3593	16676 16677	♀	19	A_1	N	R_1r	—	+	+	0.89	P	15	16	69	—
3615	16722 16723	♂	15	O	MN	R_1R_1	—	+	+	0.88	P	15	15	79	—
3621	16734 16735	♀	15	A_1	MN	R_1R_1	—	+	+	0.88	C	11	7	73	—
3626	16744 16745	♂	17	O	N	R_1r	—	+	+	0.88	P	10	12	73	—
3645	16777 16778	♀	15	O	MN	R_1R_2	—	+	+	0.89	P	9	10	44	—
C. Discordant twin pairs considered to be dizygotic															
3532	16553 16554	♀	20	A_1 A_1B	MN MN	R_1r R_1r	— —	+ +	+ +	0.00	C	8	8	73	—
3533	16555 16556	♀	14	O O	MN MN	R_1r R_1r	— —	+ —			P-J	16	16	89	—
3535	16559 16560	♀	18	O A_1	MN MN	R_1r R_2r	— —	+ —	 +		P	16	16	74	—
3546	16585 16586	♂	12	O O	MN MN	R_1R_2 R_1r	— —	+ +			P	20	15	86	78
3547	16587 16588	♀	13	O A_1	M N	R_1R_2 R_1R_2	— —	+ +			P	12	12	81	—

3548	16589	♀	12	A_2	MN	R_1r	—	+	—	P	20	13	93	—
	16590			O	MN	R_1r	—	+						
3549	16591	♂	14	A_1	MN	rr	—	+		P	12	12	68	—
	16592			O	MN	rr	—	—						
3551	16595	♂	15	A_1	MN	R_2r	—	+	+	P	16	17	82	—
	16596			A_1	MN	R_2r	—	—	+					
3553	16599	♂	18	O	N	R_1R_2	—	+		P	12	12	58	58
	16600			O	M	R_1R_2	—	+						
3556	16605	♀	17	A_1	M	R_1r	—	—		P	16	15	86	73
	16606			O	MN	R_1r	—	—						
3563	16622	♂	17	O	N	R_2R_2	—	+	+	P	8	8	60	—
	16623			O	N	R_2r	—	+	+					
3564	16624	♀	18	O	MN	R_1R_2	+	+		P	8	14	50	—
	16625			O	MN	R_1r	+	+						
3570	16636	♀	18	B	MN	R_0r	+	+	—	P	17	14	81	78
	16637			B	MN	rr	—	—	+					
3594	16678	♀	16	A_1	MN	R_1R_1	—	—		P	16	12	76	76
	16679			A_2	N	R_1R_1	—	—						
3596	16682	♀	16	A_2	MN	R_1R_1	—	—		P	12	12	73	—
	16683			O	MN	R_1R_2	—	—						
3598	16686	♀	15	A_1B	N	R_1r	—	—		P	16	14	81	—
	16687			A_1	N	R_1r	+	—						
3612	16716	♀	16	O	MN	R_1r	—	+		P	14	16	81	—
	16717			O	MN	R_2r	—	+						
3616	16724	♀	18	B	MN	R_1r	+	—	—	P	4	8	60	46
	16725			B	MN	R_1R_2	+	+	+					
3617	16726	♀	17	O	M	R_2r	—	—		P	9	10	47	—
	16727			A_1	N	rr	—	+						
3622	16736	♀	17	O	MN	R_0r	—		+	P	9	7	48	—
	16737			O	MN	R_1r	—		+					
3623	16738	♂	18	O	M	rr	—	+		P	7	8	73	—
	16739			A_1	M	R_1r	—	+						
3624	16740	♂	17	A_1	MN	R_1R_1	—		+	P	3	8	—	—
	16741			A_1	MN	R_1r	—		+					
3625	16742	♀	16	O	N	R_1R_1	—	+		P	13	12	67	—
	16743			A_1	N	R_2r	—	+						
3635	16757	♂	18	A_2	MN	R_1r	—	+		C	8	8	60	—
	16758			A_2	N	R_1r	—	+						
3636	16759	♂	16	A_1	M	rr	—	+		M	6	7	47	—
	16760			A_2	MN	rr	—	+						
3639	16765	♂	18	A_1	M	rr	—	+	+	P	12	10	81	—
	16766			A_1	M	rr	—	—	—					

3640	16767	♀	15	A_1	MN	R_1R_1	+	+		C	8	10	81	—
	16768			A_1B	N	R_1R_1	—	+						
3642	16771	♀	16	O	MN	R_1r	—	—	++	P	10	12	73	—
	16772			O	MN	R_1R_1	—	—						
3644	16775	♀	16	A_2	MN	rr	—	+		P	12	10	58	—
	16776			O	MN	rr	—	+						
3649	16783	♀	17	O	MN	R_1r	—	+		C	6	8	44	—
	16784			A_2	MN	R_1r	—	+						

*Computed according to the method presented in Sutton, Clark and Schull (1955) using the gene frequencies referred to in Table 2 of this paper.

