

# Articles

## Sources of Human Psychological Differences: The Minnesota Study of Twins Reared Apart

THOMAS J. BOUCHARD, JR.,\* DAVID T. LYKKEN, MATTHEW MCGUE,  
NANCY L. SEGAL, AUKE TELLEGEN

Since 1979, a continuing study of monozygotic and dizygotic twins, separated in infancy and reared apart, has subjected more than 100 sets of reared-apart twins or triplets to a week of intensive psychological and physiological assessment. Like the prior, smaller studies of monozygotic twins reared apart, about 70% of the variance in IQ was found to be associated with genetic variation. On multiple measures of personality and temperament, occupational and leisure-time interests, and social attitudes, monozygotic twins reared apart are about as similar as are monozygotic twins reared together. These findings extend and support those from numerous other twin, family, and adoption studies. It is a plausible hypothesis that genetic differences affect psychological differences largely indirectly, by influencing the effective environment of the developing child. This evidence for the strong heritability of most psychological traits, sensibly construed, does not detract from the value or importance of parenting, education, and other propaedeutic interventions.

**M**ONOZYGOTIC AND DIZYGOTIC TWINS WHO WERE SEPARATED early in life and reared apart (MZA and DZA twin pairs) are a fascinating experiment of nature. They also provide the simplest and most powerful method for disentangling the influence of environmental and genetic factors on human characteristics. The rarity of twins reared apart explains why only three previous studies of modest scope are available in the literature (1-4).

More than 100 sets of reared-apart twins or triplets from across the United States and the United Kingdom have participated in the Minnesota Study of Twins Reared Apart since it began in 1979. Participants have also come from Australia, Canada, China, New Zealand, Sweden, and West Germany. The study of these reared-apart twins has led to two general and seemingly remarkable conclusions concerning the sources of the psychological differences—behavioral variation—between people: (i) genetic factors exert a pronounced and pervasive influence on behavioral variability,

and (ii) the effect of being reared in the same home is negligible for many psychological traits. These conclusions will not come as revelations to the many behavioral geneticists who have observed similar results and drawn similar conclusions (5). This study and the broader behavioral genetic literature, nevertheless, challenge prevailing psychological theories on the origins of individual differences in ability, personality, interests, and social attitudes (6). Here we summarize our procedures and review our results and interpretations of them.

Participants complete approximately 50 hours of medical and psychological assessment. Two or more test instruments are used in each major domain of psychological assessment to ensure adequate coverage (for example, four personality trait inventories, three occupational interest inventories, and two mental ability batteries). A systematic assessment of aspects of the twins' rearing environments that might have had causal roles in their psychological development is also carried out. Separate examiners administer the IQ test, life history interview, psychiatric interview, and sexual life history interview. A comprehensive mental ability battery is administered as a group test. The twins also complete questionnaires independently, under the constant supervision of a staff member.

Reared-apart twins have been ascertained in several ways, such as: (i) friends, relatives, or the reunited twins themselves, having learned of the project, contact the Minnesota Center for Twin and Adoption Research (MICTAR); (ii) members of the adoption movement, social workers, and other professionals who encounter reared-apart twins serve as intermediaries; (iii) twins who are, or become aware of, a separated co-twin solicit assistance from the MICTAR staff in locating this individual. Selection on the basis of similarity is minimized by vigorously recruiting all reared-apart twins, regardless of known or presumed zygosity and similarity. We have been unable to recruit to the study six pairs of twins reared apart whom we believe to be monozygotic.

Zygosity diagnosis is based on extensive serological comparisons, fingerprint ridge count, and anthropometric measurements. The probability of misclassification is less than 0.001 (7). Where appropriate, our data are corrected for age and sex effects (8). Due to space limitations and the smaller size of the DZA sample (30 sets), in this article we focus on the MZA data (56 sets). The results reported here are, for the most part, based on previously reported findings, so that the sample sizes do not include the most recently assessed pairs and vary depending on when in the course of this ongoing study the analyses were conducted.

As shown in Table 1, the sample consists of adult twins, separated very early in life, reared apart during their formative years, and reunited as adults. Circumstances of adoption were sometimes

T. J. Bouchard, Jr., and M. McGue are in the Department of Psychology and the Institute of Human Genetics, University of Minnesota, Minneapolis, MN 55455. D. T. Lykken, N. L. Segal, and A. Tellegen are in the Department of Psychology, University of Minnesota, Minneapolis, MN 55455.

\*To whom reprint requests should be addressed.

**Table 1.** Means, standard deviations (SD), and ranges for age, measures of contact, IQ, and parental educational level for MZA twins. Two MZA male triplet sets were each entered as one set. Data are based on the first 56 sets of MZAs recruited, although the sample size varies slightly from measure to measure, as data are not always available or relevant (for example, rearing mother died very early in twins' life or twins could not be tested with an English language WAIS).