†P = Protestant, C = Roman Catholic, G = Greek Orthodox, J = Jewish, M = Moslem.

‡Based on the ratings of 90 occupations as published in a report of the National Opinion Research Center (1947).

environments of monozygotic twins than of dizygotic twins, whereas a tendency for parents to treat monozygotic twins more alike than dizygotic pairs may cause the postnatal environments of the monozygotic sets to be more alike than those of dizygotic pairs. Although the two kinds of biases are in other. These considerations have been reviewed by Price (1950), who con- opposite directions there is no reason to suppose that they neutralize one an- siders that the resultant of the two biases leads to underestimates of heritability. In our work we have assumed the comparability of the environments, both prenatal and postnatal, recognizing that estimates of heritability based on this premise may be somewhat biased. The statistical methods appropriate to such analyses as well as the interpretation of the results are discussed in an earlier paper (Clark, 1956). With the relatively small numbers of twins studied, attempts to estimate the heritability would have little quantitative meaning. Consequently, we have generally only tested for a difference between the within twin pair variances, a significant ratio being interpreted as evidence for a large genetic component.

In The Hereditary Abilities Study we have attempted to make two improvements over previous studies of twins, namely, a more accurate diagnosis of zygosity and the inclusion of more measures than has heretofore been possible. The primary basis for diagnosing zygosity available to earlier workers was the degree of resemblance in physical characteristics. Twins who were very imilar in their physical make-up were regarded as monozygotic, while less similar sets were classified as dizygotic. The estimation of heritability for traits which are employed in the diagnosis of zygosity or which are correlated with such traits obviously involves an element of circular reasoning, which would tend to overestimate heritability.

With the advent of blood group techniques, and particularly as the number of available antisera has increased, the diagnosis of zygosity can be made with a high degree of accuracy. Approximately 90 per cent of all like-sexed dizygotic twins are discordant in their reaction to one or more of the antisera used in this study. If the blood group data are supplemented with information from physical traits known to be largely free from environmental influences, then probably not more than two or three per cent of dizygotic twins fail to be recognized as such. This virtually removes the errors in heritability estimates caused by incorrect diagnosis of zygosity.

In addition to a more thorough diagnosis of zygosity than has previously been possible, this study has included many measures whose heritability has not previously been examined. These measures were taken from the fields of psychology, biochemistry, and anthropometry. They afford the opportunity of investigating the covariances of groups of measures between as well as within the three general areas presented.

This report is concerned with the selection of twins, the diagnosis of their zygosity and a general account of the several observations and measurements made on them. Other reports will present in detail the results obtained from the study.

DESCRIPTION OF SUBJECTS

A total of 82 pairs of like-sexed twins was examined. Except for three pairs of undergraduate twins from the University of Michigan, the twins were obtained from junior and senior high schools of Ann Arbor, Ypsilanti, Dearborn, and Detroit, Michigan. They were contacted through their schools, which furnished the names of all the twins of which they were aware. The twins and their parents were then asked to participate in the study, which was expected to take at least three days of the twin's time. Although most of them readily agreed to cooperate, there is a possibility that those few pairs who refused may differ in some respects from the twins who were studied, while any twins not recognized as such by the school authorities may have been less alike than those who did cooperate. However, if any bias has resulted from such a difference it is almost certainly small. The fact that the twins who participated in the study have quite diverse backgrounds is shown in table 1.

DIAGNOSIS OF ZYGOSITY

The first step in diagnosing the zygosity of the twins was to separate them into two groups on the basis of their concordance or discordance with respect to blood groups ABO, MN, Rh, Kell and Duffy and the secretor factor. The antisera employed in the blood typing were anti-A, absorbed anti-A, and anti-B; anti-M and anti-N; anti-C, anti-D, anti-E, anti-c and anti-e; anti-K; and anti-Fy^a. Discordance for one or more of these antisera was regarded as sufficient evidence for dizygosity. A comparison of the frequencies of the various blood types found in this study with the predicted number is shown in table 2. The results of this study lie within the expected range. The serological reactions of each individual as well as the probability of monozygosity for each pair of twins, computed by the method of Sutton, Clark, and Schull (1955), are presented in table 1. The mean probability of monozygosity for concordant twins is 0.90, so that roughly 10 per cent of the 52 sets of concordant twins may be expected to be dizygotic.

Several supplementary observations were used to detect the dizygotic concordant twins. Some of the sets (Nos. 3531, 3578, 3593, and 3645) were so dissimilar in physical appearance as to preclude any possibility of their being genetically identical. For most of the twins, several Kodachrome transparencies were made separately for each eye. For three pairs of twins (Nos. 3615, 3621, and 3626), the differences in color and structure of the irides were inconsistent with genetic identity. Lateral and frontal cephalograms and plates of the hands including the wrist were made in the Orthodontics Department of the Dental School. Visual inspection of these confirmed our decisions regarding the non-identity of the seven pairs of concordant twins. Similar results were obtained in a like manner from dental casts made of the twins.