Statistic	Age (years)	Time together prior to separation (months)	Time apart to first reunion (years)	Total contact time (weeks)	IQ (WAIS)	Rearing father's education level (years)	Rearing mother's education level (years)
Mean	41.0	5.1	30.0	112.5	108.1	10.7	10.3
SD	12.0	8.5	14.3	230.7	10.8	4.5	3.7
Range	19.0–68.0	0–48.7	0.5–64.7	1–1233	79–133	0–20	0–19

informal, and the adoptive parents, in comparison to parents who volunteer to participate in most adoption studies, have a lower level of education (mean equals 2 years of high school), and are quite heterogeneous in educational attainment and socioeconomic status (SES). Because our sample includes no subjects with IQs in the retardate range ( $\leq 70$ ), the mean IQ is higher and the standard deviation lower than for the general population.

## Components of Phenotypic Variance

If genetic and environmental factors are uncorrelated and combine additively (points we return to later), the total observed variance,  $V_t$ , of a trait within a population can be expressed as

$$V_t = V_g + V_e + V_m \quad (1)$$

where  $V_g$  is variance due to genetic differences among people,  $V_e$  is variance due to environmental or experiential factors, and  $V_m$  is variance due to measurement error and unsystematic temporal fluctuations. For measures of psychological traits,  $V_m$  ranges from approximately 10% (of  $V_t$ ) for the most reliably measured and stable of traits (for example, IQ) to as high as 50 to 60% for traits that are less reliable or that show considerable secular instability (for example, some social attitudes). The environmental component,  $V_e$ , can be divided into variance due to experiences that are shared,  $V_{es}$ , and experiences that are unshared,  $V_{eu}$ . Shared events may be experienced differently by two siblings (for example, a roller coaster ride or a family vacation), in which case they contribute to the  $V_{eu}$  component. If the total variance,  $V_t$ , is set at unity, the correlation between MZ twins,  $R_{mz}$ , equals  $V_g + V_{es}$ . The heritability of a trait equals  $V_g$ ; the heritability of the stable component of a trait (for example, the mean value around which one's aggressiveness varies) equals  $V_g/(V_t - V_m)$ .  $V_t$  and  $V_m$  can be estimated from studies of singletons, but  $V_g$  is more elusive: for monozygotic twins reared together (MZT), some of the within-pair correlation might be due to effects of shared experience,  $V_{es}$ . The power of the MZA design is that for twins reared apart from early infancy and randomly placed for adoption,  $V_{es}$  is negligible, so that  $V_g$  can be directly estimated from the MZA correlation.

## Similarity in the IQ of MZA Twins

The study of IQ is paradigmatic of human behavior genetic research. There are more than 100 relevant twin, adoptee, and family studies of IQ, and IQ has been at the center of the nature-nurture debate (9). The analysis of IQ is also paradigmatic of the approach taken by this study. It illustrates our use of replicated measures, evaluation of rearing environmental effects, and analysis of environmental similarity. We obtain three independent measures

of IQ: (i) the Wechsler Adult Intelligence Scale (WAIS); (ii) a Raven, Mill-Hill composite; and (iii) the first principal component (PC) of two multiple abilities batteries.

The WAIS consists of a set of six verbal and five performance subtests that are individually administered, requiring about 1.5 hours, and that yield an age-corrected estimate of IQ (10). To avoid examiner bias, we administer the WAIS simultaneously to the twins in different rooms by professional psychometrists. The Raven Progressive Matrices (Standard Set) is a widely used nonverbal measure of problem-solving ability often paired with the Mill-Hill Vocabulary Test, a multiple-choice word knowledge test (11). In this study, the Raven and Mill-Hill are both administered and scored by computer. The two age- and sex-corrected scores are transformed to have a mean equal to 50 and a standard deviation of 10. The sum of these transformed scores (which intercorrelate about 0.57) provides a separate estimate of IQ. The first major ability battery included in our assessment is an expanded version of the battery used in the Hawaii Family Study of Cognition (12). The second major ability battery is the Comprehensive Ability Battery (13). Detailed results from analysis of both tests are reported elsewhere (14).

In each of the three prior studies of MZA twins, two independent estimates of intelligence were obtained. The sample sizes and intraclass correlations for all four studies are compared in Table 2. The table illustrates the remarkable consistency of the MZA correlations on IQ across measurement instrument, country of origin, and time period. These correlations vary within a narrow range (0.64 to 0.74) and suggest, under the assumption of no environmental similarity, that genetic factors account for approximately 70% of the variance in IQ.

This estimate of the broad heritability of IQ is higher than the recent estimates (0.47 to 0.58) based on a review of the literature that includes all kinship pairings (9, 15). Virtually the entire literature on IQ similarity in twins and siblings is limited, however, to studies of children and adolescents. It has been demonstrated (16) that heritability of cognitive ability increases with age. A heritability estimate of approximately 70% from these four studies of mainly middle-aged adults is not inconsistent with the previous literature.

## Do Environmental Similarities in Rearing Environments Explain MZA IQ Similarity?

Such marked behavioral similarities between reared-apart MZ twins raise the question of correlated placement: were the twins' adoptive homes selected to be similar in trait-relevant features which, in turn, induced psychological similarity? If so, given that the total variance equals 1.0, then  $V_{es}$  will equal at least  $R_{ff} \times r_{ft}^2$ , where  $R_{ff}$  is the within-pair correlation for a given feature,  $f$ , of the adoptive homes (the placement coefficient), and  $r_{ft}$  is the product-

**Table 2.** Sample sizes and intraclass correlations ( $\pm$  standard error) for all IQ measures and weighted averages for four studies of MZA twins.

Study and test used (primary/secondary/tertiary)	<i>n</i> for each test	Primary test	Secondary test	Tertiary test	Mean of multiple test (43)
Newman <i>et al.</i> (1) (Stanford-Binet/Otis)	19/19	0.68 $\pm$ 0.12	0.74 $\pm$ 0.10		0.71
Juel-Nielsen (1) (Wechsler-Bellevue/Raven)	12/12	0.64 $\pm$ 0.17	0.73 $\pm$ 0.13		0.69
Shields (1) (Mill-Hill/Dominoes)	38/37	0.74 $\pm$ 0.07	0.76 $\pm$ 0.07		0.75
Bouchard <i>et al.</i> (42) (WAIS/Raven, Mill-Hill/ first principal component)	48/42/43	0.69 $\pm$ 0.07	0.78 $\pm$ 0.07	0.78 $\pm$ 0.07	0.75

moment correlation between the feature and the trait in question, *t*.

A checklist of available household facilities (for example, power tools, sailboat, telescope, unabridged dictionary, and original artwork) provides an index of the cultural and intellectual resources in the adoptive home (17). Each twin completes the Moos Family Environment Scale (FES), a widely used instrument with scales describing the individual's retrospective impression of treatment and rearing provided by the adoptive parents during childhood and adolescence (18). The age- and sex-corrected placement coefficients for these and other measures are shown in Table 3, together with the correlations between twins' IQ and the environmental measure ( $r_{fi}$ ) and the total estimated contribution to MZA twin similarity. The maximum contribution to MZA trait correlations that could be explained by measured similarity of the adoptive rearing environments on a single variable is about 0.03 (19). The absence of any significant effect due to SES or other environmental measures on the IQ scores of these adult adopted twins is consistent with the findings of other investigators (20). Rearing SES effects on IQ in adoption studies have been found for young children but not in adult samples (21), suggesting that although parents may be able to affect their children's rate of cognitive skill acquisition, they may have relatively little influence on the ultimate level attained.

## Has Pre- and Post-Reunion Contact Contributed to MZA Twin Similarity in IQ?

MZA twins share prenatal and perinatal environments, but except for effects of actual trauma, such as fetal alcohol syndrome, there is little evidence that early shared environment significantly contributes to the variance of psychological traits. Twins are especially vulnerable to prenatal and perinatal trauma, but these effects are most likely to decrease, rather than increase, within-pair similarity (22). There is evidence that twins who maintain closer contact with each other later in life tend to be more similar in some respects than twins who engage in infrequent contact (23). It appears, however, that it is the similarity that leads to increased contact, rather than the other way around (24). MZA twins in this study vary widely in the amount of contact they have had prior to assessment. All twin pairs spent their formative years apart. Some had their first adult reunion at the time of assessment, whereas others met as much as 20 years earlier and had experienced varying degrees of contact. A small number of the pairs actually met at intervals during childhood. As shown in Table 1, total contact time for the MZA twins ranges from 1 to 1233 weeks. In the one case of 1233 weeks of contact, the twins met as teenagers and lived near each other until assessment when they were adults. Since they met on a regular basis, most of this time was coded as contact time. Degree of social contact between two members of a reared-apart twin pair accounts for virtually none of their similarity. The correlations with the within-pair absolute

**Table 3.** Placement coefficients for environmental variables, correlations between IQ and the environmental variables, and estimates of the contribution of placement to twin similarity in WAIS IQ.

Placement variable	MZA similarity ( $R_{ff}$ )	Correlation between IQ and placement variable ( $r_{fi}$ )	Contribution of place- ment to the MZA correlation ( $R_{ff} \times r_{fi}^2$ )
SES indicators			
Father's education	0.134	0.100	0.001
Mother's education	0.412	-0.001	0.000
Father's SES	0.267	0.174	0.008
Physical facilities			
Material possessions	0.402	0.279**	0.032
Scientific/technical	0.151	-0.090	0.001
Cultural	-0.085	-0.279**	-0.007
Mechanical	0.303	0.077	0.002
Relevant FES scales			
Achievement	0.11	-0.103	0.001
Intellectual orientation	0.27	0.106	0.003

\*\* $r_{fi}$  significantly different from zero at  $P < 0.01$ .