In table 1, the twins are separated into three groups — 45 monozygotic pairs who are concordant for serological traits, 7 dizygotic pairs who are concordant for serological traits and 30 dizygotic pairs who are discordant for serological traits. In subsequent statistical analyses, they will be considered only as monozygous or dizygous.

PROGRAM OF MEASURES

Detailed descriptions of the methods of making measurements will be given in the papers which present the results from each area of study. Only a brief account of the measures made on the twins will be given here.

Anthropometric traits. A large number of the usual anthropometric traits were measured. In addition, palm and fingerprints were made, photographs of the face and profile, ears, hands, and eyes were taken, the last in color for most of the subjects. Included as part of the anthropometric battery also were handedness, the ability to curl the tongue, and the presence of mid-digital hair. An audiogram was made for each subject as was a recording of the voice.

Estimates of heritability for most of the metric traits which were measured directly and for some of the indices have been published by Clark (1956), who made the anthropometric measurements.

Frontal and lateral cephalograms, roentgenograms of the hands and wrists, and dental casts were made by James P. Alderisio of the Orthodontics Department, School of Dentistry, through the cooperation of Robert E. Moyers.

Biochemical measurements. Genetic variation in phenotype may be presumed to arise initially as an alteration in some biochemical process. The emphasis in recent years on biochemical techniques as a means of detecting genetic differences has proved very fruitful with micro-organisms. Some information has been gained on man also, although the difficulties of maintaining a constant environment and discovering the appropriate matings have hindered progress. The twin study method offers a means of estimating the heritabilities of biochemical variations. In the Hereditary Abilities Study an effort was made to assess the genetic contribution to the normal variation in some of the biochemical measures for which genetic heterogeniety has been suggested. These consisted largely of the amino acid levels of urine, saliva and blood, as determined by a quantitative paper chromatographic technique. Also included as part of the biochemical studies were erythrocyte and leukocyte counts and other hematological measures. H. Eldon Sutton was in charge of the biochemical studies.

Cardiovascular studies. Measurements of blood pressure and pulse rate under casual and resting conditions and following a cold pressor test were made at the Cardiovascular Unit of the University Hospital under the direction of Sibley W. Hoobler.

Ophthalmologic studies. Harold F. Falls conducted an extensive examination of the eyes, including a cycloplegic refraction.

Psychological measurements. The psychological measurements obtained might be grouped in several ways, depending either on (1) the nature of the traits measured or on (2) the methods of measuring. The traits measured included various aspects of intelligence, motor skill or dexterity, personality, and interests. Approximately half of the measures consisted of paper and pencil group tests given in the schools to all the cooperating twins from each school. These groups varied in size from 4 to 22 individuals. The paper and pencil tests were with few exceptions of the "objective" type where a choice

TABLE 2. FREQUENCIES OF BLOOD TYPES AND SECRETOR TRAIT IN TWIN SAMPLES*

Locus	ABO						MN			Rh							Kell		Duffy		Secretor	
Phenotype	A_1	A_2	B	A_1B	A_2B	O	M	N	MN	R_1R_1	R_2R_2	R_1R_2	R_1r	R_2r	rr	R_0r	K+	K−	Fy^{a+}	Fy^{a-}	Se+	Se−
Found	25	8	12	1	0	32	20	16	42	16	1	12	30	5	12	2	7	71	57	20	40	8
Predicted	27	8	7	2	1	34	22	17	39	14	2	9	28	9	13	2	9	69	52	25	39	9

*Results from concordant sets were counted only once. In the case of discordant sets, only the results from the twin of lower individual number were counted. Kindreds 3600, 3601, 3602, and 3622 were not considered in compiling this table since their Negro ancestry would require the use of different frequencies in computing the predicted values.

The sources of the gene frequencies used for prediction were as follows: for the ABO locus, Race and Sanger, p. 24, "Southern England"; for the MN locus, Mourant, p. 357, "American Whites"; for the Rh locus, Mourant, p. 395, "American Whites"; for the Kell locus, Mourant, p. 404, "Minnesota Whites"; for the Duffy locus, Mourant, p. 409, "Minnesota Whites"; and for the secretor locus, Race and Sanger, p. 189, "New York City Whites."

of answers is provided for each question and the subject has to indicate which he considers to be the correct answer. Although the majority of the tests given in the schools were concerned with the measurement of abilities, several questionnaires designed to measure personality traits or interests and occupational preferences were also answered at that time.

The remainder of the tests selected to "sample" the universe of psychological traits were individually administered on The University of Michigan campus. In addition to various standardized performance tests, several new perceptual experiments adapted to the study of individual differences were included. In each case the procedure was such that an objective quantitative score was obtained. Also included were the responses to a sudden light and loud noise as shown in a continuous record of breathing, heartbeat, and galvanic skin resistance.

Steven G. Vandenberg was in charge of the psychological studies.

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The completion of the program described here was possible only because a great many school officials helped us in locating our subjects, in making available the time in which to administer tests, and in arranging facilities for testing in the schools. We would like particularly to cite the following individuals for their cooperation:

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