WAIS IQ difference are  $0.06 \pm 0.15$  for time together prior to separation,  $0.08 \pm 0.15$  for time apart to first reunion,  $-0.14 \pm 0.15$  for total contact time, and  $0.17 \pm 0.15$  for percentage of lifetime spent apart (25).

The absolute within-pair difference in WAIS IQ of co-twins as a function of degree of contact are plotted in Fig. 1. Also shown are the expected absolute IQ differences between randomly paired individuals and between two testings of the same individual (26). Although the MZA average difference approximates the absolute difference expected between two testings of a single individual, we do observe a wide range of differences. It is not that we have found no evidence of environmental influence; in individual cases environmental factors have been highly significant (for example, the 29 IQ point difference in Fig. 1). Rather, we find little support for the types of environmental influences on which psychologists have traditionally focused (27).

## Similarity of MZA Twins on a Variety of Dimensions

Table 4 (28) gives the MZA correlations, most previously published, on variables ranging from anthropometry and psychophysiology, to aptitudes, personality and temperament, leisure-time and vocational interests, to social attitudes. Correlations for MZA twins and retest stability coefficients are also provided for comparison. Stable, reliably measured variables like fingerprint ridge count and stature show the highest correlations. Brain wave spectra are highly

reproducible (29) and are strongly correlated in both MZA and MZT twins. Most other psychophysiological variables (for example, blood pressure and electrodermal response) vary considerably across time so that the retest correlations between repeated measurements on the same persons range from 0.5 to 0.8 (30). These retest correlations set the upper limit of similarity that might be found between MZ co-twins. The retest stability of aptitude measures, such as IQ, is rather better, ranging from 0.8 to 0.9 (10), whereas stability of personality and interest measures ranges from 0.6 to 0.7.

With these upper limits in mind, the findings in Table 4 demonstrate remarkable similarity between MZA twins. In terms of standardized tests and measures, the MZA twin similarities are often nearly equal to those for MZT twins (last column) and constitute a substantial portion of the reliable variance (column 5) of each trait.

## The Minimal Effect of Being Reared Together

Some of the MZA twins have had considerable contact as adults,

but all of them were reared apart throughout the formative periods of childhood and adolescence. If being reared together enhances similarity in twins, within-pair correlations for MZA twins are expected to be smaller than those for MZT twins. For example, the mean MZT correlation for IQ, based on 34 studies of primarily children or adolescents, is 0.86 (9) as compared to 0.72 for all, primarily adult, MZA twins. If the mean MZT correlation were maintained into adulthood, its difference from the MZA correlation would suggest that common rearing increases the similarity of IQ in twins (and siblings). However, the MZT correlation apparently declines with age (for example, as a result of the accumulation of nonshared environmental effects) (16), in which event the small MZT-MZA correlation difference would suggest little influence of common rearing on adult IQ. In any case, a significant contribution of shared environment is found for the personality trait of social closeness (31), and possibly religious interests and values (32).

As illustrated in Table 4, however, adult MZ twins are about equally similar on most physiological and psychological traits, regardless of rearing status. This finding and the failure to find

**Table 4.** Interclass correlations (*R*), sample sizes, and MZA/MZT ratio for monozygotic twins reared apart and together for nine classes of variables. NA, not available.

Variables (reference)	Minnesota MZAs		MZTs		Reliability*	$R_{MZA}/R_{MZT}$
	<i>R</i>	Pairs (no.)	<i>R</i>	Pairs (no.)		
Anthropometric variables (28)						
Fingerprint ridge count	0.97	54	0.96	274	0.99	1.01
Height	0.86	56	0.93	274	0.98	0.925
Weight	0.73	56	0.83	274	NA	0.880
Electroencephalographic (brainwave) variables (28)						
Amount of 8- to 12-Hz (alpha) activity	0.80	35	0.81	42	NA	0.987
Midfrequency of alpha activity	0.80	35	0.82	42	NA	0.975
Psychophysiological variables (29)						
Systolic blood pressure	0.64	56	0.70	34	0.70	0.914
Heart rate	0.49	49	0.54	160	0.58–0.80	0.907
Electrodermal response (EDR) amplitude†						
Males	0.82	20	0.70	17	NA	1.17
Females	0.30	23	0.54	19	NA	0.555
Trials to habituation EDR	0.43	43	0.42	36	NA	1.02
Information processing ability factors (17)						
Speed of response	0.56	40	0.73	50	NA	0.767
Acquisition speed	0.20	40	NA	NA	NA	NA
Speed of spatial processing	0.36	40	NA	NA	NA	NA
Mental ability—general factor (44)						
WAIS IQ—full scale	0.69	48	0.88	40	0.90	0.784
WAIS IQ—verbal	0.64	48	0.88	40	0.84	0.727
WAIS IQ—performance	0.71	48	0.79	40	0.86	0.899
Raven, Mill-Hill composite	0.78	42	0.76	37	NA	1.03
First principal component of special mental abilities	0.78	43	NA	NA	NA	NA
Special mental abilities (14)						
Mean of 15 Hawaii-battery scales	0.45	45	NA	NA	0.80	NA
Mean of 13 Comprehensive Ability Battery scales	0.48	41	NA	NA	0.78	NA
Personality variables (31)						
Mean of 11 Multidimensional Personality Questionnaire (MPQ) scales	0.50	44	0.49	217	0.88	1.02
Mean of 18 California Psychological Inventory (CPI) scales	0.48	38	0.49	99	0.65	0.979
Psychological interests (45)						
Mean of 23 Strong Campbell Interest Inventory scales (SCII)	0.39	52	0.48	116‡	0.82	0.813
Mean of 34 Jackson Vocational Interest Survey scales (JVIS)	0.43	45	NA	NA	0.84	NA
Mean of 17 Minnesota Occupational Interest scales	0.40	40	0.49	376	0.75	0.816
Social attitudes (32)						
Mean of 2 religiosity scales	0.49	31	0.51	458	0.80	0.961
Mean of 14 nonreligious social attitude items	0.34	42	0.28	421	0.48	1.21
MPQ traditionalism scale	0.53	44	0.50	217	0.49	1.06

\*The correlation between two testings of the same individual. These estimates of the stable component of the observed trait variance also estimate the upper limit for  $R_{MZ}$ . †The marked difference in EDR amplitude between males and females is discussed in Lykken *et al.* (29). ‡This value is for 116 studies, not pairs.

significant  $r_{ft}$  effects for cognitive abilities (17) or personality (31), together with findings from numerous studies of MZT and DZT twins, sibs, and foster sibs, implies that common rearing enhances familial resemblance during adulthood only slightly and on relatively few behavioral dimensions. This conclusion is given detailed discussion by Plomin and Daniels (5).

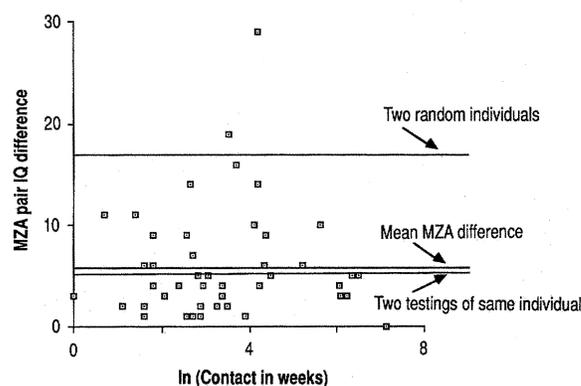
## Why Are MZA Twins So Similar?

It is well known to naturalists and to animal breeders that there are wide and heritable differences in behavior within other species, but there is a curious reluctance among some scientists (33) to acknowledge the contribution of genetic variation to psychological differences within the human species. Our findings support and extend those from many family, twin, and adoption studies (15), a broad consilience of findings leading to the following generalization: For almost every behavioral trait so far investigated, from reaction time to religiosity, an important fraction of the variation among people turns out to be associated with genetic variation. This fact need no longer be subject to debate (34); rather, it is time instead to consider its implications. We suggest the following:

1) *General intelligence or IQ is strongly affected by genetic factors.* The IQs of the adult MZA twins assessed with various instruments in four independent studies correlate about 0.70, indicating that about 70% of the observed variation in IQ in this population can be attributed to genetic variation. Since only a few of these MZA twins were reared in real poverty or by illiterate parents and none were retarded, this heritability estimate should not be extrapolated to the extremes of environmental disadvantage still encountered in society. Moreover, these findings do not imply that traits like IQ cannot be enhanced. Flynn (35), in a survey covering 14 countries, has shown that the average IQ test score has significantly increased in recent years. This increase may be limited to that part of the population with low IQs (36). The present findings, therefore, do not define or limit what might be conceivably achieved in an optimal environment. They do indicate that, in the current environments of the broad middle-class, in industrialized societies, two-thirds of the observed variance of IQ can be traced to genetic variation.

2) *The institutions and practices of modern Western society do not greatly constrain the development of individual differences in psychological traits.* The heritability of a psychological trait reveals as much about the culture as it does about human nature. Heritability must increase as  $V_e$ , the variance affected by the environment, decreases. Where the culture's influence is relatively homogeneous and efficacious,  $V_e$  will decrease and heritability will increase; most American boys, for example, have similar opportunities to play baseball, so that one expects heritability of baseball skill in American young men to be high. Where culture is efficacious, but heterogeneous,  $V_e$  (and total phenotypic variance) will increase; thus, one would expect the heritability of specific linguistic or religious behaviors in the United States or in the Soviet Union to be low. Individuals in Western societies are heterogeneous with respect to personality traits, interests, and attitudes, yet the heritabilities of these traits are relatively high. We infer that the diverse cultural agents of our society, in particular most parents, are less effective in imprinting their distinctive stamp on the children developing within their spheres of influence—or are less inclined to do so—than has been supposed.

Psychologists have been surprised by the evidence that being reared by the same parents in the same physical environment does not, on average, make siblings more alike as adults than they would have been if reared separately in adoptive homes. It is obvious that parents can produce shared effects if they grossly deprive or mistreat



**Fig. 1.** The absolute value of the MZA within-pair IQ difference as a function of the natural logarithm of pair contact in weeks. The horizontal lines are the expected absolute IQ difference between two randomly selected individuals, the observed average MZA absolute difference, and the expected IQ difference between two testings of the same individual.

all their children. It seems reasonable that charismatic, dedicated parents, determined to make all their children share certain personal qualities, interests, or values, may sometimes succeed. Our findings, and those of others (37), do not imply that parenting is without lasting effects. The remarkable similarity in MZA twins in social attitudes (for example, traditionalism and religiosity) does not show that parents cannot influence those traits, but simply that this does not tend to happen in most families.

3) *MZA twins are so similar in psychological traits because their identical genomes make it probable that their effective environments are similar.* Specific mechanisms by which genetic differences in human behavior are expressed in phenotypic differences are largely unknown. It is a plausible conjecture that a key mechanism by which the genes affect the mind is indirect, and that genetic differences have an important role in determining the effective psychological environment of the developing child (38).

Infants with different temperaments elicit different parenting responses. Toddlers who are active and adventurous undergo different experiences than their more sedentary or timid siblings. In addition, children and adolescents seek out environments that they find congenial. These are forms of gene-environment covariance,  $C_{ge}$ . Moreover, different individuals pay different attention to or respond differently to the same objective experience, or both. These are forms of gene-environment interaction,  $V_{ge}$ . From infancy onwards, genetic individuality helps to steer the developing organism through the multitude of possible experiences and choices. That is, Eq. 1 must be elaborated to include these indirect and modifiable ways in which the genome exerts its influence

$$V_t = V_g + V_e + C_{ge} + V_{ge} + V_m \quad (2)$$

The proximal cause of most psychological variance probably involves learning through experience, just as radical environmentalists have always believed. The effective experiences, however, to an important extent are self-selected, and that selection is guided by the steady pressure of the genome (a more distal cause). We agree with Martin *et al.* (39) who see "humans as exploring organisms whose innate abilities and predispositions help them select what is relevant and adaptive from the range of opportunities and stimuli presented in the environment. The effects of mobility and learning, therefore, augment rather than eradicate the effects of the genotype on behavior" (p. 4368).

If this view is correct, the developmental experiences of MZ twins are more similar than those of DZ twins, again as environmentalist critics of twin research have contended. However, even MZA twins tend to elicit, select, seek out, or create very similar effective

environments and, to that extent, the impact of these experiences is counted as a genetic influence. Finally, if the genome impresses itself on the psyche largely by influencing the character, selection, and impact of experiences during development—if the correct formula is nature via nurture—then intervention is not precluded even for highly heritable traits, but should be the more effective when tailored to each specific child's talents and inclinations.

## Relevance to Evolutionary Psychology and Sociobiology

This research focuses on individual differences, but like other animals we share certain species-specific tendencies by virtue of our being human. Whereas behavioral geneticists study variations within a species, evolutionary psychologists or sociobiologists attempt to delineate species-typical proclivities or instincts and to understand the relevant evolutionary developments that took place in the Pleistocene epoch and were adaptive in the lives of tribal hunter-gatherers. The genes sing a prehistoric song that today should sometimes be resisted but which it would be foolish to ignore.

At the interface of behavioral genetics and sociobiology is the question of the origin and function, if any, of the within-species variability we have been discussing. One view is that it represents evolutionary debris (40), unimportant to fitness and perhaps not expressed in prehistoric environments. Another view is that variability has an adaptive function and has been selected for. Whether sociobiologists can make evolutionary sense of the varieties of human genetic variation we have discussed here remains to be seen (41).

Whatever the ancient origins and functions of genetic variability, its repercussions in contemporary society are pervasive and important. A human species whose members did not vary genetically with respect to significant cognitive and motivational attributes, and who were uniformly average by current standards, would have created a very different society than the one we know. Modern society not only augments the influence of genotype on behavioral variability, as we have suggested, but permits this variability to reciprocally contribute to the rapid pace of cultural change. If genetic variation was evolutionary debris at the end of the Pleistocene, it is now a salient and essential feature of the human condition.

### REFERENCES AND NOTES

- H. H. Newman, F. N. Freeman, K. J. Holzinger, *Twins: A Study of Heredity and Environment* (Univ. of Chicago Press, Chicago, 1937); N. Juel-Nielson, *Acta Psychiatr. Neurol. Scand. Suppl.* **183**, (1965); J. Shields, *Monozygotic Twins: Brought up Apart and Brought up Together* (Oxford Univ. Press, London, 1962). There are two other ongoing studies of twins reared apart, one in Sweden (2) and one in Finland (3). The questionable study by Burt (4) has been omitted.
- N. Pedersen, G. E. McClearn, R. Plomin, L. Friberg, *Behav. Genet.* **15**, 407 (1985); R. Plomin, P. Lichtenstein, N. L. Pedersen, G. E. McClearn, J. R. Nesselroade, *Psychol. Aging* **5**, 25 (1990).
- H. Langainvainio, J. Kaprio, M. Koskenvuo, J. Lönnqvist, *Acta Genet. Med. Gemellol.* **33**, 259 (1984).
- L. Hearnshaw, *Cyril Burt: Psychologist* (Hodder & Stoughton, London, 1979); but see R. B. Joynton, *The Burt Affair* (Routledge, London, 1990).
- R. Plomin and D. Daniels, *Behav. Brain Sci.* **10**, 1 (1987); L. J. Eaves, H. J. Eysenck, N. G. Martin, *Genes Culture and Personality: An Empirical Approach* (Academic Press, New York, 1989).
- T. J. Bouchard, Jr., in *The Chemical and Biological Bases of Individuality*, S. Fox, Ed. (Plenum, New York, 1984), p. 147; N. L. Segal, W. M. Grove, T. J. Bouchard, Jr., in *Genetic Issues in Psychosocial Epidemiology*, M. Tsuang, K. Kendler, M. Lyons, Eds. (Rutgers Univ. Press, New Brunswick, NJ, in press).
- D. T. Lykken, *Behav. Genet.* **8**, 437 (1978).
- M. McGue and T. J. Bouchard, Jr., *ibid.* **14**, 325 (1984).
- T. J. Bouchard, Jr., and M. McGue, *Science* **212**, 1055 (1981).
- J. D. Matarazzo, *Wechsler's Measurement and Appraisal of Adult Intelligence* (Williams and Wilkins, Baltimore, ed. 5, 1972).
- J. Raven, *Manual for Raven's Progressive Matrices and Vocabulary Scales* (Lewis, London, 1986).
- J. C. DeFries *et al.*, *Behav. Genet.* **9**, 23 (1979).
- A. R. Hakstian and R. B. Cattell, *J. Educ. Psychol.* **70**, 657 (1978).
- T. J. Bouchard, Jr., N. L. Segal, D. T. Lykken, *Acta Genet. Med. Gemellol.* **39**, 193 (1990).
- J. C. Loehlin, *Am. Psychol.* **44**, 1285 (1989); R. Plomin and J. C. Loehlin, *Behav. Genet.* **19**, 331 (1989).
- K. McCartney, M. J. Harris, F. Bernieri, *Psychol. Bull.* **107**, 26 (1990).
- M. McGue and T. J. Bouchard, Jr., in *Advances in the Psychology of Human Intelligence*, R. J. Sternberg, Ed. (Erlbaum, New York, 1989), vol. 5, p. 7. This checklist yields four relatively independent scales: scientific or technical, cultural, mechanical, and material possessions.
- R. H. Moos and B. S. Moos, *Manual: Family Environment Scale* (Consulting Psychologists Press, Palo Alto, CA, 1986).
- Formally, this is the maximum linear contribution; nonlinear effects are, of course, possible. For these data, however, investigation of higher-ordered relationships (quadratic and cubic) showed no associations that did not exist at the linear level, and there was no discernible nonlinearity detected in visual inspection of the scatterplots.
- T. J. Bouchard, Jr., *Intelligence* **7**, 175 (1983).
- C. Capron and M. Duyme [*Nature* **340**, 552 (1989)] have shown an SES effect in an adoption study of young children; S. Scarr and R. Weinberg [*Amer. Sociol. Rev.* **43**, 674 (1978)] did not find an SES effect in a study of young adult adoptees.
- B. Price, *Am. J. Hum. Genet.* **2**, 293 (1950).
- R. J. Rose and J. Kaprio, *Behav. Genet.* **18**, 309 (1988).
- D. T. Lykken, T. J. Bouchard, Jr., M. McGue, A. Tellegen, *Behav. Genet.*, in press.
- As in our earlier analysis, nonlinear relationships were tested for and found not to exist. Additionally, deletion of a single outlier (IQ difference of 29 points) did not appreciably change the correlation estimates.
- Expected difference ( $D$ ) can be expressed as a function of the correlation ( $r$ ) and standard deviation as  $D = 1.13 \sigma \sqrt{1 - r}$  [R. Plomin and J. C. DeFries, *Intelligence* **4**, 15 (1980)].
- K. R. White, *Psychol. Bull.* **86**, 461 (1982).
- D. T. Lykken, T. J. Bouchard, Jr., M. McGue, A. Tellegen, *Acta Genet. Med. Gemellol.* **39**, 35 (1990); and (6).
- H. H. Stassen, D. T. Lykken, G. Bomben, *Eur. Arch. Psychiatry Neurol. Sci.* **237**, 244 (1988).
- Systolic blood pressure from Minnesota twin studies. Heart rate from B. Hanson *et al.*, *Am. J. Cardiol.* **63**, 606 (1989). Electrodermal and habituation data from D. T. Lykken, W. G. Iacono, K. Haroian, M. McGue, T. J. Bouchard, Jr., *Psychophysiology* **25**, 4 (1988). Reliability data from K. Matthews, C. Rakoczy, S. Stoney, S. Manuck, *ibid.* **24**, 464 (1987); M. Llabre *et al.*, *ibid.* **25**, 97 (1988).
- MPQ data from A. Tellegen *et al.*, *J. Pers. Soc. Psychol.* **54**, 1031 (1988); CPI data from T. J. Bouchard, Jr., and M. McGue, *J. Pers.* **58**, 263 (1990). Reliability data from test manuals.
- MZA and MZT Religiosity data from N. G. Waller, B. A. Kojetin, T. J. Bouchard, Jr., D. T. Lykken, A. Tellegen, *Psychol. Sci.* **1**, 138 (1990). Reliability of religious leisure time interests and religious occupational interests and mean of 14 nonreligious social attitude items from Minnesota twin study data base (28). Reliability of other scales from test manuals. For a general discussion of the reliability of traits such as those measured in this study, see K. C. H. Parker, R. K. Hanson, J. Hunsley [*Psychol. Bull.* **103**, 367 (1988)] and J. J. Conley [*Pers. Individ. Differ.* **5**, 11 (1984)].
- R. C. Lewontin, S. Rose, L. J. Kamin, *Not in Our Genes; Biology, Ideology, and Human Nature* (Pantheon, New York, 1984).
- S. Scarr, *Behav. Genet.* **17**, 219 (1987).
- J. R. Flynn, *Psychol. Bull.* **101**, 171 (1987).
- R. Lynn, *Pers. Individ. Differ.* **11**, 273 (1990); T. W. Teasdale and D. R. Owen, *Intelligence* **13**, 255 (1989).
- R. Wilson, *Child Dev.* **54**, 298 (1983).
- K. J. Hayes, *Psychol. Rep.* **10**, 299 (1962); C. J. Lumsden and E. O. Wilson, *Genes, Mind and Culture* (Harvard Univ. Press, Cambridge, MA, 1981); S. Scarr and K. McCartney, *Child Dev.* **54**, 424 (1983).
- N. G. Martin *et al.*, *Proc. Nat. Acad. Sci. U.S.A.* **3**, 4364 (1986).
- M. W. Feldman and R. C. Lewontin, *Science* **190**, 1163 (1975); D. Symonds, *The Evolution of Human Sexuality* (Oxford Univ. Press, New York, 1979).
- D. M. Buss, *J. Pers.* **58**, 1 (1990).
- T. J. Bouchard, Jr., D. T. Lykken, M. McGue, N. L. Segal, A. Tellegen, this article.
- The MZA correlation of 0.771 reported by the late Sir Cyril Burt and questioned for its authenticity after his death (4) falls within the range of findings reviewed here.
- WAIS data for MZTs from K. Tambs, J. M. Sundet, P. Magnus, *Intelligence* **8**, 283 (1984). Reliabilities from (10). Raven, Mill-Hill, and composite data from Minnesota twin studies (6, 42).
- MZA data on SCII and JVIS from D. Moloney, unpublished thesis (University of Minnesota, Minneapolis, 1990). Minnesota Occupational Interest Scale data from N. Waller, D. T. Lykken, A. Tellegen, in *Wise Counsel: Essays in Honor of Lloyd Lofquist*, R. Dawis and D. Lubinski, Eds. (Univ. of Minnesota Press, Minneapolis, in press). SCII MZT data from Nichols [*Homo* **29**, 158 (1978)]. Reliability data from test manuals.
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